

2012 FRONTIERS IN EDUCATION CONFERENCE

October 3-6, 2012 • • • Seattle, Washington

PROCEEDINGS ***Soaring to New Heights*** ***in Engineering Education***



| | | |
|--|---|-----------------------------|
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IEEE  computer society

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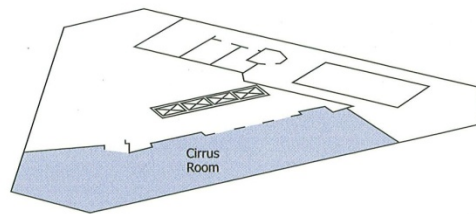
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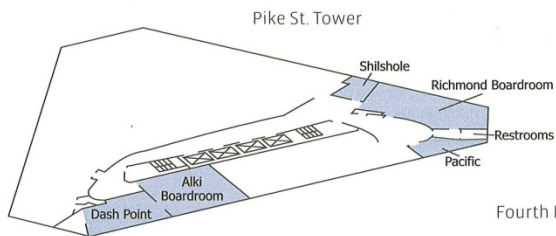
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HOTEL FLOOR PLANS

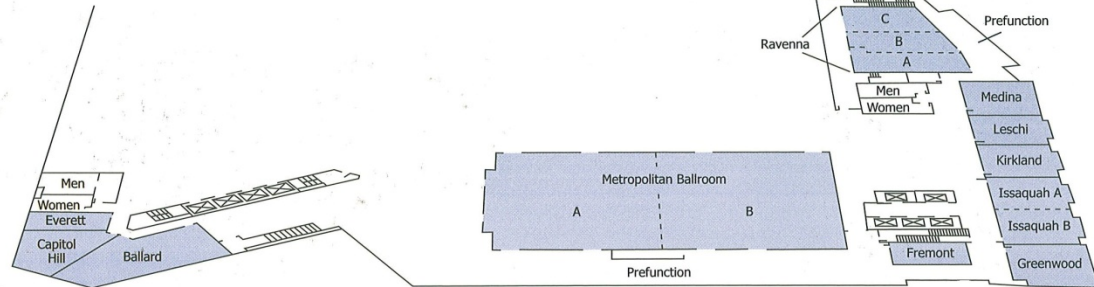
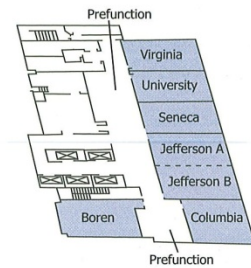


35th Floor

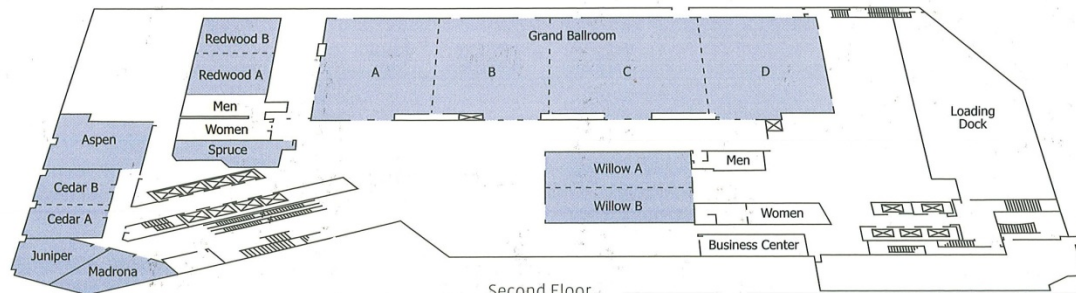
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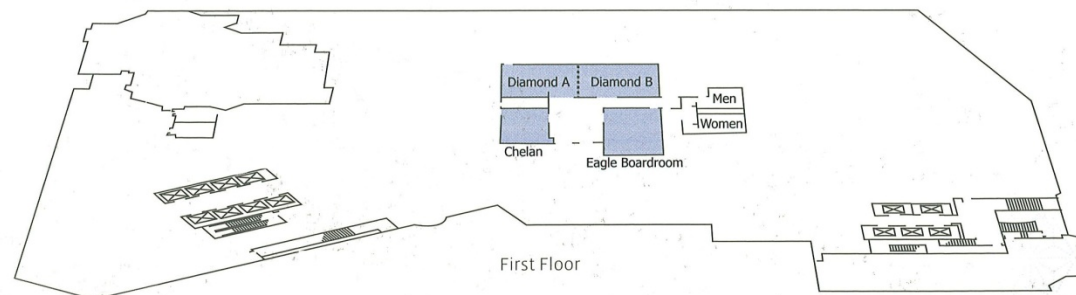
Fourth Floor



Third Floor



Second Floor



First Floor

CONFERENCE AT A GLANCE

Wednesday, October 3

| | |
|--------------------|--|
| 11:00 am – 6:00 pm | Registration Metropolitan Ballroom Prefunction Area |
| 1:30 pm – 6:00 pm | Exhibit Setup Metropolitan Ballroom |
| 1:30 pm – 4:30 pm | Pre-conference Workshops Session A |
| 5:30 pm – 8:30 pm | Pre-conference Workshops Session B |

Thursday, October 4

| | |
|--------------------|--|
| 7:00 am – 5:00 pm | Registration Metropolitan Ballroom Prefunction Area |
| 7:00 am – 8:00 am | Focus on New Attendees Breakfast Buffet Metropolitan Ballroom Prefunction Area |
| 8:00 am – 9:30 am | Plenary Session Grand Ballroom WIKISPEED - Revolutionizing Transportation through Agile, Lean and Scrum |
| 9:30 am – 5:00 pm | Exhibit Hall Open Metropolitan Ballroom |
| 9:30 am – 10:00 am | Exhibit Hall Break |
| 10:00 am – Noon | Technical Sessions (T1) |
| Noon – 1:30 pm | HP Terman and Rigas Awards Lunch Sponsored by the Hewlett-Packard Company Grand Ballroom AB |
| 1:30 pm – 3:00 pm | Technical Sessions (T2) |
| 3:00 pm – 3:30 pm | Exhibit Hall Break |
| 3:30 pm – 5:00 pm | Technical Session (T3) |
| 5:10 pm – 6:00 pm | Catalyzing Collaborative Conversations Sessions |
| 6:00 pm – 8:30 pm | Reception and Awards Banquet Ticketed Event Cirrus Ballroom |

Friday, October 5

| | |
|--------------------|---|
| 7:00 am – 5:00 pm | Registration Open Metropolitan Ballroom Prefunction Area |
| 7:00 am – 8:00 am | Breakfast Grand Ballroom AB |
| 8:00 am – 9:30 am | Plenary Session Grand Ballroom AB Is There a MOOC in Your Future? |
| 9:00 am – 4:30 pm | Exhibit Hall Open |
| 9:30 am – 10:00 am | Exhibit Hall Break |
| 10:00 am – Noon | Technical Sessions (F1) |
| Noon – 1:30 pm | Premier Award Lunch Sponsored by John Wiley & Sons, Microsoft Research, Autodesk, and TechSmith Grand Ballroom AB |
| 1:30 pm – 3:00 pm | Technical Sessions (F2) |
| 3:00 pm – 4:00 pm | Focus on Exhibits and New Faculty Fellows Metropolitan Ballroom |
| 4:00 pm – 5:50 pm | Technical Sessions (F3) |
| 6:15 pm – 9:30 pm | Transportation to and Reception at Museum of Flight Bus loading zone on Union Street: Walk to the left after exiting the main hotel doors |

Saturday, October 6

| | |
|---------------------|--|
| 7:00 am – 10:00 am | Registration Metropolitan Ballroom Prefunction Area |
| 7:00 am – 8:00 am | Breakfast Metropolitan Ballroom |
| 8:00 am – 10:00 am | Technical Sessions (S1) |
| 10:00 am – 10:30 am | Break Metropolitan Ballroom Prefunction Area |
| 10:30 am – 12:30 pm | Technical Sessions (S2) |

WELCOME FROM THE GENERAL CO-CHAIRS



On behalf of the three sponsoring societies and Seattle University, we are pleased to welcome you to FIE 2012. The lifetime of FIE, 42 years and counting, has been a time of many innovations in engineering and computing education. The Frontiers in Education Conference has become the premiere conference for presentation and discussion of excellent educational research and innovative curricula in engineering education. This accomplishment would not have been possible without the vision and strong leadership of the three sponsoring professional societies – ASEE Educational Research and Methods Division, IEEE Computer Society, and the IEEE Education Society. We, along with the sponsoring societies, are proud of the rich traditions of the FIE and the many

engineering educators and educational researchers from around the globe who have contributed so much to our present understanding of how students learn. We are excited to bring this year's conference to the West Coast, where it is more easily accessible to our colleagues around the Pacific Rim. The theme of this year's conference, "Soaring to New Heights in Engineering Education" focuses on expanding the diverse community of international scholars and enriching the foundation of educational research that FIE has built over its history. It seems only fitting then that we continue this celebration of "soaring to new heights" by hosting this year's reception at the Museum of Flight.

Also fitting with this year's theme and location, we have expanded our outreach efforts to include Asia and Australia and are quite eager to learn of your educational efforts. Welcome to all first timers at FIE, whether international or local. We hope you become ambassadors for FIE by supporting our goals of enriching engineering education and informing other colleagues of your experiences.

FIE 2012 has an exciting and innovative technical program which is made possible by the Planning Committee, a large group of dedicated professionals who volunteer their time to this cause. The program co-chairs from the sponsoring societies – Reid Bailey and Archie Holmes of ERM, Steve Frezza of the IEEE Computer Society, and Lance Perez of the IEEE Education Society – coordinate the paper review process and organize the technical sessions. The program co-chairs are joined by the International Program Chairs, Ming Zhang, Mark Lee, Edmundo Tovar Caro and Melany Ciampi and the Special Sessions Chair Kevin Gary. Ingrid Russell, as the New Faculty Fellows Chair, coordinates the new faculty fellows program, a valuable influx of new people and innovations. Robert Hofinger continues in his key role as Exhibits Chair and Ed Jones as Conference Historian. We are pleased to have had such a dedicated group of program chairs who provide countless hours to organize the technical sessions, workshops, and special sessions that make FIE the innovative and compelling conference that it is.

In addition to selecting the technical program, there is a great deal of logistics and support planning that must be accomplished to make FIE the special conference that it is. We are both fortunate and thankful for the logistics support from Kevin Curry, Assistant to the General Chairs, and the University of Kansas Continuing Education staff and to Chris Dyer, Publications Chair. In addition to providing all of the logistical support that is necessary for the conference, Kevin continues to provide the continuity and institutional memory that is necessary for the planning committee to do its job. In addition, we would like to thank Jennifer Karlin and Stuart Kellogg and the FIE 2011 Planning Committee who continue to offer the support and guidance for the FIE 2012 program. Finally, we would like to thank the FIE Steering Committee for their leadership in ensuring the uniqueness that is FIE.

FIE is more than just a place to present papers. It is a place to meet and welcome new people and reconnect with old colleagues. It is a place to interact and discuss new ideas and new innovations. In short, it is a place to build not only a community of scholars but a community of friends. While you are here, we hope that you will have an opportunity to enjoy some of the many attractions that Seattle has to offer.

Our conference hotel is located in the heart of downtown Seattle, within walking distance of many fine restaurants, the Seattle Art Museum, multiple live music venues, the Seattle waterfront with its stunning views across Puget Sound, and the unique Pike Place Market. If you are able to spend an extra day in Seattle, you can explore the natural beauty of the city and its surroundings, take a trip to Mt. Rainier National Park, or visit the Boeing factory to see the latest commercial airliners being constructed. Seattle offers something for every taste, including all of the great coffee you can drink!

Your Co-Chairs,
Richard Leblanc and Ann Sobel

MESSAGE FROM THE FIE STEERING COMMITTEE



Welcome to Seattle and the 42nd annual Frontiers in Education Conference. This year the conference continues its long tradition of offering an outstanding technical program. Each year I learn so many new things at FIE. I have always particularly liked the sessions on first-year classes, curriculum assessment, and cooperative learning because these are areas I spend significant time thinking about each day on the job. But, last year one of the sessions that had the greatest impact on me was a workshop on the Philosophy of Engineering Education because it asked tough questions to participants about the nature of engineering, engineering knowledge, and engineering education. The effect of this workshop on my thought processes has been profound. I am confident that this year you will find many conference events that can similarly transform the way you think about engineering and education. **Immerse** yourself in hands-on learning at a workshop on

Wednesday. **Start** Thursday and Friday at the Plenary sessions where you can interact with leaders from both industry and academia as they challenge you to think differently about modern product development and the education of engineering and computer science students. **Attend** and ask questions at scores of high quality paper presentations in the many parallel tracks. **Engage** with others at the unique Catalyzing Collaborative Conversations Sessions on Thursday evening where anyone can catalyze educational change by bring forth new topics for group discussion. Finally, **enjoy** the many opportunities to network with colleagues from around the world at the breakfasts, lunches, exhibit hall breaks, and the fantastic reception at the Museum of Flight on Friday evening.

Dr. Edwin C. Jones is the Frontiers in Education conference historian. He notes that FIE began in Atlanta in the year 1971 as an IEEE Education Society sponsored event. Thirty-four papers were presented in six sessions and enjoyed by approximately 100 registrants. In just a few years, the ASEE Educational Research and Methods (ERM) division joined as a sponsor, the conference community grew, and the conference matured into a premier event in engineering educational theory and practice. In 1995, the IEEE Computer Society became the third sponsor and helped to expand the community even more by reaching out to computer science and software engineering professionals. Over the past four decades, the conference has grown from these historic roots to a four day event with more than 400 papers and 600 registrants.

Each of the three sponsoring societies elects three members to serve on the FIE Steering Committee.

The Steering Committee is responsible for strategic mission and vision, long-term conference planning, conference management, and conference site selection. The committee meets in person twice each year and holds considerable discussion electronically throughout the year. Important questions that we have recently answered include:

- **Should FIE periodically move to a venue outside of North America (IEEE Regions 1 - 7)?** The Steering Committee recognized that FIE has a reputation as a premier North American conference. Thus, the committee wrote a long-term policy statement that encourages venues in other IEEE Regions but requires at least five years in North America after any such event. Be sure to reserve October on your calendar and join us in Madrid, Spain in 2014!
- **How can FIE continue to improve its technical program quality and impact factor?** The Steering Committee recognized that FIE has a highly respected proceedings record but also believed that a clear categorization of papers could help peer reviewers better judge the merit of each contributed work. Thus, the conference adopted three paper categories called innovative practice, research-to-practice, and research. The committee continues to work with Technical Program Chairs to improve the quality metrics used by peer reviewers in each category.
- **How can FIE assist its volunteers in learning about and contributing to the conference event?** The Steering Committee is working on a number of informational documents that describe the various volunteer conference roles, the city bid process, and the expectations of Technical Program Chairs. These documents will become visible on the main FIE conference website when they are finished (www.fieconference.org).
- **How can FIE provide the highest quality product while maintaining registration price?** The Steering Committee worked for a number of years to move to transparent bidding processes for publications and for conference logistics. Formal request-for-proposal documents were written describing the responsibilities of these two important aspects of conference management. Bids were received from a number of vendors and through this fiscal process we have been able to leave the FIE registration price fixed for a number of years.

These are just some examples of work going on behind the scenes to make your conference experience better. The Steering Committee works for the Societies and the member communities. We encourage you to contact any one of us to discuss the FIE conference. We can be identified by Steering Committee ribbons on our conference badges.

ASEE Educational Research and Methods Division Representatives

- Beth Eschenbach, Humboldt State University, Elizabeth.Eschenbach@humboldt.edu
- Archie Holmes, University of Virginia, ah7sj@virginia.edu
- James Morgan, Texas A&M University, jmorgan@civil.tamu.edu

IEEE Computer Society Representatives

- Stephen Frezza, Gannon University, FREZZA001@gannon.edu
- Fernando Naveda, Rochester Institute of Technology, jfnaveda@computer.org
- Arnold Pears, Uppsala University, Arnold.Pears@it.uu.se

IEEE Education Society Representatives

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

I hope you enjoy your conference and I look forward to meeting and talking with you in Seattle!

Sincerely,

Russ Meier
Steering Committee Chair
Milwaukee School of Engineering
Milwaukee, WI, USA

CONFERENCE SPONSORS

FIE 2012 is sponsored by:

American Society for Engineering Education (ASEE)
Educational Research Methods (ERM) Division

Institute of Electrical and Electronics Engineers (IEEE)
IEEE Computer Society
IEEE Education Society



FIE 2012 is hosted by:

Seattle University



Seattle University, founded in 1891, is a Jesuit Catholic university located on 50 acres in Seattle's Capitol Hill neighborhood. More than 7,700 students are enrolled in undergraduate and graduate programs within eight schools and colleges.

Seattle University is the most racially and culturally diverse, the most genuinely urban, and the largest multidisciplinary independent university of the Northwest. Utilizing these three assets for the education of our students and the service of society presents opportunities unique to Seattle University. Three out of four Seattle University undergraduate students engage in community service, three times the national average. Students, faculty and staff contribute 200,000 hours of service annually.

CORPORATE AFFILIATES AND SPONSORSHIPS

Corporate affiliates play an important role in supporting FIE conferences. This support subsidizes the cost of the award presentations and of meal functions. We appreciate these supporters and the part they play in making the 2012 FIE conference an outstanding event.

Thursday Activities

Hewlett-Packard

Frederick Emmons Terman and Harriet B. Rigas Award Luncheon

Friday Activities

TechSmith, Wiley, Microsoft
Research, and Autodesk

Premier Award Luncheon
Special Session F2A will be devoted to the demonstration and dissemination of the award-winning software.

FIE 2012 PLANNING COMMITTEE

General Co-Chair

Richard LeBlanc
Seattle University

General Co-Chair

Ann E.K. Sobel
Miami University

Assistant to the General Chairs

Kevin Curry
University of Kansas

ASEE/ERM Program Co-Chairs

Reid Bailey
University of Virginia
Archie Holmes
University of Virginia

IEEE/Computer Society Program Co-Chair

Steve Frezza
Gannon University

IEEE/Education Society Program Co-Chair

Lance Perez
University of Nebraska - Lincoln

Workshop, Special Sessions & Panels Chair

Kevin Gary
Arizona State University

Exhibits Chair

Robert J. Hofinger
Purdue University

Publications Chair

Chris Dyer
Conference Catalysts, LLC

New Faculty Fellows Chair

Ingrid Russell
University of Hartford

International Co-Chair, Asia

Ming Zhang
Peking University

International Co-Chair, Australasia

Mark Lee
Charles Sturt University

International Co-Chair, Europe

Edmundo Tovar Caro
Universidad Politecnica de Madrid

International Co-Chair, South America

Melany M. Ciampi
VP COPEC- Science and Education Research Council

Conference Historian

Ed Jones
Iowa State University

Awards Chair

Manuel Castro
Spanish National Distance University

FIE STEERING COMMITTEE

ASEE Educational Research and Methods Division Representatives

Beth Eschenbach, Humboldt State University
(June 2010 - June 2013)
Jim Morgan, Texas A&M University
(June 2011-June 2014)
Archie Holmes, University of Virginia
(June 2012 - June 2015)

IEEE Computer Society Representatives

Fernando Naveda, Rochester Institute of Technology
(June 2007 - June 2013)
Stephen Frezza, Gannon University
(June 2011 - June 2014)
Arnold Pears, Uppsala University
(June 2009 - June 2015)

IEEE Education Society Representatives

Russ Meier, Milwaukee School of Engineering
(June 2007 - June 2013) Steering Committee Chair
Edmundo Tovar Caro, Universidad Politecnica de Madrid (June 2008 - June 2014)
James Sluss, University of Oklahoma
(June 2012 - June 2015)

FUTURE FIE CONFERENCES

FIE 2013 Oklahoma City, Oklahoma, October 23 – 26
FIE 2014 Madrid, Spain

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

FIE 2012 EXHIBITORS

The FIE vendor and association exhibits are a popular and rewarding tradition for both attendees and exhibitors. Exhibits will include materials, equipment, textbooks, software, and state-of-the-art tools applicable to engineering education. We thank the vendors for their financial support and contributions to making FIE 2012 a meaningful experience.

Exhibit Hall Hours

The exhibits will be open in the Metropolitan Ballroom 9:00 a.m.–5:00 p.m. Thursday and 9:00 a.m.–4:30 p.m. Friday. As of September 1, the following companies have committed to exhibiting at FIE 2012:

| EXHIBITOR | WEBSITE |
|--|---|
| AEFIS | http://www.goaefis.com/ |
| Agilent Technologies | www.agilent.com |
| Answer Underground | www.answerunderground.com/ |
| Arizona State University JDSP | http://jdsp.engineering.asu.edu |
| Center for Engineering Learning and Teaching, University of Washington | depts.washington.edu/celtweb |
| CRC Press - Taylor and Francis | www.crcpress.com |
| Cypress University Alliance | http://www.cypress.com/?id=1163 |
| Digilent | www.digilentinc.com |
| EMA Design Automation | www.ema-eda.com |
| EPICS – Purdue University | https://engineering.purdue.edu/EPICS |
| IEEE Education Society | www.ewh.ieee.org/soc/es |
| John Wiley & Sons, Inc. | www.wiley.com/WileyCDA |
| The MathWorks | www.MathWorks.com |
| McGraw Hill Higher Education | catalogs.mhhe.com/mhhe/home.do |
| Morgan & Claypool Publishers | www.morganclaypool.com |
| NCEES | ncees.org |
| Objet 3D Printing | objet.com |
| Piazza | piazza.com |
| Purdue Engineering Education | engineering.purdue.edu/ENE |
| Utah State University Department of Engineering Education | www.eed.usu.edu/ |
| Xilinx | www.xilinx.com |

Focus on Exhibits and New Faculty Fellows Poster Presentation

Attendees and participants will be encouraged to visit the exhibit area throughout the conference. In order to provide full exposure for the exhibits, a special "Focus on Exhibits" session is planned for the afternoon of Friday, October 5th, during which time there will be no technical sessions scheduled. The New Faculty Fellows will also display their posters at this time. Door prizes contributed by some of the exhibitors will be awarded during the Focus on Exhibits. You must be present to win.

EXHIBITOR SHOWCASE PRESENTATIONS

Thursday, October 4

| | |
|---------------------|---------------|
| 10 am – Noon | Piazza |
|---------------------|---------------|

| |
|--------------------|
| Seneca Room |
|--------------------|

Topic: Peer-Based Learning with Piazza

Speaker: Nick LaVassar

Description:

Piazza is a **free** online question and answer platform built from the ground up to replace less effective discussion boards commonly adopted in classrooms. It was made popular by widespread use at Stanford, Harvard, Princeton, and MIT. Today, it's used by hundreds of thousands of students every term.

You are encouraged to bring your own laptop to the session to test drive Piazza, but are also welcome to just watch the demo and participate in the discussion. In this session, you'll learn how to:

- Solicit high levels of participation from students;
- Enable shy students to ask questions with varying degrees of privacy;
- Save time and eliminate redundant effort in larger classes

Again, Piazza is **free** and can be adopted by individual instructors. Sign up and get started in just minutes by visiting www.piazza.com.

| | |
|--------------------|----------------------|
| 1:30 – 3 pm | The MathWorks |
|--------------------|----------------------|

| |
|--------------------|
| Seneca Room |
|--------------------|

Topic: Enabling Project-Based Learning with MATLAB, Simulink, and affordable hardware

Speaker: Dr. Ye Cheng is a member of the Educational Technical Evangelist team at MathWorks who explore how best to work with universities to help prepare the next generation of engineers and scientists. Ye holds PhD and MS degrees in mechanical and aerospace engineering, specialized in advanced imaging techniques for the study of fluid mechanics. After four-years teaching of senior lab courses, Ye has been working with professors across disciplines from various universities to leverage MATLAB and Simulink for teaching.

Description:

Project-Based learning is extremely effective because students can see, hear, and touch what would otherwise be very abstract. In this presentation we will show you how MATLAB, Simulink, and the new Run on Target Hardware feature can easily interface with a broad range of very affordable hardware and experiments to teach courses focused on:

- Mechatronics
- Circuit design
- Programming
- Controls
- Robotics
- Renewable energy

New with Release 2012a of Simulink, the Run on Target Hardware feature can automatically generate standalone applications to run in real-time on the BeagleBoard, LEGO® MINDSTORMS® NXT, and Arduino Mega without the need for either MATLAB Coder or Simulink Coder™. Using this new capability, we explore integrating simulation and hardware to show the following concepts:

- Reading sensors and writing to actuators
- Interactive prototyping of algorithms for control and signal processing
- Testing algorithms with physical hardware components
- Deploying real-time algorithms to standalone hardware
- Integrating algorithms with robots and real-world systems

| | | |
|--------------------|-----------------|--------------------|
| 3:30 – 5 pm | Digilent | Seneca Room |
|--------------------|-----------------|--------------------|

Topic: Hands-on with Digilent chipKIT Arduino Compatible boards and Cerebot Pic32 Microcontroller Boards

Speaker: Mr. Gene Apperson, VP of Engineering, Digilent Inc.

Description:

Digilent will lead a hands-on review of the chipKIT™ and Cerebot™ line of microcontroller boards. Featuring compatibility with the popular Arduino™ open source platform, Digilent kits add the performance and functionality of the Microchip PIC32 microcontroller. Come learn how to enable students to easily and inexpensively integrate electronics into their projects, even if they do not have an engineering background. Participants will receive hands-on instruction on the use of chipKIT™ and Cerebot™ boards and how to integrate the boards into your curricula.

Friday, October 5

| | | |
|---------------------|--------------------------|--------------------|
| 10 am – Noon | Objet 3D Printing | Seneca Room |
|---------------------|--------------------------|--------------------|

| | | |
|--------------------|-----------------|--------------------|
| 1:30 – 3 pm | Digilent | Seneca Room |
|--------------------|-----------------|--------------------|

Topic: Hands-on Analog Design for Every Student - New Analog Discovery

Speaker: Mr. Clint Cole, Washington State University, and President of Digilent

Description:

The Digilent Analog Discovery is an inexpensive professional grade hardware and software system that provides a platform for students to explore principles of analog and digital circuits through hands-on design projects. Building on Digilent's successful EE board and with support of Analog Devices, the Discovery board is half the price of the EE board but contains the same key features. It allows students to build and verify real circuits and systems at their own pace and at any location. Participants will receive hands-on instructions on the use of the board and curriculum examples.

| | | |
|-----------------------|----------------------|--------------------|
| 3:30 – 5:50 pm | The MathWorks | Seneca Room |
|-----------------------|----------------------|--------------------|

Topic: Enabling Project-Based Learning with MATLAB, Simulink, and affordable hardware

Speaker: Ye Cheng is a member of the Educational Technical Evangelist team at MathWorks who explore how best to work with universities to help prepare the next generation of engineers and scientists. Ye holds PhD and MS degrees in mechanical and aerospace engineering, specialized in advanced imaging techniques for the study of fluid mechanics. After four-years teaching of senior lab courses, Ye has been working with professors across disciplines from various universities to leverage MATLAB and Simulink for teaching.

Description:

See the description for Thursday afternoon's showcase. This will be the same workshop that was given then.

PLENARY SESSIONS

Thursday, October 4, 8 – 9:30 am
Grand Ballroom A

WIKISPEED - Revolutionizing Transportation through Agile, Lean and Scrum

WIKISPEED is a globally distributed team of over 150 volunteers that are building 100 MPG cars that are safe, fun, light, fast, sleek and affordable. We've taken popular software development practices: - Agile, Lean and Scrum - and applied them to manufacturing. This has resulted in Extreme Manufacturing which leverages resources and team potential to quickly create viable prototypes and products in a short amount of time. WIKISPEED is now spreading these practices to organizations in other manufacturing sectors and helping them achieve even greater success.

Speaker

Tom Taber has been a very active volunteer with the WIKISPEED team for over a year. He has been able to leverage his experiences in software development, rock climbing, project management, competition barbecuing, 3D modeling, plumbing, social psychology, sweeping and public speaking to contribute to a number of team successes. He currently lives in Las Vegas, NV, but has been spending increasing long stints in Seattle working with the WIKISPEED team to help create a more awesome world to live in.

Friday, October 5, 8 – 9:30 am
Grand Ballroom AB

Is There a MOOC in Your Future?

This plenary session will examine current trends and future prospects in online education. Massive Open Online Courses (MOOCs) have gotten a great deal of publicity in the last year, although the most widely-known MOOC offerings do not capture all of the richness of the original MOOCs. Much of the attention paid to MOOCs in the press has been centered around the idea that they may challenge the organizational structures and cost models of higher education. The participants in this session will address many of these issues through a moderated discussion and a question and answer session with the audience.

Participants:

Fred Martin, Ph.D., Associate Professor, Department of Computer Science and Associate Dean, College of Sciences, University of Massachusetts Lowell

Fred Martin directs the Engaging Computing Group, which develops tangible computational materials for science education, robotics education, and computer science education. His publications include work on informal robotics education, teachers' attitudes toward inquiry-based science using data-loggers, artificial intelligence education, and robotic sensing. He recently published an essay in the Communications of the ACM detailing his experiences teaching in the "flipped classroom" style using a MOOC.

Dan Grossman, Ph.D., Associate Professor of Computer Science & Engineering, University of Washington

Dan Grossman has authored over 50 research publications in programming languages, including collaborations with researchers in computer architecture, software engineering, and databases. Dan has chaired the SIGPLAN Education Board and currently serves on the steering committee for the ACM / IEEE-CS 2013 Computer Science Curriculum. He is preparing to teach a programming-languages course on Coursera in January 2013 that is attracting roughly 300 registrations per day. More generally, he is leading the effort in his department to offer 4-5 courses over the next year while interacting with Coursera and other interests at the University of Washington to best align goals and plans.

Jennifer Dalby, M.Ed., Instructional Designer, Seattle University

Jennifer Dalby has supported faculty in the adoption of innovative learning technologies since 2001. In 2007, she began practicing Viral Professional Development, hosting open online learning sessions, which attracted international participation from faculty across disciplines. She practices open teaching and learning, connecting her students with external peers and experts. Through her consulting work, Jennifer advises administrators on emerging trends and opportunities in both profit and non-profit higher education. You may access her portfolio and shared resources at <http://portfolio.injenuity.com/>

GROUP MEETINGS

Wednesday, October 3, 2012

| | | |
|----------------|--------------------------------|-----------|
| 5:00 – 6:30 pm | FIE Steering Committee Meeting | Diamond A |
|----------------|--------------------------------|-----------|

Thursday, October 4, 2012

| | | |
|--------------|--------------------------------|-----------|
| 10 am – Noon | IEEE EDUCON Steering Committee | Diamond A |
|--------------|--------------------------------|-----------|

| | | |
|----------------|------------------------------------|-----------|
| 1:30 – 3:00 pm | ASEE ERM Division Business Meeting | Diamond A |
|----------------|------------------------------------|-----------|

Friday, October 5, 2012

| | | |
|--------------|---|-----------|
| 10 am – Noon | IEEE Education Society Board of Governors meeting | Diamond A |
|--------------|---|-----------|

Saturday, October 6, 2012

| | | |
|----------------|--|-----------|
| 8:00 – 9:30 am | FIE Steering Committee Meeting Executive Session | Diamond A |
|----------------|--|-----------|

| | | |
|----------------|-------------------------------------|-----------|
| 1:00 – 3:00 pm | FIE 2013 Planning Committee Meeting | Diamond A |
|----------------|-------------------------------------|-----------|

FIE 2012 WORKSHOPS

Wednesday, 1:30 – 8:30 p.m. (Pre-Registration is required.)

On Wednesday afternoon and evening, FIE features workshops—highly interactive sessions selected for their timeliness and value. Workshops offer a concentrated professional development experience. The wide range of workshop topics offers opportunities for everyone from new faculty members to the most experienced educators to expand their skills and knowledge.

Conference attendees must register separately for workshops. There is a \$50 registration fee for each workshop. Complete abstracts for the workshops can be found in the Wednesday schedule of the program book.

NEW FACULTY FELLOW PROGRAM

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

The purpose of the program is to promote the involvement of new faculty in the Frontiers in Education Conference so they will be exposed to the "latest and greatest" in engineering educational practices and will have the opportunity to exchange information with leaders in education innovations. This year, FIE 2012 will provide two registration and travel grants for awardees to attend the conference.

Focus on New Faculty Fellows

Each fellow will present a conference paper during FIE 2012. Join them in their session and share your thoughts and ideas about the future of engineering education. Also, during the Focus on Exhibits session Friday at 3 p.m., the Fellows will display posters describing their interests and activities and previewing the full papers that they will present as part of the FIE 2012 technical sessions.

2012 New Faculty Fellows:

Christine F. Reilly

Department of Computer Science
University of Texas – Pan American

Session T1H *The Impact of Real-World Topic Labs on Student Performance in CSI*, Christine Reilly (University of Texas - Pan American, USA); Noe De La Mora (University of Texas - Pan American, USA)

Adam Carberry

College of Technology & Innovation, Department of Engineering
Arizona State University

Session T1G *Peer Mentoring: Linking the Value of a Reflective Activity to Graduate Student Development*, Brook Sattler (University of Washington, USA); Adam R Carberry (Arizona State University, USA); Lauren Thomas (Virginia Tech, USA)

Session T2E *Work in Progress: Developing an Innovation Self-Efficacy Survey*, Elizabeth Gerber (Northwestern University, USA); Caitlin K Martin (Northwestern University & Stanford University, USA); Adam R Carberry (Arizona State University, USA); Elizabeth Kramer (Northwestern University, USA); Jennie Braunstein (Northwestern University, USA)

Session F1F *Work in Progress: Teaching Game Design and Robotics Together: A Natural Marriage of Computing and Engineering Design in a First-Year Engineering Course*, Adam R Carberry (Arizona State University, USA); Ashish Amresh (Arizona State University, USA)

Session F3F *Standards-Based Grading: Preliminary Studies to Quantify Changes in Affective and Cognitive Student Behaviors*, Adam R Carberry (Arizona State University, USA); Matthew Siniawski (Loyola Marymount University, USA); John Dionisio (Loyola Marymount University, USA)

CONFERENCE AMENITIES

Breakfast

7:00 a.m.–8:00 a.m. Thursday Metropolitan Ballroom Prefunction Area

7:00 a.m.–8:00 a.m. Friday Grand Ballroom AB

7:00 a.m.–8:00 a.m. Saturday Metropolitan Ballroom

Refreshment Breaks • Exhibit Hall - Metropolitan Ballroom

Morning and afternoon breaks Thursday and Friday

Lunches

Frederick Emmons Terman and Harriet B. Rigas Awards Luncheon - Grand Ballroom AB **Sponsored by the Hewlett-Packard Company**

Noon –1:30 p.m. Thursday

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

Premier Award Luncheon - Grand Ballroom AB

Sponsored by John Wiley & Sons, Microsoft Research, Autodesk, and Techsmith

Noon –1:30 p.m. Friday

The Premier Award for Excellence in Engineering Education Courseware recognizes high-quality, noncommercial courseware that enhances engineering education. The award promotes successful courseware and provides models of excellence for educators.

Session F2A, directly following the luncheon, has been reserved for the presentation, demonstration and dissemination of the Premier Award Winner software.

Reception

6:15 p.m.–9:30 p.m. Friday

Join your colleagues as we board busses and take the short ride to the Museum of Flight for a reception. We will have drinks and heavy hors d'oeuvres catered by McCormick & Schmick's. We will also have exclusive access to the exhibits. Be sure to bring the drink tickets you received when you checked in at registration.

New Faculty Fellows • Exhibit Hall – Metropolitan Ballroom

3:00 p.m.–4:00 p.m. Friday

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

Focus on Exhibits • Exhibit Hall – Metropolitan Ballroom

3:00 p.m.–4:00 p.m. Friday

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

Awards Banquet • Cirrus Ballroom

6:00 p.m.–8:30 p.m. Thursday

This year's awards banquet features fine food, drink, and camaraderie along with presentation of special awards from FIE, the IEEE Education Society, and the IEEE Computer Society. There is a separate charge for the banquet.

FIE Registration Conference Desk • Metropolitan Ballroom Prefunction

Registration will be open during these times:

| | |
|-----------|------------------------|
| Wednesday | 11:00 a.m. – 6:00 p.m. |
| Thursday | 7:00 a.m. – 5:00 p.m. |
| Friday | 7:00 a.m. – 5:00 p.m. |
| Saturday | 7:00 a.m. – 10 a.m. |

Hospitality Table • Near Conference Registration

If you are looking for a certain kind of a restaurant, shop, golf course, or health club, stop by the hospitality table close to the registration area. Maps and brochures of area attractions will be available.

FIE Message Center • Near Conference Registration

The conference will maintain a message board by the registration area. Messages received for conferees will be posted there. In an emergency, we will make every effort to locate you.

2012 FIE CONFERENCE AWARDS PRESENTATIONS

Thursday, October 4..... Terman/Rigas Awards Luncheon

Noon - 1:30 p.m.

ASEE ECE Division Hewlett-Packard Frederick Emmons Terman Award

IEEE Education Society Hewlett-Packard/Harriet B. Rigas Award

Thursday, October 4..... Awards Banquet

6:00 p.m - 8:30 p.m.

Frontiers in Education (FIE) Conference Awards

FIE 2011 Benjamin J. Dasher Best Paper Award

FIE 2011 Helen Plants Award

FIE Ronald J. Schmitz Award

IEEE Education Society

William E. Sayle Award for Achievement in Education

IEEE Transactions on Education Best Paper Award

Chapter Achievement Award

Distinguished Chapter Leadership Award

Distinguished Member Award

Edwin C. Jones, Jr. Meritorious Service Award

Mac Van Valkenburg Early Career Teaching Award

Student Leadership Award

AWARD SELECTION COMMITTEE CHAIRS

Frontiers in Education Conference

| | |
|---|-------------------|
| Benjamin J. Dasher Best Paper Award | Arnold Pears |
| Helen Plants Award | Cordelia M. Brown |
| Ronald J. Schmitz Award | Susan Lord |

ASEE Electrical and Computer Engineering Division

| | |
|---|---------------|
| Hewlett-Packard Frederick Emmons Terman Award | Tony Givargis |
|---|---------------|

IEEE Education Society

| | |
|--|--------------------------------|
| IEEE William E. Sayle Award for Achievement in Education | Lyle D. Feisel |
| IEEE Transactions on Education Best Paper Award | Charles B. Fledderman |
| Chapter Achievement Award | Trond Clausen |
| Distinguished Chapter Leadership Award | Edmundo Tovar |
| Distinguished Member Award..... | Ted Batchman |
| Edwin C. Jones, Jr. Meritorious Service Award | Edwin C. Jones, Jr. |
| Hewlett-Packard/Harriet B. Rigas Award | Joanne Bechta Dugan |
| Mac Van Valkenburg Early Career Teaching Award | Seyed Hossein Mousavinezhad |
| Student Leadership Award..... | Emmanuel A. Gonzalez |



Ali Niknejad
University of California,
Berkeley

Past Recipients

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

ASEE ECE Division Hewlett-Packard Frederick Emmons Terman Award

Presented by Martina Trucco

For an outstanding young electrical engineering educator in recognition of his contribution to the profession

Ali M. Niknejad received the B.S.E.E. degree from the University of California, Los Angeles, in 1994, and his Master's and Ph.D. degrees in electrical engineering from the University of California, Berkeley, in 1997 and 2000. During his graduate studies, he authored *ASITIC*, a CAD tool that aids in the simulation and design of passive circuit elements such as inductors into silicon integrated circuits. After graduation from Berkeley he worked in industry focusing on the design and research of analog RF integrated circuits and devices for wireless communication applications. He is currently an associate professor in the EECS department at UC Berkeley and co-director of the Berkeley Wireless Research Center and the BSIM Research Group. He served as an associate editor of the IEEE JSSC and on the TPC for ISSCC/CICC. Prof. Niknejad was co-recipient of the Outstanding Technology Directions Paper at ISSCC 2004 for co-developing a modeling approach for devices up to 65 GHz. He is also co-recipient of the 2010 Jack Kilby Award for Outstanding Student Paper for his work on a 90 GHz pulser with 30 GHz of bandwidth for medical imaging. His students have also been awarded numerous best paper awards at RFIC. Prof. Niknejad is a co-founder of HMicro and inventor of the REACH^(TM) technology, which has the potential to deliver robust wireless solutions to the healthcare industry. His research interests lie within the area of wireless and broadband communications and biomedical imaging (RF, mm-wave, and sub-THz), including the implementation of integrated communication systems in silicon using CMOS, SiGe, and BiCMOS processes. His focus areas of his research include analog, RF, mixed-signal, mm-wave circuits, device physics and compact modeling, and numerical techniques in electromagnetics. He is currently an IEEE Solid-State Circuits Society Distinguished Lecturer.

'03 Wayne Wolf
'04 Keshab K. Parhi
'05 Ali H. Sayed
'06 Vijay K. Madiseti
'07 Russel Jacob (Jake) Baker
'08 Keith M. Chugg
'09 David Tse
'10 Bhaskar Krishnamachari
'11 Tony Givargis

ASEE ECE Division Hewlett-Packard Frederick Emmons Terman Award (continued)

About the Terman Award

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

The recipient must be an electrical engineering educator who is less than 45 years old on June 1 of the year in which the award is presented and must be the principal author of an electrical engineering textbook published before June 1 of the year of his/her 40th birthday. The book must have been judged by his/her peers to be an outstanding original contribution to the field of electrical engineering. The recipient must also have displayed outstanding achievements in teaching, research, guidance of students, and other related activities.



About Frederick Emmons Terman

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

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

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

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



Tanja Karp
Texas Tech University

Past Recipients

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

IEEE Education Society Hewlett-Packard Harriet B. Rigas Award

Presented by Martina Trucco

For her sustained work in creating a pipeline of robotics programs that effectively encourage young people to pursue careers in engineering

Dr. Tanja Karp received her Dipl.-Ing. (M.S.) and Dr.-Ing. (Ph.D.) degrees in Electrical Engineering from the Technical University of Hamburg-Harburg, Germany, in 1993 and 1997, respectively. She is currently an Associate Professor of Electrical and Computer Engineering at Texas Tech University in Lubbock, Texas. Prior to joining the faculty at Texas Tech in 2000, Dr. Karp was a Senior Research and Teaching Associate at the Institute of Computer Engineering at Mannheim University, Germany. Her research interests include digital signal processing, multicarrier communications, and STEM education. She has published over 75 journal and conference articles in these areas.

Since 2005, Dr. Karp has been involved in K-12 engineering outreach geared at attracting more and better qualified students into engineering careers and increasing the retention of engineering undergraduate students. She has taken a leadership role in among her colleagues at the university in organizing high school student summer camps at Texas Tech University and has implemented a pipeline of engineering activities for K-12 students during the academic year. She annually organizes the Get Excited About Robotics (GEAR) competition in Lubbock. During this 8-week long competition students from elementary and middle schools design LEGO NXT robots to autonomously perform tasks described in the annually changing challenge. Participants are mentored by engineering freshmen enrolled in a Service Learning introductory engineering course which she regularly teaches. Since 2006 the Lubbock GEAR competition has grown from a single participating school to over 600 students from 50 schools and attracts a large percentage of female participants (>40%).

Dr. Karp is a senior member of IEEE and a member of the Society of Women Engineers (SWE). Since 2011 she has served as the faculty advisor of the Texas Tech student SWE section, which organized the SWE Region C conference in Lubbock in January 2012. She also serves as the Fulbright Program Adviser for Texas Tech University.

Dr. Karp has received several awards for her excellence and innovation in teaching including the Lockheed Martin Aeronautics Company Excellence in Engineering Teaching Award (2003 and 2009), the Spencer A. Wells Creativity in Teaching Award from the Texas Tech Parent Association (2006), the College of Engineering George T. & Gladys Abell Hanger Faculty Teaching Award (2006) and the Butler Distinguished Educator Award (2012). She was a Service Learning Fellow during the academic year 2009/2010 and served as a Mentor for TTU's Service Learning Program in 2010/2011.

IEEE Education Society Hewlett-Packard Harriet B. Rigas Award (continued)

About the Rigas Award

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

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

About Harriett B. Rigas

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

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

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



Kristi J. Shryock
Texas A&M University



Arun R. Srinivasa
Texas A&M University



Jeffrey E. Froyd
Texas A&M University

Past Recipients

- '73 Walter D. Story
- '74 Richard Hooper
- '75 John J. Alan III and
J.J. Lagowski
- '76 John Hipwell and
David Blaume
- '77 John W. Renner
- '78 Albert J. Morris

Frontiers in Education Conference Benjamin J. Dasher Best Paper Award

Presented by Arnold Pears

Developing Instruments to Assess First-year Calculus and Physics Mechanics Skills Needed for a Sophomore Statics and Dynamics Course
by K. Shryock, A. R. Srinivasa, and J. E. Froyd
FIE 2011, Session F1J

Kristi J. Shryock received her B.S. and M.S. degrees in Aerospace Engineering at Texas A&M University in 1998 and 2000, respectively. She received her Ph.D. degree in Interdisciplinary Engineering at Texas A&M University in 2011 with a research focus on engineering education. She currently serves as the Assistant Department Head for Undergraduate Programs and Outreach in the Department of Aerospace Engineering at Texas A&M University. She is also a Senior Lecturer in the Department.

Her teaching and research focuses on improving the undergraduate engineering experience through evaluating preparation in mathematics and physics. In addition, she works to incorporate new technologies, experiential education, and multi-disciplinary design into the classroom. The work in the Dasher paper specifically evaluates the alignment of the mathematics and physics students learn in their freshman year with the knowledge needed in their sophomore year and beyond in engineering.

Arun Srinivasa obtained his bachelor's degree from the mechanical engineering department in IIT Madras in 1986. He received his PhD from the University of California at Berkeley in 1991 in Mechanical Engineering with minors in Materials Science and Mathematics. His PhD thesis was on dislocation dynamics. He subsequently joined the University of Pittsburgh faculty from 1993 to 1997 and then moved to Texas A&M University, where he is a professor of mechanical engineering. He was the holder of the Halliburton Professorship between 2010 and 2011 and is now William Kheeler Faculty fellow. He spent a year at Texas A&M Qatar from 2011 to 2012. He is the author of the book *Inelasticity of Materials, An Engineering Approach and a Practical Guide* (World Scientific Press) along with Dr. Sivakumar Srinivasan from IIT Madras.

His research interests include simulation of materials processing and other dissipative phenomena, design of "smart components" using shape memory alloys and polymers, cosserat continua and algorithms for fast virtual reality simulations for educational purposes. He is very much involved in the use of technology in education and in the use of DIY toys and manipulatives for educational purposes.

Jeffrey E. Froyd (Fellow, IEEE) received the B.S. degree in mathematics from Rose-Hulman Institute of Technology, Terre Haute, IN, in 1975 and the M.S. and Ph.D. degrees in electrical engineering from the University of Minnesota, Minneapolis, in 1976 and 1979, respectively.

He is a TEES Research Professor in the Engineering Student Services and Academic Programs at Texas A&M University, College Station. Prior to this, he was an Assistant Professor, Associate Professor, and Professor of Electrical and Computer Engineering at Rose-Hulman Institute of Technology. He served as

'79 Donald R. Woods,
Cameron M. Crowe,
Terrence W. Hoffman,
and Joseph D. Wright
'80 Marilla D. Svinicki
'81 Martha Montgomery
'82 A.L. Riemenschneider
and Lyle D. Feisel
'83 Davood Tashayyod,
Banu Onaral, and
James M. Trosino
'84 Bill V. Koen
'85 Bill V. Koen
'86 Richard S. Culver
'87 David A. Conner,
David G. Green,
Thomas C. Jannett,
James R. Jones,
M.G. Rekoff, Jr.,
Dennis G. Smith, and
Gregg L. Vaughn
'88 Richard M. Felder
'89 Richard C. Compton and
Robert York
'90 Cindy A. Greenwood
'91 Robert Whelchel
'92 William LeBold and
Dan D. Budny
'93 Daniel M Hull and
Arthur H. Guenther
'94 Burks Oakley II and
Roy E. Roper
'95 Curtis A. Carver, Jr. and
Richard A. Howard
'96 Val D. Hawks
'97 Edwin Kashy,
Michael Thoennessen,
Yihjia Tsai,
Nancy E. Davis, and
Sheryl L. Wolfe
'98 A.B. Carlson,
W.C. Jennings, and
P.M. Schoch
'99 Wayne Burleson,
Aura Ganz, and
Ian Harris
'00 David W. Petr
'02 Zeynep Dilli,
Neil Goldsman,
Lee Harper,
Steven I. Marcus,
and Janet A. Schmidt

Project Director for the Foundation Coalition, a National Science Foundation (NSF) Engineering Education Coalition in which six institutions systematically renewed, assessed, and institutionalized their undergraduate engineering curricula, and extensively shared their results with the engineering education community. At Rose-Hulman, he co-created (with Brian Winkel) the Integrated, First-Year Curriculum in Science, Engineering and Mathematics, which was recognized in 1997 with a Hesburgh Award Certificate of Excellence. He has authored over 70 papers on faculty development, curricular change processes, curriculum redesign, and assessment.

Prof. Froyd is a Fellow of the American Society for Engineering Education, an Accreditation Board for Engineering and Technology (ABET) Program Evaluator, and a Senior Associate Editor for the Journal of Engineering Education. He has served as a program co-chair for the 2003, 2004, and 2011 Frontiers in Education Conferences and the general chair for the 2009 Frontiers in Education Conference.

'03 Glenn W. Ellis, Gail E. Scordilis, and Carla M. Cook
'04 Matthew W. Ohland, Guili Zhang, Brian Thorndyke, and Timothy J. Anderson
'05 Gregory A. Moses and Michael Litzkow
'07 Donna Riley and Gina-Louise Sciarra
'08 Eric Hamilton and Andrew Hurford
'09 Steve Krause, Robert Culbertson, Michael Oehrtman, Marilyn Carlson,
Bill Leonard, C.V. Hollo, and William Gerace
'10 Glenda Stump, Jenefer Husman, Wen-Ting Chung and Aaron Done
'11 Jeffrey L. Newcomer

Frontiers in Education Conference Benjamin J. Dasher Best Paper Award (continued)

About the Dasher Award

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

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

About Benjamin J. Dasher

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

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

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

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

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



Şenay Purzer
Purdue University



Jonathan C. Hilpert
Georgia Southern
University

Past Recipients

- '80 Helen Plants
- '81 Jim Russell and
John C. Lindenlaub
- '82 Karl A. Smith and
Harold Goldstein
- '83 E. Dendy Sloan and
Charles F. Yokomoto
- '84 David W. Johnson and
Karl A. Smith
- '85 Billy V. Koen
- '86 Martha A. Nord and
Patricia H. Whiting
- '87 John C. Lindenlaub
- '89 Karl A. Smith
- '91 Troy E. Kostek
- '92 Barbara M. Olds and
Ronald L. Miller
- '93 John C. Lindenlaub and
Alisha A. Waller
- '94 Billy V. Koen
- '95 Burks Oakley II and
Mark Yoder

Frontiers in Education Conference Helen Plants Award Best Nontraditional Session at FIE 2011

Presented by Susan Lord

Cognitive Processes Critical for Ill-Defined Problem Solving: Linking Theory, Research, and Classroom Implications

Şenay Purzer and Jonathan C. Hilpert, FIE 2011, Session T2A

Şenay Purzer is an Assistant Professor in the School of Engineering Education and is the Director of Assessment Research for the Institute for P-12 Engineering Research and Learning (INSPIRE) at Purdue University. She received a B.S.E with distinction in Engineering at Arizona State University in 2009 and a B.S. degree in Physics Education in 1999. Her M.A. and Ph.D. degrees are in Science Education from Arizona State University earned in 2002 and 2008, respectively.

Dr. Purzer is a NAE/CASEE New Faculty Fellow. She is also the recipient of a 2012 NSF CAREER award, which examines how engineering students approach innovation. Her research focuses on assessment, engineering innovation, and mixed-methods research. She is currently leading projects funded by NSF, NASA, and corporate foundations. She has published over 70 peer-reviewed conference and journal papers on engineering and science education. Her research laboratory, Engineering Learning Observatory, houses projects on video and discourse analysis methods to examine engineering students' approaches to innovation, design thinking, and collaborative decision-making processes. She is a 2009 National Effective Teaching Institute (NETI) fellow and currently teaches courses on educational research methods and engineering design.

Dr. Purzer has been active in engineering education since 2005 as an author and paper reviewer. She has chaired the ASEE Educational Research and Methods Division (ERM) best paper award selection committee in 2012 and is currently a Director of ASEE-ERM division. She serves in the review boards of several journals including the Journal of Engineering Education (JEE) and Science Education and is an editorial board member for the Journal of Pre-College Engineering Education (JPEER).

Jonathan C. Hilpert, a professor of Educational Psychology at Georgia Southern University in the College of Education, received his bachelor's degree in education from Pepperdine University in 2000 and his masters and PhD from Arizona State University in 2008. His area of expertise is the content application and statistical specification of domain general learning models to engineering classrooms. The models he develops are grounded in information processing theory and focus primarily on the intersection of motivation, cognition, and instructional strategies at the post-secondary level. Some notable accomplishments include being named an FIE new faculty fellow in 2008 and being awarded an NSF RAPID grant in 2009 to study the impact of engineering professors' efforts to improve instruction on student motivation and knowledge building.

Helen Plants Award Past Recipients, Continued

- '96 Alisha A. Waller, Edward R. Doering, and Mark A. Yoder
- '97 Karl A. Smith, James D. Jones and Elizabeth Eschenbach
- '98 Alice Agogino
- '99 Melinda Piket-May and Julie L. Chang
- '03 William C. Oakes
- '04 Susan M. Lord, Elizabeth A. Eschenbach, Alisha A. Waller, Eileen M. Cashman, and Monica J. Bruning
- '05 Ruth A. Streveler
- '06 Ruth A. Streveler, Karl A. Smith, and Ronald L. Miller
- '08 Maura Borrego, Lynita Newswander, and Lisa McNair
- '09 Lisa C. Benson, Sherrill B. Biggers, William F. Moss, Matthew Ohland, Marisa K. Orr, and Scott D. Schiff
- '10 Russell Korte and Karl A. Smith
- '11 Mark Somerville, Dave Goldberg, Sherra E. Kerns, and Russell Korte

About the Plants Award

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

About Helen Margaret Lester Plants

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

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

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

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

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



Arnold Pears
Uppsala University

Past Recipients

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

Frontiers in Education Conference Ronald J. Schmitz Award

Presented by Susan Lord

For outstanding service to the Frontiers in Education Conference

Arnold Pears received his BSc(Hons) in 1986 and PhD in 1994, both from La Trobe University, Melbourne, Australia. He occupied positions as lecturer and senior lecturer at La Trobe University between 1991 and 1998. In 1999 he was appointed as senior lecturer at Uppsala University, Sweden. He was awarded the Uppsala University Pedagogy Prize in 2008, and appointed as Associate Professor of Computing Education Research in May 2011. Roles at Uppsala University include appointment to the University Academic Senate, Programme Director for the IT Engineering programme, member of the selection committee for the Uppsala University Pedagogy prize and as member of the educational advisory board of the Faculty of Technology and Natural Sciences.

He has a strong interest in teaching and learning research in computer science and engineering, and leads the UpCERG research group in computing and engineering education research at Uppsala University. He has published 25 articles in the area internationally, and is well known as a computing education researcher through his professional activities in the ACM, and IEEE. In the IEEE he serves as a member of the Board of Governors of the IEEE Computer Society, where he is active in the Education Activities Board, serving also on the steering committee of the Frontiers in Education Conference and as Chair of the newly established Special Technical Community (STC) for Education. In addition he is a Director of CeTUSS (The Swedish National Center for Pedagogical Development of Technology Education in a Societal and Student Oriented Context, www.cetuss.se) and the IEEE Education Society Nordic Chapter.

He as a reviewer for a number of major journals and conferences, including the Computer Science Education Journal (Taylor and Francis), the ACM SIGCSE and ITiCSE and Koli Calling International Computer Science Education conferences.

Recent publications include "Does Quality Assurance Enhance the Quality of Computing Education?", in the Proceedings of the 12th Australasian Computer Science Education Conference, 2010, and models for research driven education in Computing, "Conveying Conceptions of Quality through Instruction", in the 7th International Conference on the Quality of Information and Communications Technology, 2010.

Frontiers in Education Conference Ronald J. Schmitz Award (continued)

About the Schmitz Award

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

About Ronald J. Schmitz

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

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

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

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

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

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



Theodore Rappaport
New York University

Past Recipients

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

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

Presented by Manuel Castro

For contributions to the theory and practice of education and educational technology through the creation of academic research centers, textbooks, software, and companies in the field of wireless communication engineering

Theodore (Ted) S. Rappaport is the David Lee/Ernst Weber Professor of Electrical Engineering at the Polytechnic Institute of New York University (NYU-Poly) and is a professor of computer science at New York University's Courant Institute of Mathematical Sciences, and professor of radiology at the New York University School of Medicine. Rappaport is founding director of NYU WIRELESS, a new kind of academic research center that combines wireless communications engineering and computer science with the practice of medicine and health care. He also serves as Director of the National Science Foundation (NSF) Industrial/University Collaborative Research Center for Wireless Internet Communications and Advanced Technology (WICAT), a national research center headquartered at NYU-Poly that involves five major universities, including the two wireless programs he founded at The University of Texas (WNCG in 2002) and Virginia Tech (MPRG in 1990).

Rappaport is a pioneer in the fields of radio wave propagation for cellular and personal communications, wireless communication system design, and broadband wireless communications circuits and systems at millimeter wave frequencies. His research has influenced many products and international standards for cellular and local/personal area wireless networks, and he and his students invented software radio and position location technologies in the early 1990's, and site-specific radio frequency (RF) channel modeling and design technologies for wireless network deployment in the late 1990's – technologies now used routinely throughout the field of wireless communications. As a faculty member, Rappaport has advised approximately 100 students who continue to accomplish great things in the communications, electromagnetics, and circuit design fields throughout industry, academia, and government.

In 2006, Rappaport was elected to the Board of Governors of the IEEE Communications Society (ComSoc), and to the Board of Governors of the IEEE Vehicular Technology Society (VTS) in 2008 and again in 2011. He is a fellow of the IEEE, is a member of the board of the Marconi Society, and serves on the editorial boards of several academic and technical journals. He received the Marconi Young Scientist Award in 1990, an NSF Presidential Faculty Fellowship in 1992, the Sarnoff Citation from the Radio Club of America in 2000, the Fredrick E. Terman Outstanding Electrical Engineering Faculty Award from the American Society for Engineering Education in 2002, and the Stuart F. Meyer Award from the IEEE Vehicular Technology Society in 2005. In 2008, he received the Industry Leadership Award from the Austin Wireless Alliance and the IEEE Communications Society WTC Recognition Award for outstanding achievements and contributions in the area of wireless communications systems and networks. The IET honored Rappaport with the Sir Monty Finniston medal in 2011 "for his outstanding academic and industrial contributions over almost three decades in the field of wireless communication." Rappaport has over 100 U.S. or international patents issued or pending and has authored, co-authored, and co-edited 18 books in the wireless field, including the best-selling textbook *Wireless Communications*

Principles & Practice (translated into 6 languages), Principles of Communication Systems Simulation with Wireless Applications, and Smart Antennas for Wireless Communications: IS-95 and Third Generation CDMA Applications. He has received three prize paper awards, including the 1999 Stephen O. Rice Prize Paper Award from the IEEE Communications Society for his work on site-specific propagation.

Rappaport has also been an entrepreneur, encouraging his students to create companies from their research. In 1989, he founded TSR Technologies, Inc., a cellular radio/PCS software radio manufacturer that he sold in 1993 to what is now Commscope, Inc. (taken private in 2011 by Carlyle Group). In 1995, he founded Wireless Valley Communications, Inc., a pioneering creator of site-specific radio propagation software for wireless network design and management that he sold in 2005 to Motorola. Rappaport has testified before the U.S. Congress, served as an international consultant for the International Telecommunication Union, consulted for more than 30 major telecommunications firms, and continues to work on many national committees pertaining to communications research and technology policy. He is a highly sought consultant and technical expert. He received BS, MS, and PhD degrees in electrical engineering from Purdue University in 1982, 1984, and 1987, respectively, and is an Outstanding Electrical Engineering Alumnus of his alma mater.

About the Sayle Award and William E. Sayle II

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

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

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

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

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

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

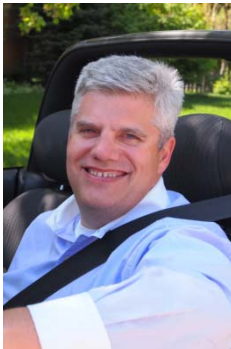
Dr. Sayle passed away on February 2, 2008.



Susan Lord
University of San Diego



Richard Layton
Rose-Hulman Institute of
Technology



Matthew Ohland
Purdue University

Past Recipients

- '99 J.A. Buck, H. Owen,
J.P. Uyemura, C.M. Verber,
and D.J. Blumenthal
- '00 David J. Russomanno
and Ronald D. Bonnell
- '01 Christopher W. Trueman
- '02 Mohan Krishnan
and Mark J. Paulik

IEEE *Transactions on Education* Best Paper Award

Presented by Manuel Castro

***Trajectories of Electrical Engineering and Computer Engineering
Students by Race and Gender, S.M. Lord, R.A. Layton and
M. W. Ohland, IEEE Transactions on Education
Vol. 54, No. 4, November 2011, pp. 610-618***

Susan M. Lord is Professor and Coordinator of Electrical Engineering at the University of San Diego. She received a B. S. with distinction in Electrical Engineering and Materials Science and Engineering from Cornell University and the M.S. and Ph.D. in Electrical Engineering from Stanford University. From 1993-1997, Dr. Lord taught at Bucknell University. Author of over eighty publications, her teaching and research interests include electronics, optoelectronic materials and devices, service-learning, feminist pedagogy, lifelong learning, and engineering student persistence. Dr. Lord's industrial experience includes AT&T Bell Laboratories, General Motors Laboratories, NASA Goddard Space Flight Center, and SPAWAR Systems Center.

Dr. Lord's research in engineering education has been supported by several National Science Foundation (NSF) grants from programs including CAREER, instrumentation and laboratory improvement (ILI), scholarships for STEM (SSTEM), gender in science and engineering (GSE), and research in engineering education. These projects span a range of topics from engineering student persistence, to helping military veterans transition to engineering programs to optoelectronics experiments for first-year students. Since entering college, Dr. Lord has been committed to increasing diversity in engineering particularly supporting women and underrepresented minorities. In 1995, she was awarded the Eta Kappa Nu Outstanding Young Electrical Engineer Honorable Mention for "outstanding technical contributions to the field of optoelectronics and dedication to education and promoting the engineering profession for minorities and women." She and her colleagues received the 2005 Helen Plants Award for "Feminist Frontiers." She was named the 2010 Outstanding Engineering Educator by the San Diego County Engineering Council.

Dr. Lord has been active in the engineering education community since 1993. She is a senior member of the IEEE and Society of Women Engineers (SWE) and a member of ASEE and Tau Beta Pi. In addition to regularly presenting papers at the Frontiers in Education (FIE) and ASEE Conferences, she has held several leadership positions including FIE Steering Committee Member, General Co-Chair of FIE 2006, FIE 2005 Program Co-Chair, and elected member of administrative boards of the IEEE Education Society (EdSoc) and ASEE Education and Research Methods (ERM) Division. She served as the Vice President of EdSoc for 2007 and 2008 and the President for 2009 and 2010. She was the 2011 National Effective Teaching Institute (NETI) fellow.

Dr. Lord and her collaborators have been recognized for their longitudinal studies of engineering students with the William Elgin Wickenden Award for the Best Paper published in the Journal of Engineering Education in 2011. She was Guest Co-Editor of the 2010 Special Issue of the *International Journal of Engineering Education* (IJEE) on Applications of Engineering Education Research. Dr. Lord is an Associate Editor of the *IEEE Transactions on Education* and a member of the Editorial Board for IJEE.

'03 Tyson S. Hall,

James O. Hamblen, and
 Kimberly E. Newman
 '04 M. Brian Blake
 '04 Russell L. Pimmel
 '05 Antonio J. Lopez-Martin
 '06 Euan Lindsay and
 Malcolm C. Good
 '07 Jason A. Day and
 James D. Foley
 '08 France Bélanger,
 Tracy L. Lewis,
 George M. Kasper,
 Wanda J. Smith and
 K. Vernard Harrington
 '09 Kenneth Ricks,
 Jeff Jackson, and
 William A. Stapleton
 '10 Keith Holbert and
 George G. Karady
 '11 Julie A. Rursch,
 Andy Luse, and
 Doug Jacobson

Richard A. Layton is an Associate Professor of Mechanical Engineering and past director of the Center for the Practice and Scholarship of Education at Rose-Hulman Institute of Technology. He received a B.S. from California State University, Northridge, and an M.S. and Ph.D. from the University of Washington. His professional work includes research in student teaming and student pathways (persistence, migration, and retention) and consulting in data visualization and graph design.

Dr. Layton's teaching practice includes formal and informal cooperative learning with a generous portion of learn-by-thinking-and-doing. For over a decade, he has worked to transform student labs from procedure-driven exercises (push this button, read that gauge, get the data and leave) to problem-based learning experiences. More recently, he and his colleagues have redesigned a first-year design course to incorporate substantive learning objectives in sustainability, communication, teaming, and professional ethics.

Dr. Layton is a founding member of the team that developed the CATME system, a web-based suite of tools for managing teams and winner of the 2009 Premier Award for Excellence in Engineering Education Courseware. He and his collaborators have been recognized for their longitudinal studies of engineering students with the William Elgin Wickenden Award for the Best Paper published in the Journal of Engineering Education in 2008 and 2011. Layton is a member of the Educational Research and Methods (ERM) Division of the American Society of Engineering Education (ASEE) and has served as Director, 2009 FIE Program Co-Chair, and 2012 ASEE-ERM Program Chair.

He is also a songwriter, singer, and guitar player who can occasionally be heard at an open-mic.

Dr. Matthew Ohland is a Professor of Engineering Education at Purdue University. He has a Ph.D. in Civil Engineering from the University of Florida in 1996. Previously, he earned an M.S. in Materials Engineering in 1992 and an M.S. in Mechanical Engineering in 1991 from Rensselaer Polytechnic Institute and a B.S. in Engineering and a B.A. in Religion from Swarthmore College. He has had previous appointments as Associate Professor of General Engineering at Clemson University, Assistant Director of the NSF-sponsored SUCCEED Engineering Education Coalition, and a National Science Foundation Postdoctoral Fellow for Science, Mathematics, Engineering, and Technology Education. His research on the longitudinal study of engineering student development, team formation, peer evaluation, and extending the use of active and cooperative learning methods has been supported by over \$11.8 million from the National Science Foundation and the Sloan Foundation.

Dr. Ohland serves the IEEE Education Society as a member of the Board of Governors (2007-2013) and as an Associate Editor of IEEE Transactions on Education. He was the Chair of the Steering Committee of IEEE Transactions on Learning Technologies (2007-2011). He has also served as an Expert in the IEEE Public Visibility program. He was elevated to Senior Member grade in 2009 and was previously recognized by IEEE with the Benjamin Dasher Award for the best paper/presentation in the 2004 Frontiers in Education conference and the Helen Plants Award for the best non-traditional session at the 2008 Frontiers in Education Conference.

Dr. Ohland is a Fellow of the American Society of Engineering Education and has served the Educational Research and Methods division as Chair (2009-2011), Director (2001-2003 and 2008-2009), and Vice-Chair for FIE Programs / Program Chair for FIE 2008. He also serves ASEE as an ABET Program Evaluator for

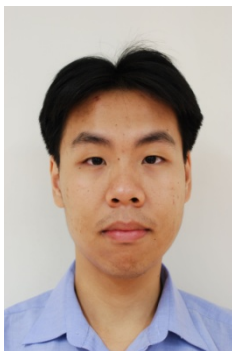
general engineering programs. Dr. Ohland was the 2002–2006 President of Tau Beta Pi, the national engineering honor society, and has delivered volunteer seminars reaching over 2000 students through the Association’s award-winning Engineering Futures program.

Dr. Ohland and his collaborators have been recognized for their longitudinal studies of engineering students with the William Elgin Wickenden Award for the Best Paper published in the Journal of Engineering Education in 2008 and 2011 and best paper awards at multiple conferences. The CATME and Team-Maker tools for managing teams developed under Dr. Ohland’s leadership received the 2009 Premier Award for Excellence in Engineering Education Courseware. Dr. Ohland was recognized by Clemson University in 2006 with the Byar’s Prize for Excellence in Teaching Engineering Fundamentals and by Purdue’s School of Engineering Education with the Best Teacher Award in 2007, 2008, and 2012.

Hong Kong Chapter



Chair –
Yuen-Yan Chan
Chinese University
of Hong Kong



Vice Chair –
Kai-Pan Mark
City University
of Hong Kong



Honorary Secretary –
Doris Ng

IEEE Education Society Chapter Achievement Award

Presented by Edmundo Tovar

In recognition of the Chapter's proven results in spreading IEEE Education Society's interests in China and Southeast Asia, thanks to outstanding leadership by its officers

Dr. Yuen-Yan Chan (M'07–SM'08) received B.Eng., M.Phil. and Ph.D. degrees in information engineering and the M.Ed. degree in educational psychology from the Chinese University of Hong Kong, Hong Kong, in 1998, 2000, 2006, and 2009, respectively. She is the Founding Chair and the current Chair of the IEEE Education Society Hong Kong Chapter. She is with the Department of Information Engineering, Chinese University of Hong Kong, Shatin, Hong Kong.

Dr. Kai-Pan Mark is currently the vice-chair of the Chapters Committee, IEEE Education Society and also the vice-chair of IEEE Education Society Hong Kong Chapter. He received his Ph.D. in Information Systems from City University of Hong Kong, his Master of Science in Information Engineering from The Chinese University of Hong Kong and his Bachelor of Science and Associate of Science, both in Computer Studies from City University of Hong Kong. Dr. Mark's research interest is on the behavioral aspects of different stakeholders in e-Learning systems addressing issues on habitual behavior formation through personalization and IT artifact design. He is an active volunteer in an IEEE Teacher in Service Program project in Hong Kong to provide assistance and support to science and technology education in rural small schools. He was a recipient of IEEE Education Society Student Leadership award 2010, and was also a FIE New Faculty Fellow in 2010.

Ms. Doris Ng (M'2007-) supports the Hong Kong Chapter as the Honorary Secretary. She received her B.B.A. in China Business from The City University of Hong Kong and M.A. in Communication from Hong Kong Baptist University in 2001 and 2009, respectively. She is now the Regional Marketing Manager, Enterprise Business, South East Asia of Huawei Technology Investment Co., Ltd. Before joining Huawei, she served as the Marketing Manager at Hewlett-Packard Hong Kong S.A.R. Limited.



Honorary Treasurer –
James Ho

Mr. Yu-Ho Ho serves as Honorary Treasurer of the Hong Kong Chapter of IEEE Education Society. He received his Postgraduate Dip. in Education and Bachelor of Engineering in Information Engineering from The Chinese University of Hong Kong, Hong Kong in 2008, and 2007, respectively. Mr. Ho's current research interest is on the anthroposophy educational philosophy, Waldorf education, a humanistic approach to pedagogy based on the educational philosophy. He is active in Developmental Kinesiology, Educational Kinesiology sectors in Hong Kong. He is a professional security consultant on IT systems in business sectors.

Past Recipients

'06 Nordic Chapter
'07 Spanish Chapter
'08 Gulf Chapter
'09 Santa Clara Valley
Chapter and
Portugal Chapter
'10 Austria Chapter
'11 Spain Chapter



German Cabuya
University Francisco José de
Caldas

Past Recipients

- '06 Michael E. Auer and
Manuel Castro
- '07 Carlos Rueda
Artunduaga and
Oliver K. Ban
- '08 Bakr Hassan and
Edmundo Tovar
- '09 Emmanuel A. Gonzalez
- '10 Martín Llamas-Nistal
- '11 Russ Meier

IEEE Education Society Distinguished Chapter Leadership Award

Presented by Edmundo Tovar

The Colombia chapter and the activity in the Andes Region has increased directly due to his efforts. Being well-aware of the situation of the Latin America region, he has dedicated himself to changing its standing in the world.

Dr. German Cabuya Parra graduated as an electronic engineer from the Universidad Distrital "Francisco José de Caldas" in 1989 and completed a postgraduate specialist degree at Escuela Superior de Administración Pública (ESAP) in 2001. He is currently the Information and communications Technology Office Head of the Special Administrative Unit of Public Services of Bogota (UAESP). He also holds a position as professor and counselor at the University Francisco José de Caldas.

Dr. Cabuya is an IEEE senior member, a Nikkoryu-kai member, and a senior management specialist of the state. His interests include engineering, education, telecommunications, aerospace, robotics, recruitment, supervision, administration, ethics, and journalism.



Matthew Ohland
Purdue University

Past Recipients

- '05 Marion O. Hagler and
Burks Oakley II
- '06 Ted Batchman and
David A. Conner
- '08 David L. Soldan
- '10 Manuel Castro
- '11 Susan M. Lord

IEEE Education Society Distinguished Member Award

Presented by Manuel Castro

For outstanding contributions in support of teamwork in higher education and student retention through research, courseware, archival publications, and presentations

Dr. Matthew Ohland is a Professor of Engineering Education at Purdue University. He has a Ph.D. in Civil Engineering from the University of Florida in 1996. Previously, he earned an M.S. in Materials Engineering in 1992 and an M.S. in Mechanical Engineering in 1991 from Rensselaer Polytechnic Institute and a B.S. in Engineering and a B.A. in Religion from Swarthmore College. He has had previous appointments as Associate Professor of General Engineering at Clemson University, Assistant Director of the NSF-sponsored SUCCEED Engineering Education Coalition, and a National Science Foundation Postdoctoral Fellow for Science, Mathematics, Engineering, and Technology Education. His research on the longitudinal study of engineering student development, team formation, peer evaluation, and extending the use of active and cooperative learning methods has been supported by over \$11.8 million from the National Science Foundation and the Sloan Foundation.

Dr. Ohland serves the IEEE Education Society as a member of the Board of Governors (2007-2013) and as an Associate Editor of IEEE Transactions on Education. He was the Chair of the Steering Committee of IEEE Transactions on Learning Technologies (2007-2011). He has also served as an Expert in the IEEE Public Visibility program. He was elevated to Senior Member grade in 2009 and was previously recognized by IEEE with the Benjamin Dasher Award for the best paper/presentation in the 2004 Frontiers in Education conference and the Helen Plants Award for the best non-traditional session at the 2008 Frontiers in Education Conference.

Dr. Ohland is a Fellow of the American Society of Engineering Education and has served the Educational Research and Methods division as Chair (2009-2011), Director (2001-2003 and 2008-2009), and Vice-Chair for FIE Programs / Program Chair for FIE 2008. He also serves ASEE as an ABET Program Evaluator for general engineering programs. Dr. Ohland was the 2002–2006 President of Tau Beta Pi, the national engineering honor society, and has delivered volunteer seminars reaching over 2000 students through the Association's award-winning Engineering Futures program.

Dr. Ohland and his collaborators have been recognized for their longitudinal studies of engineering students with the William Elgin Wickenden Award for the Best Paper published in the Journal of Engineering Education in 2008 and 2011 and best paper awards at multiple conferences. The CATME and Team-Maker tools for managing teams developed under Dr. Ohland's leadership received the 2009 Premier Award for Excellence in Engineering Education Courseware. Dr. Ohland was recognized by Clemson University in 2006 with the Byar's Prize for Excellence in Teaching Engineering Fundamentals and by Purdue's School of Engineering Education with the Best Teacher Award in 2007, 2008, and 2012.



Susan Lord
University of San Diego

Past Recipients

- '78 Warren B. Boast
- '79 Joseph M. Biedenbach
- '80 Edwin C. Jones, Jr.
- '81 Lyle D. Feisel
- '82 Roy H. Mattson
- '83 Robert F. Fontana
- '84 Gerald R. Peterson
- '85 Luke H. Noggle
- '86 James A. Mulligan
Sidney S. Shamis
- '87 Thomas K. Gaylord
- '88 Robert F. Cotellessa
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- '10 Michael E. Auer
- '11 Russ Meier
- '11 Claudio da Rocha Brito
and Melany M. Ciampi

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

Presented by Manuel Castro

For contributions to engineering education and the Education Society through service as President, Ad Com Member, General and Program Chairs for the Frontiers in Education Conference, Strategic Planning, Editorial Board Member, and the All Society Review Panel

Susan M. Lord is Professor and Coordinator of Electrical Engineering at the University of San Diego. She received a B. S. with distinction in Electrical Engineering and Materials Science and Engineering from Cornell University and the M.S. and Ph.D. in Electrical Engineering from Stanford University. From 1993-1997, Dr. Lord taught at Bucknell University. Author of over eighty publications, her teaching and research interests include electronics, optoelectronic materials and devices, service-learning, feminist pedagogy, lifelong learning, and engineering student persistence. Dr. Lord's industrial experience includes AT&T Bell Laboratories, General Motors Laboratories, NASA Goddard Space Flight Center, and SPAWAR Systems Center.

Dr. Lord's research in engineering education has been supported by several National Science Foundation (NSF) grants from programs including CAREER, instrumentation and laboratory improvement (ILI), scholarships for STEM (SSTEM), gender in science and engineering (GSE), and research in engineering education. These projects span a range of topics from engineering student persistence, to helping military veterans transition to engineering programs to optoelectronics experiments for first-year students. Since entering college, Dr. Lord has been committed to increasing diversity in engineering particularly supporting women and underrepresented minorities. In 1995, she was awarded the Eta Kappa Nu Outstanding Young Electrical Engineer Honorable Mention for "outstanding technical contributions to the field of optoelectronics and dedication to education and promoting the engineering profession for minorities and women." She and her colleagues received the 2005 Helen Plants Award for "Feminist Frontiers." She was named the 2010 Outstanding Engineering Educator by the San Diego County Engineering Council.

Dr. Lord has been active in the engineering education community since 1993. She is a senior member of the IEEE and Society of Women Engineers (SWE) and a member of ASEE and Tau Beta Pi. In addition to regularly presenting papers at the Frontiers in Education (FIE) and ASEE Conferences, she has held several leadership positions including FIE Steering Committee Member, General Co-Chair of FIE 2006, FIE 2005 Program Co-Chair, and elected member of administrative boards of the IEEE Education Society (EdSoc) and ASEE Education and Research Methods (ERM) Division. She served as the Vice President of EdSoc for 2007 and 2008 and the President for 2009 and 2010. She was the 2011 National Effective Teaching Institute (NETI) fellow.

Dr. Lord and her collaborators have been recognized for their longitudinal studies of engineering students with the William Elgin Wickenden Award for the Best Paper published in the Journal of Engineering Education in 2011. She was Guest Co-Editor of the 2010 Special Issue of the *International Journal of Engineering Education* (IJEE) on Applications of Engineering Education Research. Dr. Lord is an Associate Editor of the *IEEE Transactions on Education* and a member of the Editorial Board for IJEE.

About the Edwin C. Jones Award

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

About Edwin C. Jones

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



Babak Ayazifar
University of California,
Berkeley

Past Recipients

'04 Parham Aarabi
'05 John R. Buck
'06 Lisa G. Huettel
'07 Susan C. Hagness
'08 Kathleen E. Wage
'09 Min Wu
'10 Craig Ziles
'11 Jonathan Makela

IEEE Education Society Mac Van Valkenburg Early Career Teaching Award

Presented by Manuel Castro

For creative, lively, challenging, and caring teaching that has sparked broad excitement and engagement among his students, even in the largest core courses.

Babak Ayazifar joined the EECS faculty at UC Berkeley in 2005, where he is now a Lecturer with Security of Employment (Lecturer SOE)—equivalent to an Associate Professor in Teaching with tenure. He earned his B.S. in EE from Caltech, and his S.M. and Ph.D. in EECS from MIT. In his doctoral research, he applied spectral graph theory to the study of the mutual influence of a network's topology and dynamics. This led to his dissertation, *Graph Spectra and Modal Dynamics of Oscillatory Networks*.

At MIT, Babak received the *Harold L. Hazen Award* for outstanding teaching. He advanced to the rank of *Instructor-G*, which conferred teaching assignments ordinarily reserved for faculty. He won the *Goodwin Medal*, MIT's most prestigious award for a graduate student whose teaching is "conspicuously effective over and above ordinary excellence." And, in spring 2002, he took leave from his graduate studies to take an appointment as a *Senior Lecturer* at MIT's School of Engineering, teaching a graduate course in digital signal processing.

Immediately prior to his faculty appointment at UC Berkeley, Babak was a Technical Specialist in the *Intellectual Property and Technology Group* of *Ropes & Gray, LLP*. His intellectual property experience spans patent prosecution and related activities over a wide range of technologies, such as mechanical devices, intravascular MRI, DNA Microarray data analysis, and encrypted communication using chaotic systems. Babak is a patent agent, registered to practice before the *United States Patent and Trademark Office* (Reg. No. 56793).

At UC Berkeley, he has focused on teaching; student learning; curriculum development and reform; mentoring graduate and undergraduate teaching assistants; and sharing the results of his pedagogical innovations and insight at international conferences and other forums. In spring 2008, Babak received the UC Berkeley EE Division's *Outstanding Teaching Award for Excellence in Teaching*.



Elio San Cristobal Ruiz
Universidad Nacional de
Educación a Distancia

Past Recipients

- '09 Seiji Isotani
- '10 Emmanuel Gonzalez and
Kai-Pan Mark
- '11 Dario Schor

IEEE Education Society Student Leadership Award

Presented by Manuel Castro

***For his outstanding contributions to the consolidation of the IEEE
UNED (Spanish University for Distance Education) Student Branch***

Elio San Cristobal Ruiz has a Ph.D. degree in electrical and computer engineering from the Spanish University for Distance Education (UNED), Madrid, Spain, in 2010.

Currently he is working as an Assistant Professor with the Electrical and Computer Engineering Department, Industrial School of UNED. He is involved in several European projects and a NSF project in the field of education and the application of virtual and remote laboratories in distance learning.

He has been involved in IEEE activities since 2006, being chairman of the IEEE UNED student branch from 2009 to 2010. Currently he is a member of the Spanish Chapter of the IEEE Education Society.



Sergio Martin
Universidad Nacional de
Educación a Distancia

Past Recipients

- '09 Seiji Isotani
- '10 Emmanuel Gonzalez and
Kai-Pan Mark
- '11 Dario Schor

IEEE Education Society Student Leadership Award

Presented by Manuel Castro

***For his outstanding contributions to the consolidation of the IEEE
UNED (Spanish University for Distance Education) Student Branch***

Sergio Martin (M'06) was born in Madrid, Spain, in 1980. He received the Ph.D. degree in electrical and computer engineering from the Spanish University for Distance Education (UNED), Madrid, Spain, in 2010.

He has worked as an Assistant Professor with the Electrical and Computer Engineering Department, Industrial School of UNED, since 2007. Since 2002, he has participated in the department's national and international research projects. He has received two best thesis awards and four best paper awards.

Dr. Martin has been involved in IEEE activities since 2006, being chairman of the IEEE UNED student branch from 2007 to 2008. Currently he is an advisory board member of the Spanish Chapter of the IEEE Education Society and of the IEEE Technology Management Council of Spain.

REVIEWERS

This year, FIE 2012 had over 680 papers and presentations submitted for consideration. The FIE2012 Program Committee wishes to thank the following individuals for acting as abstract and paper reviewers. The program committee asked these individuals to help control the quality of the presentations at this year's conference by reviewing the submissions for FIE2012. Their outstanding effort has helped maintain the high standard that has become the reputation of each FIE conference.

If you are interested in becoming a reviewer for a future FIE conference, please visit FIEconference.org.

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| Pablo Ordu  a | Deusto Institute of Technology - DeustoTech, University of Deusto |
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| Eric Pappas | James Madison University |
| Luis Paquete | University of Coimbra |
| Rafael Pastor | National Distance University of Spain |
| Arnold Pears | Uppsala University |

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| Jian Peng | Southeast Missouri State University |
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| Lance Pérez | University of Nebraska, Lincoln |
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| Karel Perutka | Tomas Bata University in Zlin |
| Anne-Kathrin Peters | Uppsala University |
| Dragutin Petkovic | San Francisco State University |
| Olivier Pfeiffer | TU Berlin |
| Chris Plouff | Grand Valley State University |
| Carolyn Plumb | Montana State University |
| Jennifer Polack-Wahl | University of Mary Washington |
| Pedro Ponce | ITESM |
| Michael Prairie | Norwich University |
| Luanna Prevost | Michigan State University |
| Marta Prim | Universitat Autònoma de Barcelona |
| John Pritchard | Iowa State University |
| Amy Pritchett | Georgia Institute of Technology |
| Andrzej Proskurowski | University of Oregon |
| Cheryl Zhenyu Qian | Purdue University |
| Rajendra Raj | Rochester Institute of Technology |
| Manikanada Rajagopal | IUPUI |
| Rajiv Ramnath | The Ohio State University |
| Suhas Ranganath | Arizona State University |
| Jodi Reeves | National University |
| Luisa Regueras | Universidad de Valladolid |
| Tom Reichlmayr | Rochester Institute of Technology |
| Christine Reilly | University of Texas - Pan American |
| Martin Reisslein | Arizona State University |
| Rodolfo Resende | Federal University of Minas Gerais |
| Renata Revelo Alonso | University of Illinois at Urbana-Champaign |
| Luz Rivas | Iridescent |
| Mona Rizvi | Norfolk State University |
| Luz Robles | Universidad Nacional de Educación a Distancia (UNED) |
| Antonio Robles-Gómez | Universidad Nacional de Educación a Distancia (UNED) |
| Kelsey Rodgers | Purdue University |
| Josef Rojter | Victoria University |
| Carla Romney | Boston University |
| Salvador Ros | UNED |
| Warren Rosen | Drexel University |

| Name | Institution |
|----------------------|---|
| Carolyn Rosiene | University of Hartford |
| Luisa-Maria Rosu | University of Illinois |
| Siegfried Rouvrais | Telecom Bretagne |
| Gerard Rowe | University of Auckland |
| Krishnendu Roy | Valdosta State University |
| Susan Ruff | MIT |
| Anthony Ruocco | Roger Williams University |
| Julie Rursch | Iowa State University |
| Ingrid Russell | University of Hartford |
| Adrian Rusu | Rowan University |
| Amalia Rusu | Fairfield University |
| Mehran Sahami | Stanford |
| Perry Samson | University of Michigan |
| Dag Samuelson | Buskerud University College |
| Luis Sanchez Ruiz | Universitat Politècnica de València |
| Aidsa Santiago-Roman | University of Puerto Rico at Mayaguez |
| A Ivaro Santos | University of Coimbra (CISUC) |
| Juan Santos | University of Vigo |
| Leonardo Santos | UFAM - Federal University of Amazonas |
| Simone Santos | Federal University of Pernambuco |
| Brook Sattler | University of Washington |
| Dirk Schaefer | Georgia Institute of Technology |
| Walter Schilling | Milwaukee School of Engineering |
| Eva Schiorring | The Research & Planning Group for California Community Colleges |
| Lizabeth Schlemer | Cal Poly, San Luis Obispo |
| Susan Schneider | Marquette University |
| Dario Schor | University of Manitoba |
| Dino Schweitzer | USAF Academy |
| Elena Seleznova | Hlukhiv Pedagogical University |
| Bhavna Sharma | University of Pittsburgh |
| Mark Sherriff | University of Virginia |
| Kristi Shryock | Texas A&M University |
| Junaid Siddiqui | Purdue University |
| Richa Singh | IIIT Delhi |
| Matthew Siniawski | Loyola Marymount University |
| Richard Smith | Rensselaer Polytechnic Institute |
| S. Diane Smith | DeVry University |
| Chris Snook | University of Southern Queensland |
| Marc Sosnick | San Francisco State University |
| John Springer | Purdue University |
| Saket Srivastava | IIIT Delhi |
| Ken Stanton | Colorado State University |
| Andrew Sterian | Grand Valley State University |

| Name | Institution |
|-------------------------|--|
| Jon Sticklen | Michigan State University |
| Itana Stiubiener | Universidade Federal do ABC UFABC |
| Rachel Straney | University of Central Florida |
| Aaron Striegel | University of Notre Dame |
| Ramakrishnan Sundaram | Gannon University |
| Mei-Huei Tang | Gannon University |
| Dan Tappan | Western New Mexico University |
| Constantine Tarawneh | The University of Texas-Pan American |
| Kassim Tarhini | United States Coast Guard Academy |
| Mohamed Tawfik | UNED |
| Ketlen K. Teles Lucena | Federal University of Amazonas |
| Marco Temperini | Sapienza University of Rome |
| Lauren Thomas | Virginia Tech |
| Julia Thompson | Purdue University |
| Neena Thota | Uppsala University |
| Jason Tinant | Oglala Lakota College |
| David Tinapple | Arizona State University |
| Carlos Tobar | Pontifical Catholic University of Campinas |
| Llanos Tobarra | UNED |
| Kathryn Trenshaw | University of Illinois at Urbana-Champaign |
| James Trevelyan | University of Western Australia |
| Michael Trevisan | Washington State University |
| Deborah Trytten | University of Oklahoma |
| Cameron Turner | Colorado School of Mines |
| Stephen Turner | University of Michigan-Flint |
| Jennifer Turns | University of Washington |
| Thomas Twardowski | Manhattan College |
| Luther Tychonievich | University of Virginia |
| Suleyman Uludag | The University of Michigan - Flint |
| Tristan Utschig | Georgia Institute of Technology |
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| Elena Verdú Pérez | Universidad de Valladolid |
| María Jesús Verdú Pérez | Universidad de Valladolid |
| Rosa Vicari | Universidade Federal do Rio Grande do Sul |
| Elsa Villa | The University of Texas at El Paso |
| Luis Villarejo | Universitat Oberta de Catalunya |
| Vimal Viswanathan | Texas A&M University |
| Alisha Waller | Georgia Institute of Technology |
| Andrew Wandel | University of Southern Queensland |

| Name | Institution |
|-----------------------|--|
| Xiaofang Wang | Villanova University |
| Jessica Ward | Drexel University |
| Steve Warren | Kansas State University |
| Cindy Waters | NCA&T State University |
| Heather Watson | James Madison University |
| Mary Katherine Watson | Georgia Institute of Technology |
| Alfred Weaver | University of Virginia |
| Carol Wellington | Shippensburg University |
| Keith Willey | The University of Technology, Sydney |
| Rob Williams | University of the West of England |
| Stephen Williams | Milwaukee School of Engineering |
| Denise Wilson | University of Washington |
| Timothy Wilson | Embry-Riddle Aeronautical University |
| Frank Xu | 109 University Square |
| Kumar Yelamarthi | Central Michigan University |
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| Liu Yuan Chen | National Taipei University of Education |
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| Sarah Zappe | Penn State University |
| Yevgeniya Zastavker | F. W. Olin College of Engineering |
| Amir Zeid | American University of Kuwait |
| Seyed (Reza) Zekavat | Michigan Technological University |
| Weizhao Zhao | University of Miami |
| Quanyan Zhu | University of Illinois at Urbana Champaign |
| Ben Zoghi | Texas A&M University |
| Danilo Zutin | Carinthia University of Applied Sciences |

CATALYZING COLLABORATIVE CONVERSATIONS

Catalyzing Collaborating Conversations are open-invitation special sessions, where members of the FIE community present an educational challenge, idea, or research result where they would like to work with others to solve the challenge or develop the idea or result further. This special session concept is unique to FIE, and allows colleagues from around the world to propose a topic and organize an impromptu session where they and other researchers get together to discuss the idea and determine ways that the participants might come together to develop the idea further. These sessions are open to any FIE participant.

5:10 PM - 6:00 PM

T4A: Informed Decisions about Majors and Possible Careers in Engineering Catalyzing Collaborative Conversations

Chairs: Philip R Brown (Virginia Tech, USA), Holly Matusovich (Virginia Tech, USA)

Catalyzing Collaborative Conversations: This session consists of a facilitated panel discussion about the effects that informed (and uninformed) decisions about degree choices can have on students and engineering programs, current and possible research related to informed decisions, and practical implications for engineering programs with regards to how they can facilitate informed decisions.

Informed Decisions about Majors and Possible Careers in Engineering

Philip R Brown (Virginia Tech, USA)

Holly Matusovich (Virginia Tech, USA)

Deciding to pursue an engineering degree, for many students, comes at a tumultuous time between secondary and higher education. This is also a time students contemplate the possibilities of what they can do with the rest of their lives. Informed decision-making could help students make better choices by helping them relate how obtaining a certain degree can connect to their goals and desired career and life outcomes. However, there are a number of potential hurdles to approaching this informed decision. Students can be uncertain about their goals and desired outcomes. They can be misinformed or have misconceptions about how a degree relates to certain outcomes. In addition, students are often required to make decisions about their degree before they can fully consider what that decision means. This session consists of a facilitated panel discussion about the effects that informed (and uninformed) decisions about degree choices can have on students and engineering programs, current and possible research related to informed decisions, and practical implications for engineering programs with regards to how they can facilitate informed decisions.

T4B: Designing Engineering Endorsements for P-12 Teacher Licensure Catalyzing Collaborative Conversations

Chairs: Susan Donohue (United States & University of Virginia, USA), Larry Richards (University of Virginia, USA)

Efforts to bring engineering to P-12 classrooms may not be as effective as possible if opportunities for professional development are not provided. Endorsements are one logical place to start, and can serve as a foundation for the design of a truly integrated STEM undergraduate major. What subjects should a teacher demonstrate knowledge of to receive an endorsement in engineering?

Designing Engineering Endorsements for P-12 Teacher Licensure

Susan Donohue (United States & University of Virginia, USA)

Larry Richards (University of Virginia, USA)

As engineering knowledge and practice filter into the P-12 classroom setting and engineering becomes part of state and national P-12 educational standards in math, science, and technology, the call will arise to provide a means for certifying P-12 teachers in engineering. We thus have an excellent opportunity to have students involved in engineering throughout their elementary and secondary education careers, and to demonstrate the power of engineering design to integrate STEM knowledge and make math and science concepts tangible and understandable. However, P-12 STEM education has long faced the issue of teachers working "out of their field," and this situation has definitely had a negative impact on student learning and achievement. Thus, efforts to bring engineering to P-12 classrooms may not be as effective as possible if opportunities for professional development are not provided. Endorsements are one logical place to start, and can serve as a foundation for the design of a truly integrated STEM undergraduate major. What subjects should a teacher demonstrate knowledge of to receive an endorsement in engineering? This conversation is related to the one on the philosophical underpinnings of engineering education facilitated by John Heywood, Russ Korte, Karl Smith, Mani Mina, John Krupczak, Jr., and William Grimson: what does it mean to be an engineer? What are the essential knowledge, skills, and abilities?

T4C: Beyond the Classroom: Preparing Faculty to Enable Student Success Catalyzing Collaborative Conversations

Chair: Emily L Allen (San Jose State University, USA)

This session will be a moderated brainstorming and sharing discussion on the topics of better preparing faculty for roles in advising, mentoring, leadership development and other elements related to student success.

Beyond the Classroom: Preparing Faculty to Enable Student Success

Emily L Allen (San Jose State University, USA)

Classrooms and laboratories, both virtual and physical, have traditionally been the sole domain of faculty. As pedagogical methods have changed and researchers have focused more on how students learn, faculty development has grown to encompass various type of teaching techniques, and practitioners strive to change the classroom to accommodate our new knowledge. However, student success is an outcome which is impacted by many factors outside of the classroom. Faculty are called upon for many tasks beyond traditional teaching and research. The "service" area of our workload, including student advising and mentoring, increasingly requires a deeper understanding of student attributes, backgrounds, and challenges, and significantly better communication skills than in previous times. With the advance of online and flipped learning, the classroom may become a thing of the past and faculty may eventually become learning mentors. Do engineering faculty know how to effectively carry out such a role? This session will be a moderated brainstorming and sharing discussion on the topics of better preparing faculty for roles in advising, mentoring, leadership development and other elements related to student success.

T4D: A Research Plan for Mind Maps for Design and Word Problems Catalyzing Collaborative Conversations

Chair: Peter A Jamieson (Miami University, USA)

A Research plan for Maps and Design and Word Problems Peter A Jamieson (Miami University, USA)

In this session, our goal is to explore the challenges students have with word and design problems, and explore the possibility of using mind maps and concept maps to help them organize and solve (begin to solve) these types of problems. Concept maps and mind maps are useful class assessment techniques that can be used to explore a student's understanding of the relationship between concepts. These relationships are a form of organization, and this suggests that mind maps and concept maps could be used to organize the concepts in a design or word problem so that a student can see the connections for the relevant aspects of a problem. Our goal during this session is to explore this possibility and design an experiment(s) to test our ideas. To achieve the above, the session will be organized over four steps with group sharing and discussion. As a precursor, the facilitator will quickly describe the two types of mapping techniques and provide some examples. As a first step, we will discuss what experience we have observed with students and problems. Second, we will establish one or two (maybe more) research questions that the group thinks will be testable questions and have value to student learning. Third, based on the questions selected, we will propose a number of hypotheses and mapping methods based on our questions, which we can experimentally test. Finally, we will establish some metrics of measurement to assess the proposed methods. With these steps, we can then decide if there is interest in the participating group and prepare to test the research in the classroom.

T4E: Developing a Classification Scheme for "Introduction to Engineering" Courses Catalyzing Collaborative Conversations

Chair: Kenneth Reid (Ohio Northern University, USA)

This session invites those interested in developing a classification scheme for "Introduction to Engineering" courses. The goal of the session will be to catalog efforts underway toward the overall goal of developing a classification scheme and to create a community of practice to facilitate this development.

Developing a Classification Scheme for "Introduction to Engineering" Courses Kenneth Reid (Ohio Northern University, USA)

Many Universities and Community Colleges offer a course entitled "Introduction to Engineering" or similar. These are often designed from scratch and tend to be "personal courses" - designed by instructors to cover what they feel is important. Therefore, while they may be prerequisites to second-year courses, first-year engineering programs are not necessarily integrated into the curriculum. Further, since they are often designed with little consideration for existing models, overall outcomes and content vary widely. This leads to three issues: first, course developers often "reinvent the wheel" by failing to disseminate successful models. The problem is exacerbated by a lack of definition of first year models: a developer may know what they want in a course, but how do they find a course with similar outcomes with nothing more than "first-year engineering" as a description? Second, with little focus on specification of models for these courses, many become a grab bag of unrelated topics. Finally, there are issues preventing community colleges from offering "Introduction to Engineering" courses, leading to disadvantages for students who could transfer into 4-year programs. Without standard outcomes for a first-year course, students may receive credit for material that is much different than material they covered, and community colleges may not be able to design an introductory engineering course that is applicable to multiple institutions. This session will invite those interested in developing a classification scheme for "Introduction to Engineering" courses. The goal of the session will be to catalog efforts underway toward the overall goal of developing a classification scheme and to create a community of practice to facilitate this development.

T4F: Communicating an Engineering Curriculum via Concept Maps Catalyzing Collaborative Conversations

Chair: Jennifer French (Massachusetts Institute of Technology, USA)

The presentation will introduce session participants to the Map using VUE, a web-based concept-mapping tool created by researchers at Tufts. We hope to facilitate a group discussion to generate innovative ideas about how this work might be transformed to benefit a broader audience.

Communicating an Engineering Curriculum via Concept Map

Jennifer French (Massachusetts Institute of Technology, USA)

In order to develop a set of curricular materials for the Singapore University of Technology and Design, the Teaching and Learning Laboratory at MIT identified pivotal concepts and skills from the first three semesters of their engineering curriculum. This exercise led to the creation of an Engineering Curriculum Map (the Map). The Map is organized around four major intended learning outcomes (ILOs, as defined by Biggs and Tang), and connects them to concepts and skills that engineering students must master. The Map links to a series of smaller, more focused maps that show connections among concepts at a finer level of granularity. We believe the Map, and the process we used to develop it, could be useful to faculty designing engineering courses and curriculum, as well as to engineering students. We have gathered preliminary feedback from engineering educators on the content and presentation format of the Map, and we will use this FIE session to collect additional comments and suggestions. This session will involve a brief presentation followed by a group discussion. The presentation will introduce session participants to the Map using VUE, a web-based concept-mapping tool created by researchers at Tufts. We will also illustrate how we utilized the overarching themes identified in the Map to create a set of 15-minute instructional videos and accompanying instructor guides. We hope to facilitate a group discussion to generate innovative ideas about how this work might be transformed to benefit a broader audience.

T4G: Global Software Engineering Collaboration Catalyzing Collaborative Conversations

Chair: Wook-Sung Yoo (Fairfield University, USA)

This session will provide opportunity for educators to share the information of updated curriculum, process, tools, and to establish collaborative projects among multiple schools to prepare our software engineering students to be successful in global environment.

Global Software Engineering Collaboration

Wook-Sung Yoo (Fairfield University, USA)

Stephen T Frezza (Gannon University, USA)

In today's global economy, software engineers are expected to operate in a distributed professional environment with geographical, temporal, and cultural distance. Global Software Engineering has more complexities over the local software development and we need to educate our future software engineers to build skills necessary to create innovative software in this global environment and to manage global software projects. To participate, one simply needs to share an interest in preparing students to operate as global software engineers, and to help them to be more successful in a global environment. This session will provide opportunity for educators to share information on successes and failures, impacts to curriculum, identification of skill sets needed, experience with process, tools that facilitate global software engineering projects. Above all, the session aims to provide opportunities to establish collaborative projects among multiple schools.

SESSION GRID - WEDNESDAY, OCTOBER 3RD

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|----------------|--|--|---|--|--|--|---|
| 1:30 PM | Workshop: A Workshop on How Learning Works | Workshop: Learning Agile Through Active Learning Activities | Workshop: Assessing Professional Skills for ABET | Workshop: What were we thinking? Critically examining our beliefs about the purposes and goals of engineering and engineering education | Workshop: Building Learning Tools using IMS Learning Tools Interoperability | Workshop: Interactive Education Tools for Earth Systems and Sustainability Applications | Workshop: Teaching Computer Security Literacy to the Masses: A Practical Approach |
| 5:30 PM | Workshop: Evaluation of Educational Research and Development Projects | Workshop: Using Student Scrums for Course and Capstone Projects | Workshop: Training students to become better raters: Raising the quality of self- and peer-evaluations using a new feature of the CATME system | Workshop: Teaching Engineering Design to Middle and High School Students using STEAM Machines™ | Workshop: Case Study Teaching in Software Development Curricula | Workshop: Project-Enhanced Learning in Engineering Science Education | Workshop: It's More Than Coding: Using Video Scenarios to Engage Students in Computing |

SESSION GRID - THURSDAY, OCTOBER 4TH

| | Boren | Columbia | Greenwood | Issaquah A&B | Kirkland | Leschi | Medina | Ravenna A&B | Ravenna C |
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SESSION GRID - FRIDAY, OCTOBER 5TH

| | Boren | Columbia | Greenwood | Issaquah A&B | Kirkland | Leschi | Medina | Ravenna A&B | Ravenna C |
|----------|--|----------------------------|---|------------------------------------|---|---|-----------------------------------|---|---|
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| | Boren | Columbia | Greenwood | Issaquah A&B | Kirkland | Leschi | Medina | Ravenna A&B | Ravenna C |
|----------|--|--|------------------------------------|---------------------------|---|---|---------------------------|--|---|
| 8:00 AM | S1B: Putting Research Findings into Practice 2 | S1H: Teams, Communication and Profession 3 | S1C: Quantifying Learning Gains 3 | S1I: Distance Education 3 | S1D: Pre-College Initiatives and Partnerships 4 | S1G: Approaches to Student-Centered Education 5 | S1F: All About Design 3 | S1A: Innovative Practice 3 | S1E: Software Engr, Computing & Informatics 4 |
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Louis Everett (National Science Foundation, USA)

Susan Finger (National Science Foundation, USA)

Zhanjing (John) Yu (National Science Foundation, USA)

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Special Session: Teaching Teamwork and Communication Skills in Core Engineering Courses

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Kelly Cross (Virginia Polytechnic Institute and State University, USA)

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Special Session: A practitioner's perspective on teaching technical writing

William Nesbit (Wm. Nesbit & Associates, Inc., USA)

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**T4A: Informed Decisions about Majors and Possible Careers in Engineering
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Chairs: Philip R Brown (Virginia Tech, USA), Holly Matusovich (Virginia Tech, USA)

Informed Decisions about Majors and Possible Careers in Engineering

Philip R Brown (Virginia Tech, USA)

Holly Matusovich (Virginia Tech, USA)

**T4B: Designing Engineering Endorsements for P-12 Teacher Licensure
Catalyzing Collaborative Conversations**

Chairs: Susan Donohue (United States & University of Virginia, USA), Larry Richards (University of Virginia, USA)

Designing Engineering Endorsements for P-12 Teacher Licensure

Susan Donohue (United States & University of Virginia, USA)

Larry Richards (University of Virginia, USA)

**T4C: Beyond the Classroom: Preparing Faculty to Enable Student Success
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Chair: Emily L Allen (San Jose State University, USA)

Beyond the Classroom: Preparing Faculty to Enable Student Success

Emily L Allen (San Jose State University, USA)

**T4D: A Research Plan for Mind Maps for Design and Word Problems
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Chair: Peter A Jamieson (Miami University, USA)

A Research plan for Maps and Design and Word Problems

Peter A Jamieson (Miami University, USA)

**T4E: Developing a Classification Scheme for "Introduction to Engineering" Courses
Catalyzing Collaborative Conversations**

Chair: Kenneth Reid (Ohio Northern University, USA)

Developing a Classification Scheme for "Introduction to Engineering" Courses

Kenneth Reid (Ohio Northern University, USA)

**T4F: Communicating an Engineering Curriculum via Concept Maps
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Chair: Jennifer French (Massachusetts Institute of Technology, USA)

Communicating an Engineering Curriculum via Concept Map

Jennifer French (Massachusetts Institute of Technology, USA)

**T4G: Global Software Engineering Collaboration
Catalyzing Collaborative Conversations**

Chair: Wook-Sung Yoo (Fairfield University, USA)

Global Software Engineering Collaboration

Wook-Sung Yoo (Fairfield University, USA)

Stephen T Frezza (Gannon University, USA)

5:10 PM - 6:00 PM

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Global Software Engineering Collaboration

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Special Session: Making an Impact: Building Transportable NSF TUES Education Projects

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Louis Everett (National Science Foundation, USA)

Susan Finger (NSF, USA)

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Special Session: CE2004 Revisions (Computer Engineering Curriculum Guidelines) Special Session

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Andrew McGettrick (University of Strathclyde, United Kingdom)
Mitch Thornton (Southern Methodist University, USA)
Timothy Wilson (Embry-Riddle Aeronautical University, USA)

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Workshop: Evaluation of Educational Research and Development Projects

Pre-Conference Workshop

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Abstract— With emphasis on project outcomes and impact, project evaluation is increasingly becoming an integral part of a NSF project. Lack of an evaluation plan in a proposal for an education project may be viewed by many NSF reviewers as a weakness. The purpose of this workshop is to give the participants enough background information so that they can work with an external evaluator to develop and implement an evaluation plan for an education research and development project, particularly NSF project.

Keywords—evaluation; evaluation types; evaluation tools; evaluation plan; data interpretation; Pimmel Format

I. GOAL AND OUTCOMES OF THE WORKSHOP

The goal of this workshop session is to prepare engineering faculty members to work with an evaluator to plan and implement an effective evaluation of an education research or development project. By the end of the workshops, the participant should be able to: 1) understand the need for evaluation; 2) explain the types of evaluations; 3) translate project goals to measurable outcomes and then to evaluation questions; 4) list and compare the evaluation tools commonly used in project evaluation; 5) interpret evaluation data; 6) explore causation relation between project outcomes and interventions; and 7) develop an evaluation plan with an evaluator.

II. WORKSHOP DESCRIPTION

A. Workshop Contents

The workshop will use the NSF 2010 User-Friendly Handbook for Project Evaluation as a guideline to discuss evaluation issues related to STEM educational and development projects.

1. The Needs for Evaluation

There are a couple of reasons that NSF grantees conduct project evaluation. First, evaluation about an on-going project provides information about the progress of the project which can be used by the project personnel to determine areas of success and failure and whether the project activities deviate from

proposed work and make adjustment accordingly. The second reason is that evaluation provides information to the stakeholders and measures the impact of the project. The information can be used to determine whether the project has achieved its objectives and whether resources have been used efficiently and effectively. The information can also be used to meet reporting requirements such as those mandated by the Government Performance and Results Act (GPRA).

2. Evaluation Types.

In general, evaluations can be classified into two categories: formative evaluation and summative evaluation. The former provides information on implementation and progress of the project and the latter provides information on the outcomes and impact.

3. Translate Project Goals into Expected Outcomes.

Evaluation methodologies depend on the expected outcomes of a project. The first step in the evaluation process is to translate the project goals into expected outcomes. The characteristics of goals may be general, broad and abstract. The expected outcomes, however, are the narrow, specific, tangible, measurable results that one expects to see if the goals are achieved.

4. Translate Expected Outcomes into Evaluation Question

Once the expected outcomes are specified, the evaluation questions should not be difficult to formulate. However, they should be designed in such a way that a determination of a causation relationship is possible.

5. Evaluation Tools

Evaluation tools can be classified into three categories: quantitative, qualitative and mixed methods. The quantitative methods are considered more objective traditionally, in which data can be analyzed with sophisticated statistical techniques. However, these methods may not be able to probe an issue in depth and sometimes, data accuracy problem may arise. Qualitative methods on the other hand rely on descriptive data and can be used to examine a topic in

more depth, but these methods may lack the statistical rigor of the quantitative analyses. The mixed methods can catch the advantages of both. The tools discussed include surveys, concept inventories, standardized tests, rubrics, observations, interviews and focus groups.

6. Interpreting Evaluation Data

When an intervention is implemented, we hope that it will have a positive impact and in most cases, it does. However, in interpreting data, one has to list the confounding factors and consider alternative explanation before drawing the conclusion. Similarly, if the results get worse after the intervention, one cannot automatically conclude that the intervention has failed and again the confounding factors must be considered.

7. Development of Evaluation Plan for an NSF Project

In developing an evaluation plan, one should consider all the topics discussed above and work with an external evaluator. The external evaluator should get involved early on in the development of the project evaluation plan. The workshop will also discuss where to find a qualified evaluator and what to expect from her/him.

B. Workshop Format

The workshop will use the Pimmel Format, named after former NSF program director Russell Pimmel. The format is based on the theories on learning and it is an active and

collaborative learning format. The theories assume that we all have some kind of prior knowledge (no matter how little or incorrect) on a topic. To learn, one has to recall prior knowledge, connect it with new concepts, correct misconceptions and reflect on new knowledge. In this format, the presenter will give some background information on a particular topic and post the central question. The audience, divided into groups, will use a think-share-report format to share their answers with the audience. The presenter will then give her/his response to the question. This way, the participants learn from the presenter as well as each other.

C. Anticipated Audience

The workshop is intended for faculty members who are either seeking external support for educational research and development projects, particularly NSF projects or are engaged in efforts to improve the educational experience of their students.

DISCLAIMER

The information in this workshop represents the opinions of the individual program directors and presenters and is not an official NSF position.

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Workshop: Learning Agile Through Active Learning Activities

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I. GOAL(S) OF THE WORKSHOP

Games and simulation are a great way to learn theories and new behaviors that can be applied to software engineering activities. The presenters are going to teach three games that can be used in a software engineering course or any course that deals with agile methods. The presenters will talk about the benefits of agile development and how these games will solidify behaviors that are essential to successful agile processes.

II. DESCRIPTION OF TOPICS/SUBJECTS/CONTENT OF THE WORKSHOP

Agile software processes are becoming more pervasive in industry settings; however these same processes have not been widely adopted in academic settings. A common thread among agile software processes is the iterative approach to the software lifecycle. It can be challenging to integrate a pure agile process in a typical software projects course due to the time constraints of a semester, but integrating elements of the agile approach can be useful from both an instructor and student perspective.

This tutorial will introduce the participants to the key principles of the agile software process which proclaims to value:

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

There are many flavors of agile processes and this tutorial will focus the Scrum model. Examples of how Scrum can be used to organize a classroom software development project will be discussed. Several open source tools that can be useful in supporting agile software projects from the requirements gathering phase through development and testing will be demonstrated.

Participants will engage in a participatory game to illustrate some of the main components of the agile software process model. Attendees will leave this tutorial with ideas for integrating agile approaches into their own projects courses.

III. WORKSHOP AGENDA (PLEASE GIVE DETAILS AND APPROXIMATE TIME ALLOTTED FOR EACH ACTIVITY)

- Introduction to Agile Methods (30 Minutes)
- Marshmallow Tower Challenge (40 Minutes)
- The Marshmallow Challenge is a remarkably fun and instructive design exercise that encourages teams to experience simple but profound lessons in collaboration, innovation and creativity.
- Collaborative Origami (30 Minutes)
- Collaborative Origami shows the importance of face to face communication (vs. distributed)
- Ball Point Game (30 Minutes)
- The ballpoint game by Boris Gloger is a great game for introducing Scrum to new agile teams.
- Reflection & Lessons Learned (20 Minutes)

IV. DESCRIPTION OF THE ANTICIPATED AUDIENCE

Instructors who teach about software development and want to learn strategies that will help teach agile software development or other software engineering techniques. Instructors of courses with non-software projects will also be interested in agile methods and their applications to such project-based courses. Students will also enjoy the hands on nature of the activities and find the reflection to be instructional.

Workshop: Assessing Professional Skills for ABET

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Abstract – The Integrated Design Engineering Assessment and Learning System (IDEALS) is a set of assessment instruments that focus on aspects of professional development such as leadership, ethics, project management and communication skills within the context of capstone engineering design projects. These instruments have been piloted across a broad spectrum of diverse engineering programs and are available in a web format that facilitates data collection from students and feedback from instructional staff. This knowledge has been synthesized into a set of engaging and transferable modules that include learning objectives, supporting resource materials, preparatory tasks, lesson plans for faculty, and recommendations for timely follow-up using the online assessments. In addition, the instruments enhance student development through both formative and summative feedback and can be used to provide evidence for demonstrating the achievement of ABET student outcomes and program specific criteria.

Index Terms – ABET, Student Outcomes assessment, professional development

INTEGRATED DESIGN ENGINEERING ASSESSMENT AND LEARNING SYSTEM (IDEALS)

The capstone engineering design course is used by many engineering programs to demonstrate the achievement of student outcomes for ABET accreditation. In particular, capstone courses often seek to assess technical outcomes such as problem solving or design and interpersonal outcomes such as teamwork and communication. Civil engineering programs may also use the capstone experience to assess program-specific ABET criteria related to management and leadership.

Since the design products of capstone courses are typically from a group of students, it can be difficult to assess individual student outcomes for ABET. To facilitate this assessment and to encourage students to be aware of professional skill development, the Transferable Integrated Design Engineering Education (TIDEE) consortium developed the Integrated Design Engineering Assessment and Learning System (IDEALS) [1].

The IDEALS assessment system targets the development of technical skills (problem solving and design) and interpersonal skills (teamwork and communication). It also

focuses on the student's growth as a self-reflective professional. The IDEALS professional development assessments consist of pre-class and in-class activities combined with a progression of two formative assessments (Professional Development Planning and Professional Development Progress) and one summative assessment (Professional Development Achieved) that are used to prepare for, monitor, and summarize student professional development during the capstone course [3]. A companion instructional module and scoring rubric is provided with each assessment instrument in an instructor-friendly format that helps the instructor guide student development.

To reduce the time associated with reviewing student work, the IDEALS assessments have been implemented in a secure, web-based environment that contains the IDEALS assessment instruments, instructor and student interfaces, data archives, data processing, reporting functions, and companion instructional modules [4]. The instructor specifies the assignment by indicating which students are to receive it, the due date for student completion, and the targeted date for receiving instructor feedback.

While the IDEALS assessments include lesson plans and recommended timelines for formative and summative assessments and other supporting materials, they are flexible and have been easily integrated into a variety of engineering programs at both large public and small private institutions. Instructors who have used IDEALS assessments often create assignments related to the ABET student outcomes of teamwork or communication. After completing a pre-class skills inventory, students identify areas of improvement and write a plan for developing those areas. The students may then be asked to evaluate their professional development progress throughout the capstone course (formative assessment) or their professional development achievement by the end of the course (summative assessment).

After students complete each assessment assignment they receive feedback from the instructor online. Instructors are prompted to use a web-implemented version of the scoring rubric for each assessment and are provided comment boxes for writing additional feedback. The web system automates data compilation for instructor and student viewing. The assessment cycle is completed when students log back into the system to read feedback from the instructor. These reports can be easily accessed, printed and included as student exemplars of achievement for ABET site visits.

WORKSHOP OBJECTIVES

This workshop will describe features of the IDEALS curricula and assessment instruments and will analyze feedback from early adopters. After a brief overview of the IDEALS learning model and curricular materials, participants will score samples of student work in small groups, discuss their results and share with the larger group. The workshop will also address how to use the assessment results for program accreditation.

WORKSHOP AGENDA

This Mini-Workshop will consist of the following interactive segments among participants:

1. Introductions
2. IDEALS Overview
3. Activity: Professional Development Assessment Review, Scoring, Group Discussion and Reporting
4. Team Member Citizenship Overview
5. Activity: Team Member Citizenship Assessment Review, Scoring, Group Discussion and Reporting
6. Using the assessments for ABET

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Workshop: Training students to become better raters: Raising the quality of self- and peer-evaluations using a new feature of the CATME system

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Abstract—The goal of this workshop is to introduce participants to tools that can help them manage teams in their classes effectively and efficiently. We review some of the factors that instructors may wish to consider when administering self- and peer-evaluations and how they might improve the quality of those evaluations using rater training. Attendees with wireless-network-capable laptop computers will interact with the system in real-time.

Keywords— *peer evaluation; rater training; teamwork.*

I. INTRODUCTION

The workshop is for instructors who use or who want to begin using team-based learning strategies in their classes.

The goal of the workshop is to introduce participants to a suite of web-based tools that can help them manage student teams effectively and efficiently. We engage the participants in discussions about their own experiences and practices and briefly review literature that relates to participants' concerns. We review factors to consider when administering peer evaluations. We discuss rating accuracy and how to use and interpret self- and peer-ratings. We engage the participants in interactive, hands-on activities using the CATME system, however, this is not just a software demonstration—faculty will learn how the system supports cooperative learning.

Fig. 1 shows that as of March 2012, just over 2,000 faculty users at nearly 500 universities worldwide use CATME and nearly 93,000 unique students have used the system for one or more classes. The web interface was professionally developed; data are secure. The system was developed with funding from the National Science Foundation and is free for instructors in higher education. Instructors can request an account at www.catme.org.

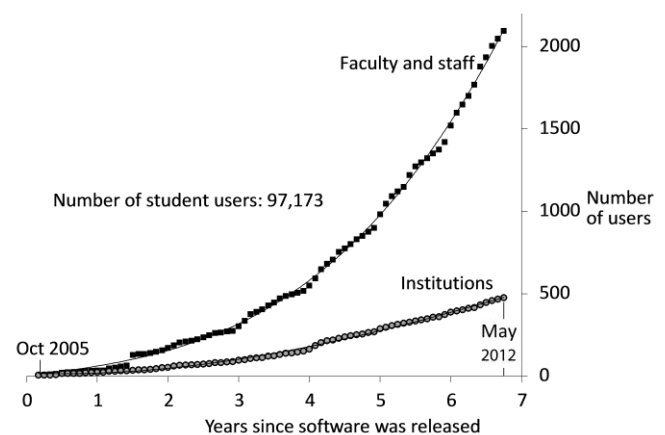


Figure 1. Growth of users of the the CATME Team Tools System

II. SELF- AND PEER-EVALUATION

The CATME self- and peer-evaluation tool uses a behaviorally anchored rating scale for assessing team-member effectiveness in five areas: contributing to the team's work, interacting with teammates, keeping the team on track, expecting quality, and having related knowledge, skills, and abilities [1, 2]. CATME provides the instructor a grade adjustment factor based on the relationship between each team member's ratings and the team average. The advantages of using the system are 1) peer evaluations increase students' accountability to their teammates and deter free riding, 2) using peer evaluations appropriately can help students learn to be more effective team members, 3) using peer evaluations is associated with more positive attitudes toward teamwork, and 4) completing self- and peer-evaluations also gives students experience with multi-rater systems, which are common in workplaces [3].

TABLE I. WORKSHOP AGENDA

| Topic | Activities |
|--------------------------------|---|
| INTRODUCTION [15 min] | Introductions of presenters and participants. Establish wireless connections. Introduce CATME SMARTER Teamwork System. Joining a community. Learning objectives. Faculty account request. |
| PEER EVALUATION [65 min] | Peer evaluation think-pair-share: Sharing problems encountered in peer evaluations. Discuss how the system addresses issues raised by participants. Importance of the instructor's role. Demonstrate creating a survey. Participants login as students and complete the survey. Demonstrate using CATME survey results for formative and summative assessment. Preview the student view of the results. Presentation of research on self-and peer evaluation. |
| [20 min] | break |
| RATER TRAINING [65 min] | Participants think/pair/share: What does it mean to be a good rater? How do you become one? Discuss how the system addresses issues raised by participants. Importance of the instructor's role. Demonstrate the instructor's CATME view for assigning training to students. Participants login as students and complete one iteration of the training. Preview the student view of results. Participants think/pair/share: How can we use this information to improve student teaming performance? Presentation on relevant literature & findings: issues in rating and types of training. |
| ASSESSMENT [15 min] | Summary of how these tools fit in an overall strategy of managing student teams. Participants create log-in passwords. Workshop assessment. |

In the workshop, we demonstrate how to create a survey for self- and peer-evaluation, how to focus on those rating patterns for individuals or teams that warrant close attention, how to use the ratings data for formative and summative assessment, and how to improve the quality of ratings using rater training.

III. TRAINING RATERS & USING RATINGS DATA

Effective use of a well-grounded peer-evaluation instrument benefits both students and faculty—students, from having an improved teaming experience, and faculty, by becoming better managers of the teaming experience. Effectiveness is enhanced when students rate accurately and faculty use rating data appropriately.

In support of these goals, we demonstrate how the system complies with research findings that peer ratings should be confidential though not anonymous [4]. The CATME system allows instructors to view each rating that each team member makes, and has a space for students to make confidential comments to the instructor. Instructors can require that students write comments to justify their ratings. Completing the peer evaluations on-line provides greater confidentiality than traditional paper-based evaluations, which are often completed during class with teammates watching.

We use the CATME system's rater calibration feature, which allows instructors to require that students practice rating fictitious team members using the peer evaluation system's behaviorally anchored rating scale. Requiring rater calibration ensures that students know how to use the scale correctly before they rate themselves and their peers. Using rater calibration before teamwork starts also ensures that

students are familiar with the components of effective and ineffective team-member behavior before they begin working with their teammates.

The CATME system flags a number of “special conditions” in the ratings data that warrant special attention. We show how to view and interpret these conditions and suggest ways to intervene with students or teams to provide targeted support to teams where needed.

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Workshop: Case Study Teaching in Software Development Curricula

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Abstract— The use of case studies is an effective method for introducing real-world professional practices into the classroom. The term “case study” is used in a variety of ways. In its most naive form, it simply refers to a realistic example used to illustrate a concept or technique. Although the use of case studies in education has shown success in law, business and medicine, it is yet to be adopted in any wide ranging and significant way in software development education. One of the reasons for the minimal use of the case-study approach is the lack of sufficient material for this purpose. The main aim of the workshop is to introduce participants to case study teaching concepts and engage them with a comprehensive case study (the DigitalHome case study - <http://www.softwarecasestudy.org/>), which can be used throughout a computing curriculum, emphasizing full software development life cycle artifacts and exercises.

Index Terms— Case Study Teaching, Computing Curricula

I. INTRODUCTION (HEADING 1)

Many computing programs have a software engineering course that involves a software development project in which students are grouped into teams to work on a semester or year-long project. Unfortunately, this is too often isolated from the rest of the curriculum and does not form a real-world basis for the entire curriculum. As a result, these programs produce graduates who are familiar with the basic theoretical concepts in software development, but lack the skills to apply these concepts in real-world development environments. Therefore, it is imperative that computing curricula introduce professional and real-world education into the academic programs. The use of case studies is a widely-used method for introducing real-world professional practices into the classroom.

Although many computing textbooks include the use of case studies to explain computing topics, these cases typically serve a specific purpose (e.g., teaching programming, project management, requirements analysis, design, or testing). They often lack the following:

- Realistic artifacts (often space does not allow providing a complete requirements or design document)
- Completeness (covers only a portion of the life-cycle, and not an end-to-end), with a focus on design and implementation
- Ability to decouple from the text and apply in ways not intended by the author

- Techniques for integration into course activities or into the curriculum as a whole
- A scenario format that would motivate students to get engaged in problem identification and solution.
- Guidance to the instructor on how to use the case study to teach a course topic or concept

The DigitalHome case study [1, 2] is intended to address these shortcomings by providing a complete set of artifacts associated with software development as well as providing case modules that can be used by faculty in teaching different subjects in a computer science curriculum. Each case module represents a mini case study and is associated with a specific teaching subject and learning objectives (e.g. requirements analysis, object oriented design, testing, and team building). Case modules also include an exercise booklet and a set of guidelines to assist the instructor in teaching the session.

II. WORKSHOP GOALS

Upon completion of the workshop, participants will possess

- increased understanding and appreciation of the value of Case Study Teaching
- knowledge about and experiences with the use of the Digital Home Case Study material in teaching software engineering concepts and practices
- ideas about how the Digital Home Case Study material could be adapted to a software development curriculum

III. WORKSHOP OUTLINE

1. (15 minutes): Introductions and background
2. (15 minutes): Basics of Case Study Teaching, previous uses, and advantages.
3. (25 minutes): Description of the DigitalHome case study, its origins, artifacts, and case modules, and how it can be used across a curriculum.
4. (55 minutes): Group exercise on the use of the DigitalHome case modules. Participants will be broken into groups of 4-5. Each group will complete the case module exercise.
5. (45 minutes): Group discussion; groups report back on their DigitalHome exercise; individuals are encouraged to discuss their ideas on how to adapt DigitalHome case modules to their teaching.

6. (25 minutes): Workshop summary, final thoughts and discussions.

ACKNOWLEDGMENT

Initial work on the DigitalHome case study was funded as part of the NSF project: “The Network Community for Software Engineering Education” (SWENET) (NSF 0080502). In addition, the current work on the case study is funded through NSF’s (DUE- 0941768) “Curriculum-wide Software Development Case Study”.

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Workshop: Interactive Education Tools for Earth Systems and Sustainability Applications

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Abstract- Earth system signals include indicators of climate change. In this workshop, the participants will use the Java-DSP/Earth Systems Edition in order to analyze and understand the components and drivers of climate change in the twentieth century. The session will be interactive and will be useful to researchers, practitioners and instructors with interests in Earth systems signal analysis. People with interests in general STEM related areas will also find this workshop useful as an important interdisciplinary application of signal processing.

Keywords- online labs; Java tools; climate change; Earth system; sustainability

I. DESCRIPTION

Analysis of Earth system signals is important to the assessment of global climate change and sustainability. The participants of this workshop will use the multidisciplinary education tools developed for such assessments using the Java-DSP/Earth Systems Edition (J-DSP/ESE) software. They will be introduced to instrumental records of Earth surface temperature, atmospheric carbon dioxide, and global sea level. Temperature is a rudimentary gauge of climate; pCO_2 controls temperature; sea level responds to temperature. The workshop will begin with an introduction to basic signal/data processing, followed by a tutorial on climate change assessment that examines modern records of global surface temperature, atmospheric carbon dioxide and sea level. The participants will investigate the variability of these three components, and the empirical evidence for their interactions. The objective is to understand the dynamics of critical Earth surface climate components, the evidence for and nature of their interactions, and how to forecast their behavior in the near future. Development of education materials for Earth sciences and geology will also be discussed. The session will be interactive with computers and participants will use and assess several exercises.

II. WORKSHOP OUTLINE AND OBJECTIVES

A. Learn basic signal processing with the online J-DSP/ESE laboratory

- Signal and noise
- Trend estimation

- Spectral analysis
- Filtering; differencing
- Correlation; coherency

B. Analyze time series data of critical climate components/drivers

- Global temperature records (GISS, NCDC, HadCrut)
- Atmospheric carbon dioxide/fossil fuel emissions records
- Global sea level records (tidal gauge v. satellite)

C. Address the following fundamental questions

- What are the variations (frequencies) in these records?
- Do fossil fuel emissions explain the rise in pCO_2 ?
- How is pCO_2 correlated with global temperature?
- Does global temperature correlate with sea level?
- Can we forecast for the next 10, 50, 100 years?

III. AUDIENCE AND EXPECTED OUTCOME

The intended participants for this workshop are researchers, instructors and practitioners with interests in time series analysis of earth systems data, and STEM related areas. They will benefit from a new intuitive environment for analysis of Earth signals, and obtain new materials and methods for studying and teaching global climate change and sustainability. Participants must bring their own laptop computers.

IV. THE J-DSP/ESE SOFTWARE

Java-DSP (J-DSP) (<http://jdsp.asu.edu>) is an educational program that enables on-line simulations and web-based computer laboratories. J-DSP is based on an object-oriented programming environment that enables students to establish and run DSP simulations on the internet. The J-DSP/ESE is a version of the software that is specialized to handle Earth system signals. Several papers on J-DSP and J-DSP/ESE have been published previously in archival conference proceedings and journals [1-9].

This workshop is supported in part by a Phase 3 CCLI-TUES project (award no. 0817596) funded by the National Science Foundation.

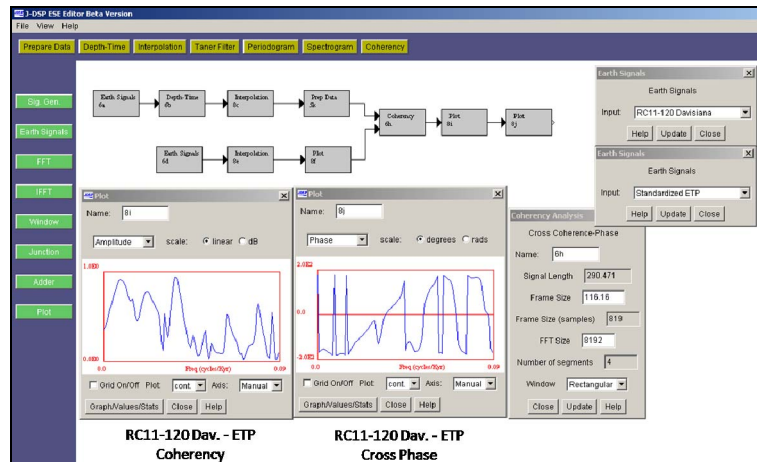


Figure 1: Analyzing the relation between pCO₂ and global temperature change using J-DSP/ESE.

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Workshop: Project-Enhanced Learning in Engineering Science Education

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I. BACKGROUND

Early drop out and poor retention rates are a major challenge to engineering education, which in many institutions have prompted a focus on improved first-year experiences. Retention and contributing learning challenges persists into the middle years, particularly when students confront the first engineering science courses in their major field. Students often perceive these courses as too abstract, intended to weed them out, and not meaningfully connected to their professional aspirations. A proven approach to improve student learning, self-efficacy, motivation, and retention is the use of active learning, including problems and projects [1-4]. Despite evidence of the benefits of active learning, engineering schools and faculty members have inadequate incentives to experiment with non-traditional approaches [5].

Over the past decade, the presenters and colleagues developed a particular model called project-enhanced learning (PEL) for core engineering science courses at the sophomore and junior levels. The project component enhances and does not replace traditional deductive exposition that most teachers find indispensable in these courses [6-7]. The requisite characteristics of project implementation in PEL evolved with experience. Critically, any intervention such as a project must be adoptable by the typical instructors of these courses, who may have career goals and incentive structures that limit teaching time commitment. Instructor willingness to add a project component in addition to traditional methods depends on project attributes that must be carefully constructed to minimize additional workload to the instructor as well as the student. Such a project component of engineering science courses at the sophomore and junior levels must be structured and mapped to the traditional topic sequence, and thus cannot be as open-ended as a senior level design project.

As reported previously [8,9], the PEL approach not only improved learning of the targeted engineering science content, but also enhanced peer-to-peer interactions, revealed student misconceptions, improved student motivation, and inculcated design skills and professionalism. The major benefits are improved learning in target courses, and potentially greater retention of students in engineering. Attendant learner benefits are improved self-efficacy in target courses, sense of belonging in the discipline, enhanced communication and team skills, and

project management skills. Benefits for the instructor include early feedback on student difficulties and misconceptions, and the relatively low workload required for the structured project.

In 2010, Indiana University – Purdue University Indianapolis (IUPUI) received a grant from the National Science Foundation (NSF) to implement and disseminate PEL in engineering science courses, as well as to identify barriers to adoption and to train faculty members. The grant activity aims to expand the PEL model to multiple courses at IUPUI and other institutions.

Project experiences were implemented in three different courses, based on initial experience in a course on *Thermodynamics*. PEL was introduced in two other courses: *Probabilistic Methods in Electrical and Computer Engineering*, and *Dynamics* in the mechanical engineering curriculum. One or two major projects based on systems, objects, or activities that are familiar to the students are designed and assigned to apply key course topics.

New instructors were initially reluctant to add the project to an already packed syllabus, but those who agreed to attempt it found that the tightly integrated project required very little extra grading effort. They also observed improved learning of the subject matter. Students were motivated to learn how to complete the project without errors, asking questions when something did not seem right, unlike with traditional piecemeal homework. Often, an online discussion forum for the project revealed student misconceptions and prompted early intervention to correct the errors.

II. GOALS OF THE WORKSHOP

The workshop is aimed at giving instructors an opportunity to evaluate and adapt the project-enhanced learning (PEL) model, which instructors at multiple institutions have found feasible and beneficial during the NSF-funded implementation program. The workshop format requires participants to actively work in groups on generating project ideas and materials for a course of interest. The expected outcomes are familiarity with the PEL methodology and rationale, increased interest in adapting PEL or other active-learning strategies in engineering education, and ideas for a project component in one or more courses.

III. CONTENT OF THE WORKSHOP

Project-Enhanced Learning (PEL) will be presented as an active learning strategy that integrates abstract concepts and deductive mathematical analysis with a concrete and meaningful project experience. The PEL experience is intended to motivate and anchor student learning and provide low-load feedback and assessment to the instructor. The workshop is intended to virally propagate an easily adaptable educational practice that is sustainable for the typical harried instructor. The experiences of project implementation (over the past ten years) and PEL dissemination make the proposed instructor-researcher team well equipped to lead this workshop.

The organization, planning, and implementation of PEL are modeled on past successes and resources available from educators who developed the method. The experiences of early adopters will be shared. Participants will review the strategies and implementation techniques of PEL, including the alignment of the most challenging course topics with project tasks, use of an on-line project discussion forum, substituting project tasks for traditional homework, and giving students ownership while managing workload and divergent thinking. Pairs or small groups of workshop participants will be formed to actively carry out a workshop 'project' to develop PEL for some common engineering science courses chosen by interest of the audience. Each group will brainstorm for project ideas for their course, and develop a feasible project outline, task structure, solution verification, and assessment approach for the project. Groups will reassemble to discuss their reactions, opinions, and ideas.

IV. WORKSHOP AGENDA

The following workshop agenda is based on a three-hour time allocation, and the goal of completing a 'project' task of developing PEL materials by each participant. It can be adapted to a different time allocation with a more or less ambitious agenda.

1. Retaining learning in students, and retaining students in engineering – what seems to work? [15 min]
2. Project-Enhanced Learning: Why and How? [15 min]
3. Minds-on learning by action – in pairs or small groups of participants:
 - a. Consider a traditional 'syllabus', with stated course topics and outcomes [15 min]
 - b. Brainstorm on possible and feasible project concepts [30 min]
 - c. Identify project tasks mapped to course outcomes [15 min]
 - d. Break and inter-group conversations [15 min]
 - e. Outline project guidelines for students; how to simplify and focus tasks [30 min]
 - f. Assess solution space for the project, and grading workload for the instructor [15 min]
4. Briefly report group experiences [15 min]
5. Review lessons learned and critique methods [15 min]

V. DESCRIPTION OF THE ANTICIPATED AUDIENCE

Workshop participants are likely to be engineering faculty members interested in new learning techniques in challenging and analytical engineering science courses, with the objective of improving learning and retention of students in engineering. Graduate students and post-docs with interest in engineering or similar STEM education can benefit as well.

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Workshop: Teaching Computer Security Literacy to the Masses:

A Practical Approach

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Abstract—We are losing the battle in cyber security. We heavily rely on technology as the main defense, instead of recognizing that the easiest attack vectors are the people who operate the computers. The general public does not understand the decisions they make each and every day have security implications for themselves, their projects and their companies. Since people are a primary target, education is one of the “secret weapons” in the cyber security battlefield. Further, if everyday users are the targets, then all audiences, not just technical staff, need training and education in cyber security basics.

We argue that computer security literacy is not only the next step in computer security defense; it may be one of the most important steps we can take. Through this workshop we want to encourage the profession to reach out to the populous and help make them security literate.

The goal of the workshop is to provide an alternative approach to teaching Computer Security Literacy. This approach, developed at Iowa State University, demonstrates how Computer Security Literacy courses for non-technical students benefit them in their daily lives, now as students and in the future as working professionals.

Keywords: security literacy, security education

I. WORKSHOP GOALS

We are losing the battle in cyber security. We heavily rely on technology as the main defense, instead of recognizing that the easiest attack vectors are the people who operate the computers. The general public does not understand the decisions they make each and every day have security implications for themselves, their projects and their companies. Since people are a primary target, education is one of the “secret weapons” in the cyber security battlefield. Further, if everyday users are the targets, then all audiences, not just technical staff, need training and education in cyber security basics.

The primary method for educating the general public about cyber security has been to construct top-ten security lists. This approach is neither effective nor sufficient as it is poor pedagogical practice to believe that students – or anyone for that matter - can remember, understand, and apply knowledge when the educator provides them with nothing more than

single-page, top-ten bullet point list of security tasks to perform.

We believe that formal computer security education is the key to combating the risks and vulnerabilities intrinsic to the Information Age. Each day, people are inundated with alerts and pop-ups informing them about patch updates, antivirus signature, and firewalls exceptions, but lack the proper education or vocabulary to make value-based decisions regarding the benefits and consequences of taking specific action on these items. What a formal pedagogical approach to practical computer security education provides is the context and knowledge for students to apply computer security best practices when faced with a novel situation and the ability to be proactive in the face of new threats, not reactive. We argue that computer security literacy is not only the next step in computer security defense; it may be one of the most important steps we can take. Through this workshop we want to encourage the profession to reach out to the populous and help make them security literate.

The goal of the workshop is to provide an alternative approach to teaching Computer Security Literacy. This approach, developed at Iowa State University, demonstrates how Computer Security Literacy courses for non-technical students benefit them in their daily lives, now as students and in the future as working professionals.

Currently course-based and security-focused learning initiatives have been primarily addressed at the university level through multiple levels of degrees. Efforts such as [1] have created a two-semester program that enables undergraduate students to learn about the technical facets of cyber security through focused learning models and laboratory environments. Similarly, Hazeyama et al. proposed a learning environment for software security education [2]. Others have sought to develop lab environments [3], and reconfigurable course modules [4, 5] to facilitate technical learning of specific and hands-on cyber security topics. More novel approaches include the use of hacking competitions [6] and capstone design courses [7].

Technical security education is also becoming a more common component of community college curriculums [8]. National Science Foundation sponsored efforts like CyberWatch [9] are committed to improve cyber security

education and have a primary focus on community colleges by providing support for curriculum development, faculty professional development, student development, career pathways, and public awareness. Opportunities are also provided to high school students by means of cyber defense competitions [10] and ad hoc courses or extracurricular activities.

Because the predominate bulk of the cyber security work force is technical in nature, the educational opportunities that support this career path have followed a similar technical emphasis. Although technical course-based initiatives are necessary, they are not sufficient to address current cyber security problems as they provide little opportunities for student of non-technical majors or for those who do not wish to pursue a career in cyber security with an opportunity to learn.

The proposed workshop centers on how two, one-hour, 8 week courses on Computer Security Literacy can be taught. The first course is on concepts found in Computer Security Literacy and the second course is a hands-on, lab-based course where students use the technology and experience how security affects them.

Participants will take home the course syllabi, labs, homeworks and lecture topics to develop Computer Security Literacy courses on their own campus.

II. WORKSHOP TOPICS

The proposed workshop will demonstrate a more effective manner in which to teach Computer Security Literacy. At Iowa State University, we have addressed the gap in security education by developing a course entitled "Introduction to Computer Security Literacy." The specific purpose of this 8-week, 16-lecture course is to provide both students from technical and non-technical majors with the opportunity to formally learn about the many facets of practical computer security knowledge. An emphasis is placed on technical and non-technical majors because previous research on this topic has discovered that despite the perceived advantage of students from technical majors (i.e., computer engineering, computer science, management information systems), students from non-technical majors are, on average, on an equal playing field with their non-technical cohorts when it comes to practical cyber security knowledge.

Because the goal of practical computer security is to provide security context to students concerning activities they already engage in on their computer and/or the Internet, the course topics and objectives of the corresponding lectures strive to keep the content focused and at a tangible level for all to learn.

What makes this course particularly effective at accomplishing its stated course outcomes is that students have the opportunity to apply the knowledge learned in lecture immediately when they leave the classroom when they begin to interaction with information technology. Furthermore, this constant interaction with technology increases the students' repetition leading to the goal of synthesis so that students can act in a safe manor when presented with a novel situation. Lectures are also incorporated with current event

topics so that students can see a direct connection to what they are learning in the classroom, often with an event that has occurred within days of the presentation of the lecture content.

Participants will take home the course syllabi, labs, homeworks and lecture topics so they can start Computer Security Literacy courses on their own campus.

III. WORKSHOP AGENDA

Introduction to the Topic (15 min)
 Current State of Computer Security Education (15 min)
 Concept of Computer Security Literacy (15 min)
 Target Audience (10 min)
 Experience in Courses at ISU (data) (15 min)
 Teaching a literacy course: (45 min)
 Syllabus/Course Outline/Topics
 How to reach a non-technical audience
 Example Lecture
 Teaching a hands-on introduction to security practice course (45 min)
 Syllabus/Course Outline/Topics
 Example Labs
 Wrap up and questions (20 min)

IV. ANTICIPATED AUDIENCE

Faculty in computer engineering, computer science, or anyone who is interested in teaching Computer Security Literacy. The audience does not need to have any security background. The materials and workshop is designed to show how security literacy can be taught.

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Workshop: It's More Than Coding- Using Video Scenarios to Engage Students in Computing

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Abstract- Studies indicate that students, particularly females, find computing most engaging when it is presented in relation to real-life problems, rather than when it is presented in ways that emphasize computing for the sake of computing. Video scenarios are a novel tool for encouraging students to explore computing in a problem-centric, rather than a code-centric, manner. Video scenarios are short films (2-5 minutes long) that depict individuals facing problems in life-like settings. The scenarios emphasize the diverse and often ill-defined nature of real world problems, and the potential for creative and entrepreneurial computing they present. The video scenarios and their associated discussion/exercise questions are freely available on the web at www.Virt-U.org.

Keywords- CS1, CS2, computing education, entrepreneurship, computational thinking, educational videos, video-based learning, problem solving, online tools ethics

I. INTRODUCTION

Using computing to find solutions to real world problems is a pursuit that presents many opportunities to be creative, entrepreneurial, inventive and imaginative. At the same time, understanding the problems to be solved can also be a complex task, requiring one to determine problem boundaries, identify parameters, clarify ambiguities and resolve unknowns, all while keeping in mind client/user expectations. Writing a computer program to solve a real world problem is not an isolated activity, but rather a step in a problem solving process. And it is far more than coding. Bringing this viewpoint into the classroom not only prepares students for the complexities they will face in real world programming, but even more importantly, brings a perspective to the programming process that is problem-centric rather than code-centric. Given that studies indicate that students, particularly females, find computing most engaging when it is presented in relation to real-life problems [1-4], it is all the more important to bring a problem-solving perspective into the computing classroom.

Video scenarios provide a novel tool for encouraging students to explore computing in just such a problem-centric manner. Video scenarios are short films (2-5 minutes long) that depict individuals facing problems in life-like settings. The scenarios emphasize the diverse and often ill-defined nature of

real world problems, and the potential for creative and entrepreneurial computing they present. They also provide everyday contexts in which to practice identifying computing algorithms, patterns and constructs.

While video scenarios provide a tool for emphasizing the problem-solving nature of computing de-coupled from coding, they are also designed to be integrated with traditional teaching approaches. The video scenario approach can enhance both the teaching and the learning experience in a variety of ways:

- The approach is highly flexible and can be used in a wide variety of contexts and for a variety of purposes. Video scenarios can be used to energize lectures with participatory activities via class or group discussions, can redefine the nature of lab activities by incorporating discussions and presentations into them and can serve as a basis for writing assignments.
- Since the scenarios reflect “real world” settings, they allow students to determine the problems to be solved and explore a variety of solutions based on their own interpretation of the scenes and the needs of the individuals depicted.
- The approach is designed to engage students in discussions to encourage critical analysis and creative problem solving. Since studies indicate that women, in particular, are drawn to problem solving rather than computing for the sake of computing, this approach has the potential to lead more women to become engaged in computing [1-4].
- By emphasizing problem solving first, and considering it as a prelude to programming, students can develop skills in computational thinking and creative problem solving at any level of experience, from general education through upper-level classes. Importantly, the scenarios can be used at the middle and secondary school levels, where studies indicate many women and minority students develop negative attitudes about computing [1].

II. TECHNIQUES FOR USING VIDEO SCENARIOS

Video scenarios are designed for a wide range of purposes, including developing computational thinking skills through critical listening and observation, encouraging creative, entrepreneurial and ethical thinking, and developing and reinforcing programming concepts and skills. Video scenarios come in a variety of styles which can be used to address the wide range of educational purposes and settings in which instructors may choose to use them.

A. Video Scenario Styles

Video scenarios come in a variety of styles which are suitable for a wide range of classroom goals and activities. These include *Enterprise* scenarios, which present fictitious companies experiencing a variety of problems that computing and on-line solutions can help, *Patterns and Constructs* scenarios, which focus on recognizing fundamental programming paradigms, constructs, patterns and algorithms in the problems presented, and *Ethics and Practices* scenarios, which present scenarios that explore the complexities of ethical dilemmas, client interactions and business practices.

B. Sample Uses and Exercises

Each video at www.Virt-U.org is accompanied by questions that can be used for a variety of exercises and activities. The following examples represent a range of activities and exercises that can be used in conjunction with video scenarios. The activities can be used in the classroom, laboratory or as the basis for written assignments, oral presentations or on-line (blogging) exercises.

- **Clients, Consultants, Critical Listening and Computational Thinking.** This role-playing exercise utilizes Enterprise Scenarios in which “clients” (members of fictitious companies) talk about their enterprises in a conversational manner as if addressing web design consultants (the audience). The “consultants” must listen critically to the conversation in order to identify the client expectations and requirements. In addition to identifying an overall concept and feature set for the web site, the consultants must also conceive of ways in which computing technologies can be utilized to enhance the client’s services, sales or web presence. This is an excellent exercise in any level of computer science class, as it is a very accessible way to encourage and develop student abilities in verbally expressing themselves to team members, presenting ideas to a critical audience and questioning and analyzing the ideas of others.
- **Problem Solving Scramble.** These exercises utilize Patterns and Constructs scenarios, which have a more computational or algorithmic flavor. In the scramble technique, small groups are given a short period of time to propose a computational solution to a video scenario problem. This time-limited technique is an ideal way of incorporating the use of videos into any setting where time is at a premium. This type of

exercise can also be used to motivate and reinforce the introduction of programming constructs at the CS1 or CS2 level.

- **Understanding the People, Understand the Problem: Recognizing and Resolving Ambiguities.** These exercises can utilize both Enterprise scenarios and Patterns and Constructs scenarios as a catalyst for exploring issues related to achieving effective interactions with clients in order to fully understand their needs and the parameters of their problems. For example, a video may feature a client explaining a task that must be replicated by a program, but the explanation contains ambiguities or contradictions. The associated exercises would involve identifying the ambiguities or inconsistencies and exploring approaches to interact with the client in order to resolve them.
- **What to Do and How to Do It: Ethics and Practices.** These exercises utilize Ethics and Practices scenarios, especially those in the *Notes from the Coach* series, to give students the opportunity to explore issues related to such areas as ethics, client relations and the value and importance of effective communication. The videos and associated discussion questions are designed to serve as a catalyst for the exploration of varying strategies and viewpoints.

III. CONCLUSION

Video scenarios provide a novel, engaging and highly interactive tool to explore computing in a problem-centric manner. Because of their flexibility and accessibility, video scenarios can be used in classes ranging from middle and high school through general education, introductory and upper-level college courses. At the pre-college, general education and CS1 levels, they can be especially useful in enhancing student perceptions of computing and in helping students envision computing as a relevant and creative problem-solving process that extends beyond writing code.

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Work in Progress: Student Outcomes of Design Projects Across the Curriculum

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Abstract— This addresses the question, "To what degree can design projects integrated into the Chemical and Biomolecular Engineering (ChBE) curriculum affect student confidence in their design skills and perceptions of ChBE as a whole?" To answer this question, students were evaluated on their confidence with engineering design and their satisfaction with ChBE as a discipline before and after the design projects, as well as their perceived learning outcomes after completing the design projects.

Keywords— design, project, chemical engineering, capstone, curriculum, student outcomes

I. INTRODUCTION

Most previous research on engineering design education [1-4] focuses on capstone courses [3-4]. The research on design integration throughout a curriculum does not give concrete student outcomes as to whether changes improve the undergraduate experience for students or increase performance in the design capstone course [1]. Since design skills gained in capstone design courses are vitally important for students' careers in both industry and academia, design should not be introduced only at the end of undergraduate programs.

Design projects were integrated into two single semester courses in the Chemical and Biomolecular Engineering (ChBE) curriculum, Principles of Chemical Engineering (ChBE 221) and Momentum and Heat Transfer (ChBE 421). Student demographics (self reported, both domestic and international) for both courses can be seen in Tables I-III. One design project was incorporated per course. Students completed the projects in teams of four to five and stayed in the same team for the duration of the project. Students in ChBE 221 were grouped into diverse teams by their Myers-Briggs Type Indicator (MBTI) type [5] and in ChBE 421 by random selection from GPA quartiles. Each team was assigned a mentor (a student who had taken the course in a previous year) to assist with team management. For grading questions, a design project teaching assistant (TA) was available. Design projects accounted for 10 percent of the final grade in each course. In the ChBE 221 project, students calculated the mass balance for a chemical production process that maximized profit. In the ChBE 421 project, a multifaceted design of a pipeline system, students rendered scale pipeline schematics, sized the piping, and calculated the energy transfer through the pipeline. The top five teams from each course presented their work to a panel of

judges from British Petroleum, p.l.c. (BP) who awarded monetary prizes to the top three teams.

TABLE I. ChBE 221 GENDER AND ETHNICITY DEMOGRAPHICS

| | Asian | Black | Latino | White | Unknown | Total | % |
|--------|-------|-------|--------|-------|---------|-------|----|
| Female | 23 | 3 | 3 | 27 | 9 | 65 | 34 |
| Male | 38 | 3 | 2 | 69 | 17 | 129 | 66 |
| Total | 61 | 6 | 5 | 96 | 26 | 194 | |
| % | 31 | 3 | 3 | 50 | 13 | | |

TABLE II. ChBE 421 GENDER AND ETHNICITY DEMOGRAPHICS

| | Asian | Black | Latino | White | Unknown | Total | % |
|--------|-------|-------|--------|-------|---------|-------|----|
| Female | 19 | 1 | 0 | 14 | 2 | 36 | 28 |
| Male | 34 | 2 | 5 | 51 | 2 | 94 | 72 |
| Total | 53 | 3 | 5 | 65 | 4 | 130 | |
| % | 41 | 2 | 4 | 50 | 3 | | |

TABLE III. EDUCATION LEVEL DEMOGRAPHICS

| | ChBE 221 | | ChBE 421 | |
|-------------------|----------|----|----------|----|
| | Total | % | Total | % |
| Freshmen | 5 | 3 | 2 | 1 |
| Sophomores | 117 | 60 | 6 | 5 |
| Juniors | 62 | 32 | 58 | 45 |
| Seniors | 10 | 5 | 63 | 48 |
| Graduate Students | 0 | 0 | 1 | 1 |
| | 194 | | 130 | |

II. METHODS

Students in both ChBE 221 and ChBE 421 completed an online pre-survey immediately after assignment of the design projects and an online post-survey after completion of the design projects. The pre-survey gathered information about the students' initial expectations and attitudes related to the design projects and ChBE as a discipline. The post-survey revisited the themes of the pre-survey and gathered students' perceptions of the learning outcomes from the design projects. The surveys consisted of both closed- and open-ended questions. The pre-survey response rate was 37% for ChBE 221 and 35% for ChBE 421. The post-survey response rate was 33% for ChBE 221 and 27% for ChBE 421.

A one-hour semi-structured focus group was held for each course after the design projects were completed. Eight students participated in the ChBE 221 focus group and three students participated in the ChBE 421 focus group. Focus group

facilitators were not involved in grading to avoid conflicts of interest. Students received pizza and soda, but no monetary compensation.

III. PRELIMINARY FINDINGS

A basic thematic approach was used in data analysis. Each individual author analyzed the open-ended survey responses and focus group transcripts, followed by collaborative analysis and consensus building to draw out major themes. Closed-ended survey responses (not shown) supported results from the qualitative data. Five major themes were identified, including feedback/grading, project design, presentation opportunities, team design/experience, and overall experience/learning outcomes and are summarized below.

Students expressed frustration because they felt that there was a lack of feedback and they had a poor understanding of grading procedures for all portions of the design project. A majority of the focus group participants noted a lack of comments on reports. Further, students did not understand how the top five teams were selected or how winners were chosen. Similarly, students felt that there was not enough contact with, or feedback on projects from the TA. Students suggested that more TAs would be necessary to properly manage the course and provide support for student concerns.

Students responded positively to the projects' open-endedness and real-world applicability. In contrast, students disliked the lack of specificity in the project guidelines, the lack of coordination between different ChBE course assignment due dates, and the course percentage given for the project. Additionally, students in ChBE 221 desired more ability to evenly split the design project assignments between team members.

Students felt that the presentation to BP was an important part of the design project and that more teams, if not all, should have presented. Students recognized the importance of presenting their work to industry sponsors. Students also understood the logistical problems with every team presenting, specifically the amount of time it would take, but felt that the benefits to student experience outweighed these concerns.

The vast majority of students preferred the grouping methods used in both courses to choosing their own teams, but wished that grouping could have been completed earlier. Additionally, most students had positive team experiences. Focus group participants said that they favored the MBTI method to random selection, and random selection to choosing their own teams. In contrast to the focus groups, four survey respondents in ChBE 221 favored picking their own teams to the MBTI method. Additionally, students commented that they enjoyed making new connections within ChBE and developing team spirit throughout the design projects.

Overall, students had a positive experience with the project, but provided both positive and negative feedback. Focus group participants were satisfied with the experience provided by the addition of a design project to the course, and several mentioned that afterward, their attitudes toward ChBE as a discipline improved. When asked the open-ended post-survey

question, "List the three most important things you learned from this design experience," survey respondents highlighted several learning outcomes, which were classified into five categories. These survey responses are shown in Table IV.

TABLE IV. NUMBER OF SURVEY RESPONSES BY LEARNING OUTCOME

| | ChBE 221 | ChBE 421 |
|--|----------|----------|
| Teamwork Skills | 20 | 11 |
| Applying Coursework to the Real World | 5 | 3 |
| Design Skills | 3 | 3 |
| Time Management Skills | 9 | 0 |
| Problem Solving Skills | 3 | 0 |

IV. FUTURE DIRECTIONS

- **Refine the design project administration.** Instructors should specify the project guidelines more precisely and coordinate between course assignment due dates in different ChBE major courses.
- **Have more than one TA.** Having additional TAs would allow for distribution of course responsibilities and more total TA contact hours for students. Future evaluations should include TA interviews to better understand TA experiences.
- **Incorporate opportunities for more students to present.** Students who presented to BP consistently mentioned it as the highlight of their experience with the design project. Thus, providing an opportunity for more students to present would improve the overall experience.
- **Begin longitudinal studies.** Comparing final grades in the capstone design course and exit interviews between previous years and students who experienced integrated design projects will become feasible when current students begin graduating.

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Differences between Same-sex and Cross-sex Mentoring Relationships in Capstone Design Courses

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Abstract— Within capstone design courses, the relationship between faculty and students can be classified as mentoring, where instructors fulfill functions that support career and psychosocial development of the students. Unlike traditional mentoring relationships, however, matching student teams to faculty mentors is not simply a process of one mentor and one mentee choosing each other. Project, team, and course structures are all dominant factors, resulting in both cross-sex and same-sex mentoring relationships. Literature on mentoring relationships in higher education has produced conflicting reports on which match yields better outcomes. Thus understanding the implications of same-sex and cross-sex relationships can be helpful in enabling faculty to effectively support the development of all students. This study applies an empirically derived model of capstone mentoring to data from a 2011 national survey of students enrolled in capstone design courses. The survey addresses students' perceptions of faculty teaching and their self-reported learning gains, and the data analysis presented in this paper focuses on similarities and differences based on the sex-pairing. The results provide preliminary insights regarding the impact of sex differences on the capstone mentoring relationship, and thus contribute to a more complete understanding of design teaching.

Keywords—Design teaching, mentoring, gender

I. BACKGROUND

The capstone course has been commonly recognized as one of the most prominent examples of project-based learning [1] in engineering. Throughout this course students are exposed to realistic design situations that simulate the engineering profession through the implementation of open-ended, hands-on projects [1-4]. This experience requires students to integrate domain knowledge from engineering sciences and design systems, and to utilize professional skills in the pursuit of the successful completion of the capstone project [5].

This work is commonly guided by faculty advisors. A recent study of faculty roles in the capstone course has shown that the faculty role is a form of mentoring where

faculty fulfill several functions commonly seen in formal mentoring environments [1].

Mentoring relationships, broadly defined, have been shown to positively influence retention and achievement among women and minorities [6]. Among women, mentoring is recommended as a means to offer the support, socialization, and direct assistance they may need to succeed; especially in alienating or hostile situations. While the capstone course is not intended to be hostile, the low representation of women on design teams can make women feel alienated and hostile environments can result [6,16]. Within mentoring literature there is conflicting reports on the effectiveness of same-sex and cross-sex mentoring [6]. Jacobi [6] indicated that there needed to be further studies towards the preferred and actual mentoring functions provided by mentors to protégés and the outcomes of these relationships.

A. Mentoring in Capstone Courses

To operationalize the mentoring that occurs in capstone courses, we applied the mentoring functions identified by Kram [7] in the workplace, to the capstone course and empirically developed operational definitions and practices [1]. Mentoring occurs in two domains, career development and psychosocial development, and each has an associated set of functions (Table 1).

TABLE I: IDENTIFIED MENTORING DOMAINS AND FUNCTIONS

| Career Development | Psychosocial Development |
|-------------------------------|-----------------------------|
| Employability-and-Sponsorship | Role Modeling |
| Exposure-and-Visibility | Acceptance-and-Confirmation |
| Coaching | Counseling |
| Protection | Rapport |
| Challenging Assignments | |

The career development domain consists of functions targeted at developing students' access and abilities so that they can find employment in the engineering industry and succeed in that employment. The related functions include providing sponsorship-and-employability, exposure-and-visibility, coaching, protection, and challenging assignments.

The mentoring associated with psychosocial development focuses on supporting the students' sense of community, identity, and effectiveness in their role with an emphasis on behaviors and values rather than skills as well as developing the students' self-identity and efficacy as a practicing engineer. The related functions include role modeling, acceptance-and-confirmation, counseling, and rapport.

Unlike traditional mentoring relationships, however, capstone mentoring represents a group-mentoring environment where students generally do not select their mentors individually and mentors generally interact with diverse student groups. Thus the implications of same-sex and cross-sex relationships are particularly crucial in capstone environments to insure that faculty can effectively support the development of all students.

B. Cross-sex/Same-sex Mentoring

Research on sex differences in mentoring relationships has focused on the selection of the mentor, the functions provided to the protégé, the perceived value of the relationship, and how effectively the protégé utilized the mentoring relationship. Unfortunately, several of the findings have been inconsistent. For example, Jacobi [6] and Erkut and Mokros [8], found that females were more likely to select female mentors [6, 8]. Erkut and Mokros also found that men tended to select mentors that could write influential letters of recommendation regardless of the sex of the mentor, whereas women were more interested in mentors that have an attractive lifestyle [8]. Moore and Amey [9] suggested that women may avoid male mentors due to a difficulty in relating to and learning from male mentors. In contrast, Olian [10] found no same-sex preference when selecting mentors.

While Erkut & Mokros saw selection preferences based on the sex of the mentor, they saw few sex differences in the type of support provided to students. In their study both groups experience similar mentoring functions, and both men and women indicated that they received no help in developing connections with people in graduate schools, professional schools or work environments despite the gender of the mentor [8]. Other studies, however, found that women saw more support of psychosocial functions, particularly role modeling with respect to the attitudes, values, and behaviors of the discipline, and opportunities to explore personal concerns more than men [11]. Otherwise there were no perceived differences and both men and women perceived similar value from the relationship [11].

When examining how effectively the mentoring relationship was utilized by each sex, Noe [12] found that in cross-sex mentoring relationships the protégés utilized the mentor more effectively than those in same-sex mentoring relationships. In addition, the male-male relationship was less effectively utilized than the female-female relationships. Moreover, an analysis of variance showed that the gender of the protégé accounted for more variance in psychosocial outcomes than the amount of time spent with mentor, utilization of the mentor, or the protégés job and career attitudes.

C. Research Questions

One of the difficulties in drawing general conclusions regarding the effect of sex on mentoring relationships is that the studies occur in a variety of contexts, including undergraduate education at small co-ed and all-female arts colleges, teacher education programs, and nursing education programs. This variation suggests that context may significantly influence the ways in which the sex of the mentor and the mentee affect the mentoring relationship. Given the importance of mentoring in capstone courses, and the group mentoring dynamic, where both male mentors and male group members dominate, this study explores the the following research questions have been investigated:

1) *How do students in same-sex and cross-sex mentoring relationships differ in their perception of mentoring received in engineering capstone design courses (ECDC)?*

2) *How do self-reported learning outcomes of students differ between students in cross-sex and same-sex mentoring relationships in ECDC?*

Addressing these questions enhances our understanding of design teaching in a way that can be used not only for professional development of current design faculty, but also in the training of new design educators.

II. METHODOLOGY

This study utilizes quantitative survey data from capstone students collected as part of a study examining the teaching practices of capstone design faculty (ExCDE) which led to an examination of mentoring functions in the capstone course.

A. Participants

Participants included 191 students enrolled in capstone design courses across the United States from 20 different institutions during the 2011 Spring term. The Spring term was chosen so that students would have a full capstone course experience, whether it was one or two terms.

The survey was distributed through faculty interview participants involved in the ExCDE project one month before the end of the school term. The faculty were asked to forward the recruitment email to their students during the last few weeks of the term and a reminder was sent to the faculty during the last week of their term to maximize response rate.

The student respondents were enrolled in capstone courses representing a variety of disciplines including mechanical (37%), chemical (34%), electrical and computer (12%), industrial systems (12%), and civil engineering (7%). The participating students were from both public (82%) and private (18%) institutions. Institution size also varied from under 5,000 students (14%) to 5,000-20,000(54%), and over 20,000 (31%). Out of the survey respondents there were 9 female students in groups mentored by females, 7 female students in groups mentored by males, 141 males students in

Identify applicable sponsor/s here. (*sponsors*)

groups mentored by males, 34 males students in groups mentored by females. (TABLE II).

TABLE II: DISTRIBUTION OF RESPONDENTS

| Mentoring → | | Students | | |
|-------------|--------|----------|--------|-------|
| | | Male | Female | |
| Faculty | Male | 141 | 7 | (148) |
| | Female | 34 | 9 | (43) |
| | | (175) | (16) | |

B. Data Collection

The student survey was developed in the Spring of 2010 using the Crocker and Aligna [13] process of survey development. It served as a means to triangulate responses from the faculty survey and interviews conducted during the first two phases of the ExCDE project. The student survey included questions that addressed course demographics, faculty roles and actions, self-report of learning outcomes, and the perception of frequency and value of interactions with capstone faculty. The questions concerning the students' perception of the capstone instructor's roles and actions included 15 questions directly related to the mentoring functions associated with career and psychosocial development identified in mentoring relationships (Table III). These items were developed specifically from the faculty survey, faculty interviews, and other quantitative studies that utilized Kram's mentoring functions [7] as a framework. These items were 5-point Likert-type, allowing for responses from strongly disagree to strongly agree. The learning outcomes, identified through the faculty survey and interviews, were evaluated on a 5-point scale from "None (I learned nothing in this area)" to "Very High (I learned a great deal in this area)".

TABLE III: MENTORING SURVEY ITEMS

| Functions | | Student Survey Items (The capstone instructor...) |
|--------------|-------------------------------|--|
| Career | Employability/ Sponsorship | <ul style="list-style-type: none"> Sponsored me for desirable positions such as assistantships, jobs, or internship |
| | Exposure/ Visibility | <ul style="list-style-type: none"> Encourage me to publish work Introduced me to experienced professionals in my field |
| | Coaching | <ul style="list-style-type: none"> Provide direct training or instruction for me |
| | Protection | <ul style="list-style-type: none"> Keeps up with status and progress of my project Keeps up with how well my team is functioning Guides the development of the project scope Acted as an intermediary between clients & team Checked work before submission |
| | Challenging Assignments | <ul style="list-style-type: none"> Allows me to synthesize and apply prior work Allows me to develop and design my project |
| Psychosocial | Role Modeling | <ul style="list-style-type: none"> Served as a role model for me |
| | Acceptance/ Confirmation | <ul style="list-style-type: none"> Offered me acceptance, support, & encouragement Allows me to interpret data and make decisions on my own |
| | Counseling | <ul style="list-style-type: none"> Provided personal guidance and counsel for me |
| | Rapport | <ul style="list-style-type: none"> Served as a friend |

Once the items were developed, they were reviewed by the research team and piloted using a convenience sample of capstone students. The pilot test allowed the students to take the full survey and provide comments on each question. The pilot test yielded a response of five students. Upon review of the pilot results, items were added that reflected student concerns and a section of items that included a drop down menu were altered for a quicker point-and click answering.

C. Data Analysis

The quantitative analysis for the surveys included descriptive statistics of the item responses for each group and comparison of differences between the item responses. The descriptive analyses for the survey included the mean, median, and modes of all items in Table III. These items were then examined to compare differences between the four groups using a Mann-Whitney U statistical test of sample medians. The Mann-Whitney U test determines if there is a significant difference between sample medians of two independent groups [14]. It is used to compensate for the non-normal distribution of the data and the use of Likert items as a data source [14]. It is also a stronger statistical measure given the low number of females represented as both faculty and students in comparison to the Male-Male relationships.

This analysis requires a pair-wise comparison of the four groups of same-sex and cross-sex relationships. These types of concurrent analyses have the tendency to increase the family-wise error rate, which can be alleviated by applying a Bonferroni correction to the alpha criterion (α) [14]. By dividing alpha by the number of comparisons being examined (α/m) a new acceptable alpha can be used to examine significance among the engineering disciplines [14, 15]. In examining the five engineering disciplines, ten pair wise comparisons were conducted. Using the nominal criterion of significance of $\alpha = 0.05$ and dividing it by the 6 statistical examinations, the new adjusted criterion became $\alpha = .0083$. Due to the small sample of female students and female faculty, effect sizes were calculated as a comparison despite the non-normality of the data.

III. FINDINGS

The analyses identified several differences based on the sex of mentor and student in terms of the mentoring functions, the self-reported learning outcomes, and other types of support and perceived value. In the following discussion, the the sex of the mentor is always listed first (Mentor/Student) – i.e. Female/Male is a female mentor and a male student.

A. Difference in Mentoring Functions

While Erkut and Mokros saw no difference in the functions of mentoring received by males and females in their work, this study identified a difference in the perception of receiving sponsorship. With respect to the functions identified in Table 1 and Table 3, the function of *sponsorship* was the only identifiable statistically significant difference between Male/Male and Female/Male mentoring relationships. Males mentored by other males perceived less

sponsorship than males mentored by females. In contrast, male students mentored by females experienced more sponsorship than females mentored by females; although this difference was not statistically significant ($p > .03$), the effect size was greater than 1. Finally, males mentored by females experienced more sponsorship than males mentored by males, though this difference was not statistically significant.

TABLE IV: DIFFERENCES PERCEIVED IN MENTORING

| Survey Items | Male ^a | | Female ^a | |
|------------------------|-------------------|---------------------|---------------------|---------------------|
| | Male ^b | Female ^b | Male ^b | Female ^b |
| Sponsorship | 2.28 | 2.89 | 3.56 | 2.14 |
| Undergraduate Research | 30% | 33% | 43% | %100 |

a. Faculty mentor sex
b. Student sex

B. Difference in Learning Outcomes

Previous studies suggest the sex of both mentor and mentee can affect the learning outcomes of the student. This study, however, found difference in the learning gains in only two areas: written communication and engineering ethics (Table V). In contrast, there were no differences in learning gains associated with project planning, concept generation, economics, design, and creativity.

TABLE V: PERCEIVED LEARNING GAINS

| Survey Items | Male ^a | | Female ^a | |
|-----------------------|-------------------|---------------------|---------------------|---------------------|
| | Male ^b | Female ^b | Male ^b | Female ^b |
| Written Communication | 3.11 | 3.66 | 3.78 | 3.71 |
| Engineering Ethics | 2.82 | 3.43 | 3.11 | 2.29 |

a. Faculty mentor sex
b. Student sex

The differences occurred between the male and female students when mentored by a male capstone instructor. In both cases, males indicated significantly lower learning gains. While not significantly different, female students saw lower learning gains in engineering ethics when mentored by females than when mentored by males (Cohen's $d > 1$), and female students saw lower learning gains in ethics that males when both were mentored by females.

C. Other Notable Differences

While not directly related to the mentoring functions described in Table 1 and Table 3 and gains in learning, one of the most notable differences between the same-sex and cross-sex mentoring relationship involved female students' perception of whether capstone instructors encouraged hands-on construction. Female students perceived significantly less ($p < .0083$) emphasis to participate in hands-on construction in comparison to male students, whether they were mentored by male or female faculty.

TABLE VI: DIFFERENCES IDENTIFIED IN HANDS-ON CONSTRUCTION

| Survey Items | Male ^a | | Female ^a | |
|-----------------------|-------------------|---------------------|---------------------|---------------------|
| | Male ^b | Female ^b | Male ^b | Female ^b |
| Hands-on Construction | 3.64 | 2.66 | 3.33 | 2.00 |

a. Faculty mentor sex
b. Student sex

IV. CONCLUSION

Capstone course represent a significant mentoring opportunity for most students. As a result, capstone faculty should work to ensure that the relationship is as effective as possible. The results of this preliminary study suggest that in many cases, male and female students experience this mentoring relationship differently, and thus the study highlights areas where, as educators and mentors, we have identifiable areas for both improvement and further study.

As Erkut and Mokros [8] noted, there are more similarities in the mentoring seen in same-sex and cross-sex relationships than differences, even within the engineering capstone course. The differences identified through this study, though, suggest that in some areas cultural stereotypes and socially defined roles may persist within the classroom. For example, the fact that females perceive less encouragement to participate in hands-on construction than their male counterparts could be a result of the capstone instructor, the group dynamic, or the environment of the capstone course or department. Thus while we see that females are experiencing mentoring at the same level as their male counterparts in many areas, more effort is needed to be made that encourage a full engineering experience that is not limited by those stereotypes and socially defined roles.

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Work in Progress: Investigating the Engineering Design Process: Novices vs. Experts

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Abstract - This study investigates the engineering design process. It compares expert and novice engineers during the processes of decomposition of a problem and the recomposition of sub-problems when working in teams. The paper describes the research questions, research design, and method of collecting data and analyzing data of the study.

Keywords - *teaming; engineering design; protocol analysis; FBS; problem decomposition; recomposition of sub-problems*

I. INTRODUCTION

Engineering design is a central subject for engineering education and a major activity for practicing engineers. There is a need for engineering graduates who are able to design effective solutions to meet customers' various requirements [1]. However, many researchers believe that engineering design is not taught properly. These problems in engineering education include focusing on analysis more than design [2] and spending insufficient resources on teaching design [3]. Engineering education has not prepared students with practical skills and knowledge, hence, engineering graduates have been considered to be unprepared to practice in the industry [4].

A series of studies shows that there is a gap between skills developed in universities and skills required in the industry [4, 5, 6]. Researchers believe that the teaching of design in engineering education is in need of improvement [3, 7]. Students need to learn more real world skills, because "the 'real world' provides the materials and devices with which engineers design, and the world is where the performance of systems is verified" [8]. To increase the quality of engineering education, researchers must study the engineering design in a real – world context, which means engineers work in teams to solve actual problems. This approach offers useful information to improve engineering education at the college level.

II. RESEARCH QUESTIONS

The vision of this research is to better understand the engineering design process as it relates to expert vs. novice. It investigates the design strategies employed by teams of engineering freshmen and teams of engineering experts. The following questions guide the study:

- How is the process of problem decomposition for teams of engineering freshmen different from teams of engineering experts?

- How is the process of problem recomposition for teams of engineering freshmen different from teams of engineering experts?

III. WORK PLAN

In this study, the engineering design process is investigated. Teams of college engineering freshmen and teams of engineering experts complete the same engineering design problem.

A. Participants

Participants including college engineering freshmen and engineer experts are selected by purposeful sampling. Student participants are from the College of Engineering at Utah State University. Participation in this study is open to all engineering freshmen regardless of their engineering major on a volunteer basis. Each student receives a \$10 honorarium to participate. Engineer expert participants are recommended by researchers at Utah State University. Emails are sent to potential engineer expert participants to introduce the purposes and procedures of the study. The engineer experts voluntarily participate in the study as well, and each engineer expert receives a \$50 honorarium for his or her participation. All participants sign informed consent forms before participating.

B. Research Setting

Participants are assigned to teams. Research [9] showed that instructors should form the student teams, because practicing engineers are not able to choose their teammates and students need to learn to work with a variety of teammates. A team of three to four students is considered optimal [9]. In this study, each team includes three members.

All the teams complete the same design problem in similar settings within two hours. They are asked to design a double-hung window opener that assists the elderly with raising and lowering windows. This design problem has been used by Gero [10] to study engineering design thinking. There are various engineering and social constraints in this problem which make it a typical engineering design problem. In addition, because a double-hung window is commonly used in households, students are able to complete the design problem without any specific engineering knowledge or background.

Due to the limitation of time, participants are not expected to completely finish the design problem. Instead of presenting practical products by the end of design process, participants

only submit design proposals as final outcomes. They do not build, test, and analyze their design.

C. Data Collection and Analysis

Data is collected mainly through Verbal Protocol Analysis (VPA). The process of performing the task is recorded by audio. At the same time, video data are collected to record participants' nonverbal communication. In addition, participants' sketches are collected as supplemental materials to the study. The data will be collected in September, 2012.

After all the participants finish their design problem, audio data are transcribed, segmented, and coded. The data are coded according to the coding system after segmenting. The coding system has two dimensions: reasoning mode and level of the problem. This two-dimension coding system has been used to investigate design strategies used by individual engineers [11]. The first dimension is the reasoning mode. It utilizes a framework known as Function-Behavior-Structure (FBS). FBS represents the process of design and was developed by Gero and Kannengiesser in 2004 [12]. They illustrated the definition and conceptualization of the framework as shown in Figure 1. Function represents designers' expectations of the products, behavior represents the ways designers accomplish their goals, and structure represents the solutions to the problem. The second dimension of the coding system is the level of the problem. Engineers decompose the design problem into multiple sub-problems and work on each sub-problem in order to find the solution. The level of the problem runs from 0 to 3. The meanings of each number are showed in Table 1.

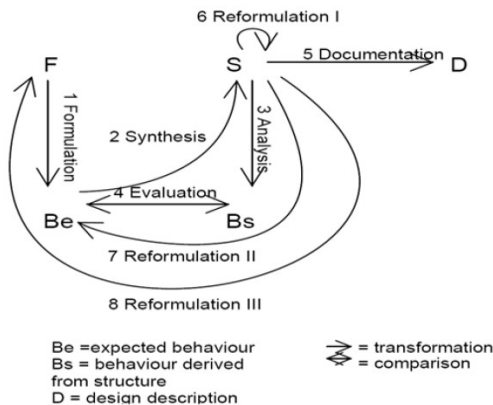


Figure 1. FBS framework

TABLE I. LEVEL OF THE PROBLEM

| Level of the Problem | Definition |
|--------------------------|---|
| 0: System | Designers consider the problem as an integral whole. |
| 1: System and subsystems | Designers consider interactions between subsystems. |
| 2: Subsystems | Designers consider details of the subsystems. |
| 3: Design details | Designers consider the detailed working of the subsystem. |

There are two raters participating in the coding section. The training content of raters includes learning references about FBS framework and problem decomposition-recomposition, and practicing the coding of previous engineering design challenges. After coding data, researchers apply nonparametric tests in analyzing quantitative data. The analysis of qualitative data is connected with the context of engineering design and allows any themes or new phenomena to emerge. These data are triangulated against each other. The data analysis is expected to be finished by the end of October, 2012.

IV. EXPECTED OUTCOMES

By analyzing the data, differences in decomposition-recomposition of the problem between engineering experts and college engineering freshmen are found. By examining those differences, we better understand engineering design thinking which can be applied to improving engineering education, especially the teaching of engineering design. The results of this research will be available at the 2012 FIE conference.

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Design Considerations: Implications of Domain Expertise

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Abstract — This paper describes how four playground experts and five engineering experts completed a task of designing a playground. The findings, derived from a qualitative coding analysis, showcase the playground experts in this sample considering social contextual factors, paying attention to human actors' playground use, and relying mainly on professional knowledge. The engineering experts in this sample also paid attention to use of the playground by people and used a combination of professional and personal knowledge as they completed a playground design task. In support of ABET's goals for the engineering discipline, the research highlights how expertise in a particular domain may be helpful for one's capacity to also focus on social and human-related elements through the design process. These outcomes aim to support the educational discussion on how to enable engineering students to develop expertise that involves broader design considerations.

Keywords - domain expertise; design process; design thinking; engineering education; context; broad thinking

I. INTRODUCTION AND BACKGROUND

The contexts in which engineering projects are situated are becoming more complex. While expert engineers hold a myriad of experiential knowledge in their domains of expertise to aid them in highlighting important contextual factors; novice engineers rely predominately upon their educational backgrounds. ABET, the engineering accreditation body, specifically states in Criterion 3H that engineering programs should help engineering students achieve "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" [1]. Teaching these skills to engineering students is a difficult task.

The research presented in this paper addresses this challenge by seeking to understand the relationships between the possession of expertise in a particular domain and the potential accompanying ability to situate problems and consider context more broadly in design processes. A domain is defined as a shared system of knowledge and activities that focus on a particular subject and expertise and "...refers to the characteristics, skills and, knowledge that distinguish experts from novices and less experienced people" [2]. Focusing on domain expertise is important for what it may encompass, as science and technology studies have long taught us that becoming expert is not simply about one's intended role, but the amalgamation of experiences that have led a person to achieve a particular level of skill and knowledge [3].

If expertise is enactment, it is also fundamentally a process of becoming rather than a crystallized state of being or knowing. So although certain forms of expertise may be culturally cast as natural or spiritual endowment, it is clear that one can learn to be an expert. [4]

In learning to become a domain expert, the literature is clear in stating that many hours of practice and experience are essential [5, 6, 7]. While a person may gain the experience to become a domain expert through several paths, for engineers, primary introductions to a discipline are encountered through their education. As Leckie [8] stated:

Undergraduates, particularly in the lower years, are exposed to certain disciplines for the first time. This exposure frequently consists of a textbook, reserve materials, and lectures. The students have no sense of who might be important in a particular field, and find it difficult to build and follow a citation trail. They do not have the benefit of knowing anyone who actually does research in the discipline (except for their professor) and so do not have a notion of something as intangible as the informal scholarly network. They have never attended a scholarly conference. Because of their level of cognitive development, ambiguity and non-linearity may be quite threatening. [8]

Reference [8] brings up an important point: having a general sense of how a discipline works is essential to developing expertise and being situated within a community helps to enable this. Lave and Wenger's [9] idea of *communities of practice*, where individuals are socialized in an environment co-constructed by its participants, are able to learn, participate, and further their particular community; modifying the implicit and explicit rules that guide them on their way. Carr [4] and Sosniak [7] also stated that disciplinary experience is the common reasoning for placing individuals in situations of apprenticeship and training, or areas of socialization, so as to allow individuals to become familiar with various cultural artifacts and processes, along with the vernacular of the domain. This "insider" knowledge becomes a first step in distinguishing oneself as an expert.

In meshing the hours of practice, knowledge derived from education, and involvement within the community itself, the development of methods for efficient participation surface through new mental capacities that foster the ability to organize information learned from an expert's domain into larger chunks

[10, 11]. If some cognitive tasks do not become automated, then other growth cannot occur [12].

[...] for instance, problem-solving activities in which a number of steps that are repeated over and over coalesce into a chunk that can be retrieved as an entity containing all of the steps, thereby eliminating the need for repeated searches of long-term memory [13]

This leaves room for higher levels of cognitive activities [10] and capacity to pay attention elsewhere or focus on the creation of new solutions [14]. While there is not space to fully discuss the literature detailing the cognitive development of expertise, the purpose of this background is to showcase the importance of experience, something domain experts possess, which may allow greater processing, connecting, and implementing of ideas that are broad in scope and linked to the world in multiple ways.

II. METHODOLOGY

A. Methods

This exploratory analysis is designed to complement the greater body of engineering education literature and the research conducted at the Center for Engineering Learning & Teaching (CELT). CELT's prior studies focused on the same playground design task wherein engineers, with varying levels of design experience, were asked to think-aloud while designing a playground in a fictitious neighborhood in a three hour time-frame. Participants gave a verbal protocol while they solved the problem. A transcript of the protocol was segmented and coded for design activity, and the playground that the participant designed was evaluated and given a quality score ranging from 0 to 1.

The initial work included first year students, graduating students and expert engineering designers as participants. These studies found differences across these three levels of engineering expertise in terms of time spent, problem scoping, information gathered, and design activity transitions throughout the design process [15, 16, 17]. Data from expert playground designers were collected in the same time period that data from the expert engineering designers were collected. Experts for both groups were identified by their peers as expert designers in their field. The analysis in this current paper is intended to provide qualitative insights for the playground expert data and for a subset of the engineering expert data.

This research is situated as a predominately qualitative analysis, with coding completed by a singular graduate research assistant at CELT. The coder was purposefully provided no details regarding the goals of this study, and had not read any papers related to previous playground analyses. Here, the intention was to diminish researcher bias, allowing themes to emerge from the data [18]. The design task transcriptions were processed using an inductive or "open" coding analysis [19]. Initial stages of coding involved a read-through of content to generate preliminary codes, followed by three iterations of application that involved code addition, and altering code applications, nomenclature, and definition. Revisions were further supported as codes were discussed in CELT research meetings to clarify definitions and application.

Finally, code application was checked by a senior researcher as an expert peer review of two randomly chosen participant transcripts for each expert type. This review resulted in a high level of agreement and confirmation of code application.

The qualitative data from the coded transcriptions were then counted and entered into Excel spreadsheets to create visualizations that showcased each instance of a code on the full three-hour timeline of the design task. These visualizations were used as tools to uncover themes and patterns in the data. The code categories discussed in this paper are: context (social, environmental, economic, political); people (actors, use); and knowledge (professional, personal) More specific code definitions will be discussed in the findings section below.

B. Sample

The participant sample included for this analysis consisted of five of the original 19 engineering experts (E) and data for all four playground design experts (P). The five engineers were selected from the 19 to both show breadth of solution quality and to match the high quality design scores displayed by the playground experts. In past publications focusing on design processes we presented timelines of three of the expert engineers: one with each of high, average and low quality scores (see reference [16] for more details). We selected these subjects as representative of the range of quality scores for the engineering experts. All four of the playground experts achieved a high quality score. The final two engineering experts, we included, matched the playground experts for high quality score and similarity in terms of design process codes in previous studies. The resulting sample of engineers had three high, one average and one low quality score.

The engineering experts were screened to ensure that they did not have in-depth knowledge of playground design so that all engineering participants would not have domain experience. The playground designers were not screened for absence of engineering knowledge. This resulted in one subject, Paul (P4), having some engineering knowledge as he was about to finish a degree in mechanical engineering. Table 1 presents a summary of the participants, note that the pseudonyms for the engineering experts start with "E" and the playground experts start with "P".

III. FINDINGS

A. Considering Context

In addition to descriptive information about the participants, Table 1 presents the total amount of time that the participants spent designing the playground, and the time spent in each of the code categories (context, people, knowledge). Fig. 1 then presents how the participants distributed their time within each category as a percentage for each of the codes in that category. In this section we describe how the participants chose to use their time as described by these codes. One of the notable findings was the amount and type of contextual information considered by both the playground experts and the engineering experts. Context can be defined as background information that situates and provides a framework for moving through a design task. This analysis identified four context categories in the data: economic, environmental, political, and social.

TABLE 1: ENGINEERING EXPERTS (E) AND PLAYGROUND EXPERTS (P): PARTICIPANT BACKGROUND AND DATA

| Pseudonym | Evan (E1) | Earl (E2) | Eldon (E3) | Eric (E4) | Elizabeth (E5) | Phil (P1) | Perry (P2) | Patrick(P3) | Paul (P4) |
|-------------------------|---|---|---|---|---|---------------------------------|------------------------------------|--------------------------|---|
| Quality Score | Low | Avg | High | High | High | High | High | High | High |
| Current Title | Product Design Engineer | Product Development Engineer | Core Tire Pressure Monitoring | Leader Engineering – Passenger Systems | Consulting Engineer - System Protection | Playground Equipment Designer | Playscape Designer | Product Designer | Engineering and Safety |
| Years in Profession | 30 | 13 | 18 | 17 | 19.5 | 42 | 14 | 20 | 5 |
| Gender | Male | Male | Male | Male | Female | Male | Male | Male | Male |
| Age Range | 51-60 | 41-50 | 31- 40 | 31-40 | 41-50 | 61-70 | 31- 40 | 41-50 | 31-40 |
| Background and Training | Electrical engineering, electronic systems integration, control systems | Mechanical Engineering , Materials science, Physics | Systems Engineer Electrical Engineering | Mechanical engineering and design, many CAD classes | Electrical Engineering | Art, design & child development | Undergraduate in industrial design | BFA in Industrial Design | Currently pursuing degree in mechanical engineering |
| Overall Times | | | | | | | | | |
| Total Time | 02:25:29 | 03:01:16 | 02:28:36 | 03:01:08 | 02:50:15 | 02:43:49 | 02:58:37 | 02:56:26 | 02:56:48 |
| Context | 1:18 | 7:48 | 6:12 | 2:54 | 3:48 | 8:54 | 43:42 | 6:48 | 3:42 |
| People | 7:42 | 7:30 | 6:24 | 5:24 | 11:54 | 29:36 | 8:48 | 36:48 | 12:06 |
| Knowledge | 1:36 | 2:24 | 1:12 | 3:54 | 4:54 | 6:24 | 4:12 | 3:06 | 10:00 |

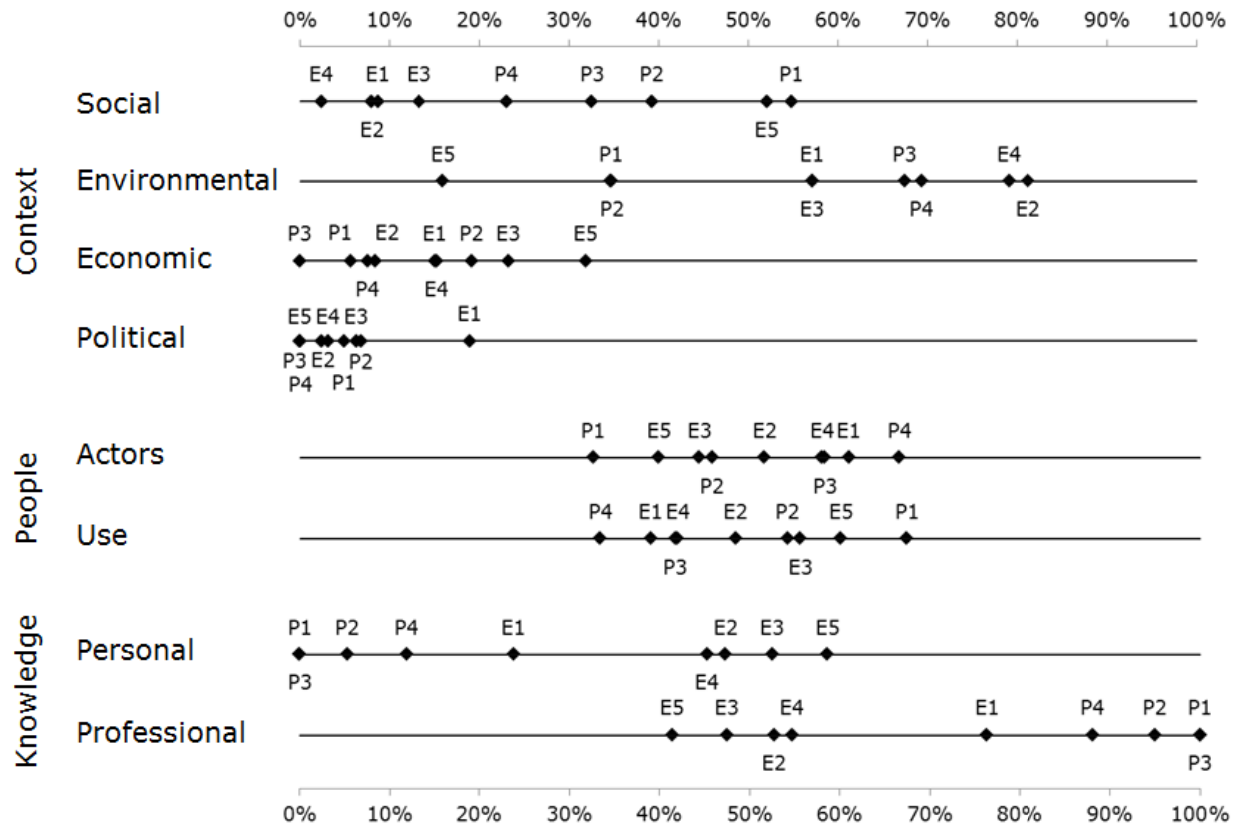


Figure 1: Allocation of time spent for each code within code category (shown as percent of total time in that category).

E1= Evan, E2=Earl, E3=Eldon, E4=Eric, E5=Elizabeth, P1=Phil, P2=Perry, P3=Patrick, P4=Paul)

All participants spent time considering context in varying amounts (see Table 1). It is interesting to note that the two who spent the most time on context issues were playground experts, and the two who spent the least amount of time on context were engineering experts. Paul (P4), the playground participant who spent the least amount of time considering context, had the fewest number of years in the field of playground design. It is also interesting to note that in the code *social* in the context category as seen in Fig. 1, the four participants who spent the least amount of time considering social issues were all engineering experts.

More interesting, may be the difference in type of context each participant considered. As demonstrated in Fig. 1, four of the five engineering experts considered environmental context more prominently than they considered social, political and economic context. As Eldon (E3) stated, "Is this a northern city that has snow, or is this a southern city that's never going to see snow?" The one exception, Elizabeth (E5), the sole female participant in this study, considered social context more than environmental. In this statement, she addressed social context in how parents would be able to situate themselves in the playground; "Seems like it might be nice to include some shade, perhaps for the neighborhood gathering area or the moms -- wow -- the parents' area, where they can sit and watch the kids."

Within the overall time participants spent on context, all the playground experts focused on social and environmental context for a large percentage of their time. Few of the playground experts spent a notable amount of time on issues of economic and political context. Perry (P) stated,

I'm trying to imagine that space, I'm imaging the families, and I'm trying to kind of feel the energy of the people and what their lives are like and how they know each other or don't know each other and trying to imagine standing in the middle of that space and thinking about the different seasons there and, um, how the sun moves through the space in the daytime and think about summer when it's hot, and maybe you need shade in places, and then thinking about wintertime and when they're plowing and wondering if they'll plow.

This greater consideration of social context by the playground experts may be the result of domain experts' capacities to pay attention elsewhere, as discussed by [14].

B. Considering People

Part of what makes noteworthy the consideration of social context by the playground experts is the fact that the engineering experts, while not as frequently as the playground experts, did consider the people-oriented codes, *actors* and *use* (Fig. 1). *Actors* relate to any human involved with the playground being designed and *use* is how the playground equipment could or should be used. It appears that the engineering experts considered people and playground use as concrete elements of specific problems in the playground task. The playground experts made broad connections to what they know about actors and playground use. As an example, Eldon (E3) stated, "Picnic tables will be handicap-accessible meaning that the table-tops will extend farther than the benches to allow

a wheelchair to be pushed up underneath". This passage was coded with *actors*, in reference to handicap users, and *use* for how the wheelchair would fit. The following excerpt illustrates how the playground expert Phil (P1) considered actors, use, and social context in a broader frame.

ADMINISTRATOR: Let me see if I have anything that addresses that. What do you mean when you say "access"?

Phil (P1): In other words, if this was a Jewish community center it would be very different from a local neighborhood. [Phil is given an information slip by the experiment administrator.] It says a lot, but it doesn't really give me a sense of whether or not we can restrict access.

Phil (P1) addressed *actors* and *use* by using the example of the Jewish community center, wherein that particular social setting provided opportunities to regulate and restrict how actors use the playground for purposes of safety. In attempting to make this playground safe, Phil noted potential issues of social context that would change the way in which the playground could or could not be enclosed.

Paul (P4), the playground expert with the engineering background, also spent a minimal amount of time considering *actors*, *use*, and *social context* together. As described previously and as seen in Fig. 1, four of the five engineering experts considered people related codes less than the playground experts. Again, Elizabeth (E5), as the sole female participant, spoke about people more often than the other engineering experts.

C. Types of Knowledge Used

Personal knowledge stems from experiences within one's personal life and interests, whereas *professional knowledge* is gained from experiences in training, education, and professional practice. While this is exploratory work with a small sample, the findings of the types of knowledge used by the engineering experts and the playground experts displayed in Fig. 1 are notable. Specifically, the engineering experts appear to be looking to their own lives and personal background to make decisions about the playground design in lieu of professional knowledge within the domain of playground design. Elizabeth (E5) stated:

So one year olds need rather small equipment. They need some large motor activity, like climbing, sliding. So, let's say one to four year olds. They also seem to enjoy the sort of places where they can climb through things and play hide and seek. Bigger kids might enjoy, ah, like a jungle gym or some sort of climbing equipment, maybe digging equipment, um. I'm thinking about the places where my kids have had the most fun playing.

Elizabeth (E5) cemented her decision on equipment choice through personal knowledge she believed to be true. The playground experts, on the other hand, tended to make decisions based on their professional knowledge. Phil (P) stated:

Okay. Well, first I would question that the neighborhood does not have time or money to buy ready-made pieces of equipment, because my experience is that it actually takes considerably more time and money to construct a quality

piece of playground equipment than a manufactured one. It's the same thing as if you were to -- if I was to say the only chairs you can have in your house are from the local lumber yard. You could not possibly duplicate a chair reasonably.

Both participant groups accessed past experiences, while the playground experts were largely focused on professional domain knowledge, and the engineers utilized both personal knowledge and professional engineering knowledge. While our participant sample was chosen to contain domain experts, this finding portrays the use of the playground experts' domain knowledge. This leads us, again, to contemplate the relationship between these domain experiences and the prominence of social and people-oriented thinking that the playground experts displayed.

IV. DISCUSSION

It is an open question as to what the engineering experts would do if designing within their own domain. Presumably, an engineering expert put in their area of domain expertise would approach a given task differently. This research suggests, however, that domain experience allowed the playground experts stronger broad contextual thinking. Again, our findings state that the playground experts were inclined to consider context (especially socially oriented factors) more often, and to think about actors' and playground use in greater amounts and in a broader fashion. The playground experts also utilized more professional knowledge, whereas the engineering experts relied on professional engineering and personal knowledge to supplement the details given to them during the task. As was shown, the knowledge the engineering experts utilized did not seem to further their consideration of broader contextual issues. Not only did the use of professional knowledge showcase that the playground experts, were domain experts, but it points toward a discussion on how greater experience in one's profession may provide a stronger base for thinking about social contextual factors and the potential for making broader connections.

Bucciarelli described the engineering discipline as one that is object oriented and focused on concrete problem solving activities, making engineers unconcerned with issues outside their area of education [21]. He stated, "What engineers do, and are expected to do, includes much more than rational problem solving and constructing efficient means to reach desired, externally specified ends". Our research describes a similar story, where the engineering experts made use of the personal and professional knowledge they believed to be applicable to complete the task of designing a playground. The playground experts we studied also showcased the importance of experience and provided an example of designers who satisfied the requirements of the task, while also considering social context and connecting people oriented factors in their design processes.

We are drawn to participants Paul (P4), a playground expert, and Elizabeth (E5), an engineering expert. Paul was pursuing a degree in mechanical engineering and he was the participant who considered social context the least, along with lesser amounts of the codes *actors* and *use*. This potentially points towards an example of engineering processes overriding

domain experience. In contrast, Elizabeth considered *social context* in the greatest amount, with the highest numbers in *actors* and *use* of the engineering experts (Fig. 1). In other work, we have documented instances where female engineers were more likely than their male counterparts to consider context while solving a design problem, showcasing evidence that inclinations to think more broadly may be partially due to differences in life experiences [20].

Overall, the findings direct us to think about domain experience as a component of expertise that is helpful in approaching any given problem. Even more, it highlights how domain experience may allow individuals to be more comprehensive in utilizing contextual factors, supplying them with the mental tools to be flexible and broad thinking in their work [22, 23].

V. IMPLICATIONS

Reference [21] again pointed to the engineering discipline as one that focuses on working to complete the task at hand, but is less concerned with external forces that may alter their designs. "The way we structure our curriculum and teach our subjects all conspire to instill in the student the idea that engineering work is value-free" [21]. Such straightforward, linear thinking in design processes may be detrimental to broader thinking. Ball and Beaty [22] prescribed activities and experiences that allow individuals different modes of exploration resulting in expanded and more creative outcomes. Others also argue for more experiences within engineering education for students to more quickly learn the industry standards as the base that will allow them to think more broadly and creatively [24].

This study seems to indicate that it is incumbent upon engineering educators to ensure that the professional knowledge that is the content of our educational programs incorporates contextual issues, so that it becomes embedded as a professional - not just a personal - concern in engineering praxis.

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A Comparison of Electrical, Computer, and Chemical Engineering Faculty's Progressions through the Innovation-Decision Process

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Abstract— Research in Engineering Education has led to the development and dissemination of a number of different instructional strategies (such as active learning, problem based learning, and concept tests) contributing to greater student learning in the classroom. However, there is little research to demonstrate how Research Based Instructional Strategies (RBIS) are being propagated from the developers to engineering faculty for use in the classroom. To examine the process of dissemination, this study uses Rogers' Diffusion of Innovation framework, which has traditionally been used to examine the dissemination of technological innovations through a population or organization. Rogers discusses five stages (knowledge, persuasion, decision, implementation, and confirmation) of the innovation-decision process to explain how adopters make a decision about an innovation. To investigate faculty members' participation in the innovation-decision process, we conducted a survey of electrical, computer, and chemical engineering faculty ($n = 221$) teaching engineering sciences courses. The results show that ECE and ChE faculty members are located at a variety of stages throughout the innovation-decision process. However, most respondents have progressed past the knowledge phase; they are aware of the different RBIS. It is important to account for this when presenting an innovation or trying to encourage adoption of new practices, such as RBIS. It was found that workshops and presentations can influence the trial and use of RBIS when faculty are at the persuasion and decision stages. Also, women are more likely to try and use an RBIS than men. Many of the results found here are consistent with those found in a similar study done in physics education.

Keywords - *Diffusion of Innovation; Engineering Sciences; innovation-decision process*

I. INTRODUCTION

Over the past 20 years tremendous effort and funding have been invested in improving engineering education, producing a number of Research-Based Instructional Strategies (RBIS) such as active learning [1], cooperative learning [1], and problem-based learning [2]. These RBIS can be seen as innovations that have been developed for implementation in the classroom. There has also been increased focus in recent years on ensuring that engineering education research is incorporated into teaching practice. However, little work has been done to examine how this is occurring or ways to help facilitate the process.

This paper investigates the intersection of these two efforts by asking how RBIS are transitioning from engineering education research to the engineering classroom. To do this, Rogers' Diffusion of Innovation framework [3] was used, specifically his discussion on the innovation-decision process which demonstrates how adopters (in this case, faculty members) make decisions about using an innovation (in this case, a RBIS). Specifically, this study seeks to answer the following research questions

- 1) At what points/stages do electrical, computer, and chemical engineering faculty members leave the innovation-decision process?
- 2) What faculty member characteristics, if any, correlate with being at the different stages of the innovation-decision process?

Engineering education is not the first field to investigate these questions. A similar study was completed by Henderson et al. in physics education [4]; adding the additional research question:

- 3) How do the results of this study compare to a similar study in physics education?

II. LITERATURE REVIEW

A. Diffusion of Innovation

To answer these research questions, we used Diffusion of Innovation (DOI). DOI describes the innovation-decision process in five stages:

- 1) Knowledge - the potential adopter gathers knowledge of the innovation's existence
- 2) Persuasion – the potential adopter develops an opinion about the innovation.
- 3) Decision - the potential adopter makes a decision about whether or not to implement the innovation.
- 4) Implementation – the potential adopter actually implements the innovation
- 5) Confirmation - when the adopter decides whether or not to continue using the innovation [3].

Within this research, the potential adopters are the engineering faculty members teaching the courses, and the RBIS will be viewed as innovations to the traditional lecture-based classroom.

Depending on where potential adopters are in the innovation-decision process, there are different ways to aid them in making adoption decisions. For example, if a faculty member is unfamiliar with an RBIS, providing him or her with more general information about the RBIS is important. On the other hand, a faculty member who is beginning to implement the RBIS in the classroom may need more detailed information about logistics. This is important to keep in mind when introducing an innovation to different audiences.

There have been multiple studies within educational contexts that have used elements of the DOI framework. Pundak and Rozner used the DOI stages in an attempt to encourage college staff to adopt active learning [5]. Tabata and Johnsrud focused on the characteristics of the innovation and the impact on adoption [6]. Borrego, Froyd and Hall investigated the adoption status of RBIS in engineering departments across the country by surveying department heads and mapping with the DOI framework [7]. Henderson and Dancy used the DOI stages to see where faculty left the innovation-decision process when adapting research-based instructional strategies (RBIS) in the introductory physics classroom [4].

III. METHODS

In spring 2011, we surveyed electrical, computer, and chemical engineering faculty teaching engineering sciences courses (thermodynamics, fluid mechanics, heat transfer, circuits, electronics, or introduction to digital logic and/or digital design) at their university. ECE and ChE ABET accredited departments were contacted to identify the faculty members teaching the desired courses.

An individual invitation was then e-mailed to each participant. Each person received up to three weekly reminders (if the survey had not been completed). To increase the response rate, the e-mail was endorsed and signed by a member of the survey committee of AIChE or the President of IEEE Education Society. Gift cards were offered as raffle incentives to those who completed the survey. The survey was sent to 1425 faculty members. A total of 241 responses were obtained; of those, 30 had not taught the courses of interest in the last 5 years, resulting in 211 usable responses. Four additional responses were removed because they did not respond to a majority of the questions, resulting in an n of 207. The overall response rate was calculated at 17%.

To understand potential response bias, a second round of data collection was conducted in fall 2011. This resulted in an additional 13 usable responses. Statistical comparison using Fisher's exact test revealed no significant differences between the two data sets for the variables reported here, so they were combined, increasing the response rate to 19%.

Of the 221 who completed the survey, 18% were female and 81% male (3 did not respond); 17 (7.7%) were lecturers (i.e., not tenure track), 63 (29%) assistant professors, 62 (28%) associate professors, 72 (33%) full professors, and 6 (2.7%) who listed their position as other (3 did not respond).

To analyze the data, each respondent was associated with one of four categories representing Rogers' stages in the innovation-decision process. Each faculty member was asked his/her level of awareness of 12 RBIS (Table I; for descriptions of the RBIS and references see [8]) ranging from "I currently use" to "I have not heard of it". Based on his/her response to these questions, each faculty member was assigned to a stage in the process; see Table II. This is similar to the analysis conducted by Henderson et al. [4]. For a respondent to have "no knowledge," he/she would have responded "I have heard the name, but know little else about it" or "I have never heard of it" for more than 10 (out of 12) RBIS. For a faculty member to be classified as "had not tried," he/she would have responded "I am familiar with it, but have never used it" or the responses listed above for more than 10 RBIS. The faculty member was classified as a "user" if he/she responded "I currently use" or "I have used it in the past" for more than 5 RBIS. To investigate the difference between those who use multiple RBIS, the faculty members were divided into a "high user" group (responded "I currently use" for more than 5 RBIS) or a "low user" group (responds "I currently use for less than 5).

The final stage, confirmation, represents the decision to continue use, which was not included in this analysis. Once a faculty member had been placed in one category, he/she was not considered for the subsequent categories, so if a faculty member is classified as “had no knowledge,” he/she was not considered for the remaining categories.

TABLE I. RBIS INVESTIGATED IN THIS STUDY. (SEE [8] FOR DESCRIPTIONS AND ADDITIONAL REFERENCES)

| <i>RBIS</i> |
|---------------------------------------|
| Active Learning |
| Case-Based Teaching |
| Collaborative Learning |
| Concept Tests |
| Cooperative Learning |
| Inquiry Learning |
| Just-In-Time Teaching |
| Peer Instruction |
| Problem-Based Learning |
| Service Learning |
| Thinking Aloud-Paired Problem Solving |
| Think-Pair-Share |

TABLE II. STAGES OF INNOVATION-DECISION PROCESS COMPARED TO STUDY VARIABLE

| <i>DOI Stage</i> | <i>Study Variable</i> |
|--------------------------|---------------------------------------|
| Not Entered I-D process | Has no knowledge |
| Knowledge | Has knowledge, but hasn’t tried |
| Persuasion | Has tried, but is not currently using |
| Decision, Implementation | Is currently using |
| Confirmation | (Not measured here) |

To address research question 2, non-parametric analysis was completed to investigate the relationship between the different stages and demographic considerations (See Table III for list of demographics.).

Chi Square analysis or Fisher’s exact test were used, depending on the cell size. All comparisons were based on 2x2 matrices comparing faculty members who were categorized into a specific stage and compared to all others (2nd column) who were not categorized into that stage. The rows contained demographic data for comparison. In some cases, demographic data were combined to fit into the 2x2 matrix format. For example, job rank was collapsed from Lecturer, Assistant, Associate, and Full Professor to Tenured (Associate and Full) and Not Tenured (Lecturer

and Assistant). Significance was determined using an alpha of 0.05. All calculations were completed using SPSS statistical software.

TABLE III. DEMOGRAPHIC VARIABLES

| <i>Demographic Variables</i> |
|--|
| Teaching Responsibility |
| Frequency of teaching discussions with colleagues |
| Number of talks/workshops on teaching attended |
| National Effective Teaching Institute attendance |
| Other one day or longer teaching workshop attendance |
| Rank |
| Gender |
| Discipline |

IV. RESULTS

From the analysis, we found that a large majority of faculty members had moved past the knowledge stage in the innovation-decision process and were more likely to have tried or to be using some of the RBIS (Figure 1). There were a number of faculty members who tried a RBIS, but then discontinued use (n = 78; 35%), but also a significant number who are currently using more than 5 RBIS in their classroom (n=58; 26%). Figure 1 shows the number of faculty members that were identified at each stage of the innovation-decision process.

| | | | | |
|---------------|-----------|---------------------|-----------|-----------|
| Has Knowledge | Has Tried | Currently Using | High User | 58 (26%) |
| | | | Low User | 54 (24%) |
| | | Not Currently Using | 78 (35%) | |
| | | Not Tried | 24 (11%) | |
| No Knowledge | 7 (3.2%) | | | |

Figure 1. Number of EE and ChE Faculty at each stage of the Innovation-Decision Process

There were very few significant differences with respect to demographics of faculty at different stages in the process. The differences can be seen in Table IV. It was found that faculty who were at the secondary persuasion phase (deciding whether or not to “try” the innovation in the classroom) and had not tried the RBIS, also had not attended very many talks about teaching. It was also found that women were more likely to try the different RBIS than men. At the next stage, where implementation has occurred and the faculty are currently using the RBIS, it was found that attending none or a few talks about teaching resulted in even use or non-use whereas attending many talks about teaching

resulted in higher use compared to non-use. Also, attending

the National Effective Teaching Institute increases the

TABLE IV. SIGNIFICANT DEMOGRAPHIC INFLUENCES ON STAGES OF INNOVATION-DECISION PROCESS

| Stage | Demographic | | p-value | Consistent with Physics Study? |
|------------------------|---|---|---------|--------------------------------|
| Tried vs. Not Tried | Number of presentations about teaching attended | 100% who attended more than 4 presentations have tried 3 or more RBIS; 86% who attended 3 or less have tried 3 or more RBIS | 0.003 | Yes |
| Tried vs. Not Tried | Gender | 100% of women have tried 3 or more RBIS; 86% of men have tried 3 or more RBIS | 0.010 | No |
| Current vs Former User | Number of presentations about teaching attended | 72% who attend more than 4 presentations also use an RBIS; 55% who attend 3 or less also use an RBIS | 0.031 | Yes |
| Current vs Former User | Attended National Effective Teaching Institute | 87% of NETI attendees use an RBIS; 57% of non-attendees use an RBIS | 0.028 | Yes |
| Current vs Former User | Attended another one day or longer workshop | 73% of workshop attendees use an RBIS; 45% of non-attendees use an RBIS | <0.001 | (Not measured) |
| Current vs Former User | Gender | 73% of women use an RBIS; 55% of men use an RBIS | 0.047 | Yes |

likelihood of using an RBIS as does attending a different 1-day or longer workshop. Also, a higher percentage of females indicated using an RBIS than males.

When comparing with the physics study, a number of results were consistent. Both studies found that attending teaching presentations at the trial and use stages (persuasion, decision, and implementation) showed an increased likelihood of trying or using an RBIS. Attending a new faculty workshop and being female correlated with using an RBIS in both studies. However, in the physics study, gender was also found to be correlated at the level of use (high or low user) and not related to trying an RBIS, as it is here.

V. DISCUSSION

These results help communicate to the Engineering Education research community how Research-Based Instructional Strategies are being disseminated into the engineering classroom and considerations for how to expedite the process. In addressing research question 1, it was found that engineering faculty members are located at every step in the innovation-decision process. Most engineering education dissemination work focuses on raising awareness of RBIS, but few faculty lacked this knowledge. Researchers and developers need to ensure that they are communicating to faculty at all levels of the innovation-decision process, for example, by emphasizing more details about implementation.

Rogers discusses the impact of different communication channels on the different stages of adoption. The conclusions drawn by Rogers are supported by the results found in Stirman [9]. Mass media channels, such as conference papers and journal articles, are more appropriate for generating initial levels of knowledge. [3]. At later stages of the process, more interpersonal communication (face-to-face exchanges) is needed [3]. This can be seen through our results in which workshops and presentations were more influential in the later stages. More efforts should be directed at the later stages, in addition to raising

awareness. The implications for this are that as a change agent or an innovation developer, it is important to account for an audience that is at different stages in the innovation-decision process.

By investigating research question 2, it was found that a number of different variables correlated to the different stages of the process. For example, ensuring that faculty members have access to workshops, such as NETI, or on-campus presentations may help faculty try an innovation, but attention also needs to be placed on helping them to continue their use of RBIS. There were a number of faculty members who had tried a RBIS, but had since discontinued their use; this is also consistent with the results found in physics education [4]. Developers should ensure that faculty have resources to help them while trying an RBIS, such as an outlet to talk to others experienced with the RBIS or access to documentation of how other faculty address frequently experienced problems.

It was also found when investigating research question 3 that there is considerable consistency between the engineering results presented here and the physics results presented by Henderson and Dancy [4]. The commonalities between the engineering and physics results aids in triangulating these results and helps show the generalizability of the RBIS to different contexts across STEM education.

VI. LIMITATIONS AND FUTURE WORK

It is suspected that due to the low response rate, even after late respondents were contacted, there is a degree of response bias. To better understand the differences, qualitative methods will be used to interview a selection of ECE and ChE faculty members teaching the courses of interest.

It is also suspected that due to the self-reported nature of the survey, faculty may have over-reported their use of RBIS or reported using an RBIS which is not supported by the activities completed in their classroom, as was found by

Henderson and Dancy [10]. Thus, these results are more useful for comparisons between and among the various stages than as absolute percentages representative of the larger engineering education community.

Future work will investigate the consistency between the reported use of RBIS and what is occurring in the classroom by investigating the percentage of class time spent on the activities associated with the different RBIS. The study will also be expanded to incorporate the engineering sciences course of statics.

VII. CONCLUSION

In conclusion, electrical, computer and chemical engineering faculty members teaching engineering sciences courses are at different stages in the innovation-decision process. However, most have progressed past the knowledge phase and are aware of various RBIS. It is important to account for this when presenting an innovation or trying to encourage adoption of new classroom practices. More information needs to be readily available regarding implementation and overcoming challenges.

It was found that workshops and presentations may influence the trial and use of RBIS when faculty are at the persuasion and decision stages and that resources should be proved to help faculty to attend such presentations or workshops. Also, women are more likely to try and use RBIS than men. Many of the results found here are consistent with those found in physics education research, which is another means of triangulating our results.

Additional work is needed to investigate the impact of the potential response bias and the accuracy of self-reported use of RBIS.

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Examining the Effect of Design Education on the Design Cognition: Measurements from Protocol Studies

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Abstract – This paper reports the progress of a three-year longitudinal study on the impact of design education on students' design thinking and practice. Students from two curricula at a large research-intensive state university are being studied. The control group is a major focused on engineering mechanics, which has little formal design education prior to the capstone experience. The experimental group is a mechanical engineering major that uses design as a context for its curriculum. A task-independent protocol analysis method grounded in the Function-Behavior-Structure (FBS) design ontology is utilized to provide a common basis for comparing students across projects and years. This paper presents results of two years of the study, which included students at the beginning and the end of their sophomore year, and at the end of their junior year. The results of analyzing and comparing the percent occurrences of design issues and problem-solution index from the protocol analysis of both cohorts are presented. These results provide an opportunity to investigate and understand how students' design cognition is affected by a design course.

Index Terms – Design cognition, verbal protocol studies, design education

BACKGROUND

How does design education affect design cognition? To answer this fundamental question, the authors are embarking on a longitudinal study of two groups of students as they progress through their undergraduate curricula. The students of the experimental group are enrolled in a mechanical engineering curriculum that contains several design courses throughout the 4-year curriculum. The students in the control group are enrolled in an engineering mechanics curriculum, which has a core focus on engineering science and theory.

To analyze effects of design education on students' design cognition, the authors compare the results of think-aloud protocol analysis of students' participation in controlled design experiments across several years. The use of verbal protocol analysis to study design behaviors is

primarily found in prior work from the Center for Engineering Learning and Teaching (CELT) at the University of Washington [1]. Atman and her colleagues at CELT used a coding scheme derived from representations of the design process in engineering texts [2]. With this methodology, CELT researchers have examined differences across experience levels (freshmen, seniors, experts) [3-5], the influence of reflection [6], team self-evaluations versus observed performance [7], and the ability to effectively contextualize design problems [8-10]. However, further research is needed to explore potential differences across engineering curricula and students' experiences throughout.

To fill this research gap, the authors in this study use the Function-Behavior-Structure (FBS) ontology as a principled coding scheme to determine design cognition [11], [12]. This coding scheme is applicable across all process-based views of designing and therefore produces results from different sessions by different designers using different design methods in such a way that the results are comparable and commensurable. In their previous work, the authors have explored the effect of a sophomore design class on the experimental group [13, 14] and a comparison of the two groups in their sophomore year [15]. In this work, the authors present a comparison of the two groups in their sophomore and junior years.

ANALYZING DESIGN COGNITION: THE FBS ONTOLOGY

I. FBS Ontology

The FBS ontology models the design process based on three classes of ontological variables: function, behavior, and structure, plus a design description [11]. It posits that the purpose of design "is to transform a set of functions into a set of design descriptions (D). The *function* (F) of a designed object is defined as its teleology; the *behavior* (B) of that object is either derived from the structure (Bs) or expected (Be) from the structure, where *structure* (S) represents the components of an object and their relationships." In addition, R is used to designate external requirements given to the designers (Figure 1).

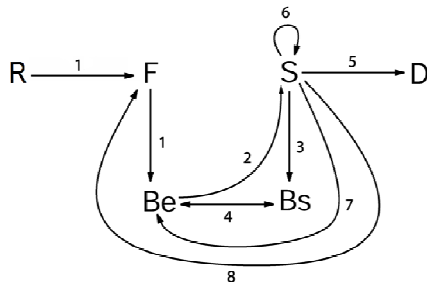


FIGURE 1
THE FBS ONTOLOGY

These ontological variables, in turn, help define a set of processes that reflect the transformations from one variable to another. In this case, the FBS ontology identifies eight separate processes. These design processes, denoted numerically in Figure 1, include 1) *formulation* which transforms requirements and functions into a set of expected behaviors; 2) *synthesis*, where a structure is proposed to fulfill the expected behaviors; 3) an *analysis* of the structure produces derived behavior; 4) an *evaluation* process acts between the expected behavior and the behavior derived from structure; and 5) *documentation*, which produces the design description. The remaining processes are types of reformulation: 6) *reformulation I* – reformulation of structure, 7) *reformulation II* – reformulation of expected behavior, and 8) *reformulation III* – reformulation of function.

II. FBS Coding Scheme

In this project we use a principled, design-based coding scheme based on the FBS ontology that translates the ontology into six design issues that map onto the ontological variables. Each design issue is coded using the FBS ontology. The six codes for the six cognitive design issues, which are used to label segments in protocol analysis, can be combined to produce eight design processes, as seen in Table 1, where “>” indicates unidirectional transformation and “<” indicates comparison. The numbers listed next to each design issue corresponds with the labels presented in Figure 1.

TABLE 1
FBS PROCESSES

| | |
|-----------------------|-----------------|
| Formulation (1) | $R > F, F > Be$ |
| Synthesis (2) | $Be > S$ |
| Analysis (3) | $S > Bs$ |
| Evaluation (4) | $Be < Bs$ |
| Documentation (5) | $S > D$ |
| Reformulation I (6) | $S > S$ |
| Reformulation II (7) | $S > Be$ |
| Reformulation III (8) | $S > F$ |

METHODS

I. Participants

Participants were recruited from mechanical engineering (ME) and engineering mechanics (EM) departments at a

large mid-Atlantic land grant university. The EM majors are considered the control group in this research, as the EM curriculum has a theoretical orientation that focuses on mathematical modeling based on first principles but has little formal design education. The ME curriculum, and its focus in design, is the experimental group. Student participation is provided by major in Table 2.

TABLE 2
PARTICIPATION IN EACH SEMESTER BY MAJORS

| | Semester 1 ($n=20$) | Semester 2 ($n=16$) | Semester 3 ($n=14$) |
|----|--------------------------|--------------------------|--------------------------|
| ME | 17 | 13 | 11 |
| EM | 3 | 3 | 3 |

The participants are a representative sample of their peer group, as determined by a series of spatial reasoning ability [16]. Students with significant design experience, as identified through a preliminary interview, were not selected as participants for this study. Those who agreed to participate in the study were compensated with a gift card to an online retailer.

Both groups had a brief first-year design experience that emphasized the engineering design process. At the time of the first data collection, the first semester of the sophomore year, the primary difference between the EM and ME students’ coursework was a focus in design. During the sophomore year, the EM students had no specific course related to design, but the ME students had a course that exposes students to engineering design methodologies. This 3-credit design course provides students with several hands-on team-based activities, which include a semester design project, product dissections, and designing products for various speculative scenarios. Further, the ME students were enrolled in a hands-on laboratory course focused on manufacturing processes (welding, machining, casting, etc.).

At the time of second and third data collection, in the second semester of participants’ sophomore and junior years, neither group was enrolled in design-related courses. Both sets of students were involved in engineering science courses (e.g., dynamics, mechanics of materials). In this regard, the two curricula are very similar aside from a handful of courses from their respective major’s core technical areas.

II. Experimental Design

Participants attended three out-of-class experiments: at midway through the fall semester (Semester 1), just after spring break (roughly mid-semester) in the spring semester (Semester 2) of their sophomore year, and late March or early April in their junior year (Semester 3). In these experiments, pairs of students worked together at a whiteboard to solve a speculative design task. In the first session, students were asked to design a device to help disabled users open a stuck double-hung window without relying on electric power. In the second session, students were asked to design a device to help stroke patients who are unable to perform bilateral tasks with opening doors

(adapted from [17]). In the third session, students were asked to design an add-on device to a hand/arm-powered wheelchair, so that paraplegic users can easily traverse over a standard roadside curb.

Student pairs worked together on the assigned design tasks for 45 minutes. Working in pairs provided for natural verbalization that was audio and video recorded, transcribed, and analyzed.

III. Protocol Analysis

A protocol analysis was conducted using the video and audio recordings of the design sessions. The research team manually transcribed all the students' verbalizations as they proceed through the design sessions. The verbalizations were then segmented and coded based on the FBS coding scheme. Two researcher assistants independently identified and coded the segments and arbitrated differences to determine the final design protocol for each session. Typical inter-coder reliability obtained by this method is in the range 85–95%. Agreement between coders is obtained using the Delphi method [18].

RESULTS

I. Design Issues Sliding Window Results

A sliding window technique was used in order to calculate moving average results, which provide a description of the dynamic behaviors across design sessions. The number of data points that will be produced from each sliding window needs to be the same for each protocol to allow for direct comparisons. In this study, 150 data points were computed from each protocol. Throughout the window movement, an independent calculation of the averages of the design issues in that window is carried out at each window position. By putting the calculated results together, a dynamic model is produced, which shows the changing values of the design issues in the course of a design session.

Figures 2 and 3 show the design issue distribution sliding window results by majors. The x-axis represents 150 segments from the design protocol and the y-axis represents the amount of cognitive effort expended in percentage. For each sliding window result, a linear regression was computed using a statistical software JMP 9.0 to calculate the goodness of fit (R^2) and the slopes (β).

For the design issue of requirement, ME students spent more cognitive efforts in semester 1, followed by semesters 2 and 3. Slight negative trends of slopes ($\beta < 0$) were identified for all semesters. For the design issue of function,

students spent significantly more cognitive effort in semester 2 than in semesters 1 and 3. Similar to the design issue of requirement, the slopes showed a slight negative trend for all semesters. These results indicate that students generally discuss design functions and requirements more in the beginning and less towards the end of the design session.

For the design issue of expected behavior, a significant difference of cognitive efforts was identified across semesters. Specifically, students expended more cognitive efforts in semester 3 followed by semesters 1 and 2. A slight negative trend was identified for semesters 2 and 3, while a slight positive trend was observed in the 1st semester.

For the design issue of structure, a noticeable difference was identified among semesters. Students spent more cognitive effort associated with structure in semester 1, followed by semesters 2 and 3. The slopes for each semester showed a slight negative trend except in semester 3.

Students expended more cognitive effort of behavior from structure as they progressed through the design session in semester 3. The change of cognitive effort was less noticeable in semesters 1 and 2. The slopes for semesters 1 and 3 showed a positive trend, while a slight negative pattern was identified in semester 2.

For the design issue of description, students spent more cognitive effort in semester 2, followed by semesters 3 and 1. While the amount of cognitive effort slightly increased towards the end of the design session in semesters 1 and 2, the amount of change in students' cognitive efforts in semester 3 was negligible.

Figure 3 illustrates the sliding window results for EM and mixed majors. In general, the amount of cognitive efforts varied more across semesters when compared to those of their ME counterparts. The changes in slopes (β) were also greater when compared to those of ME majors. This result can mostly be accounted by the change of slopes in semester 2.

For the design issue of requirement, a similar negative trend was observed for all semesters. Specifically, students expended significantly more cognitive efforts in the beginning of semester 2, followed by semesters 1 and 3. For the design issue of function, the difference of the amount of cognitive efforts among semesters were almost negligible among semesters and the slopes for each semester were all very close to zero. However, a slight increase of students' cognitive effort was identified in the middle of design sessions in semester 2.

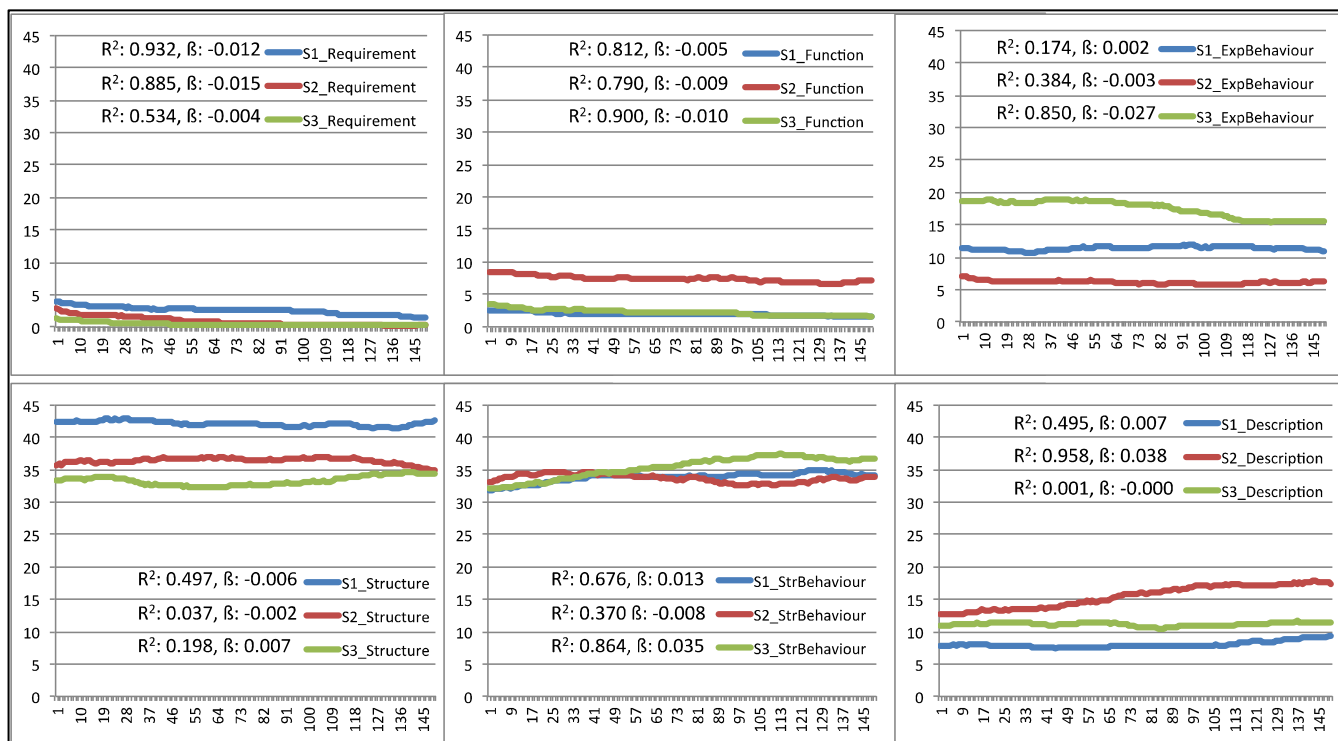


FIGURE 2.
ISSUE DISTRIBUTION SLIDING WINDOW RESULTS—ME MAJORS

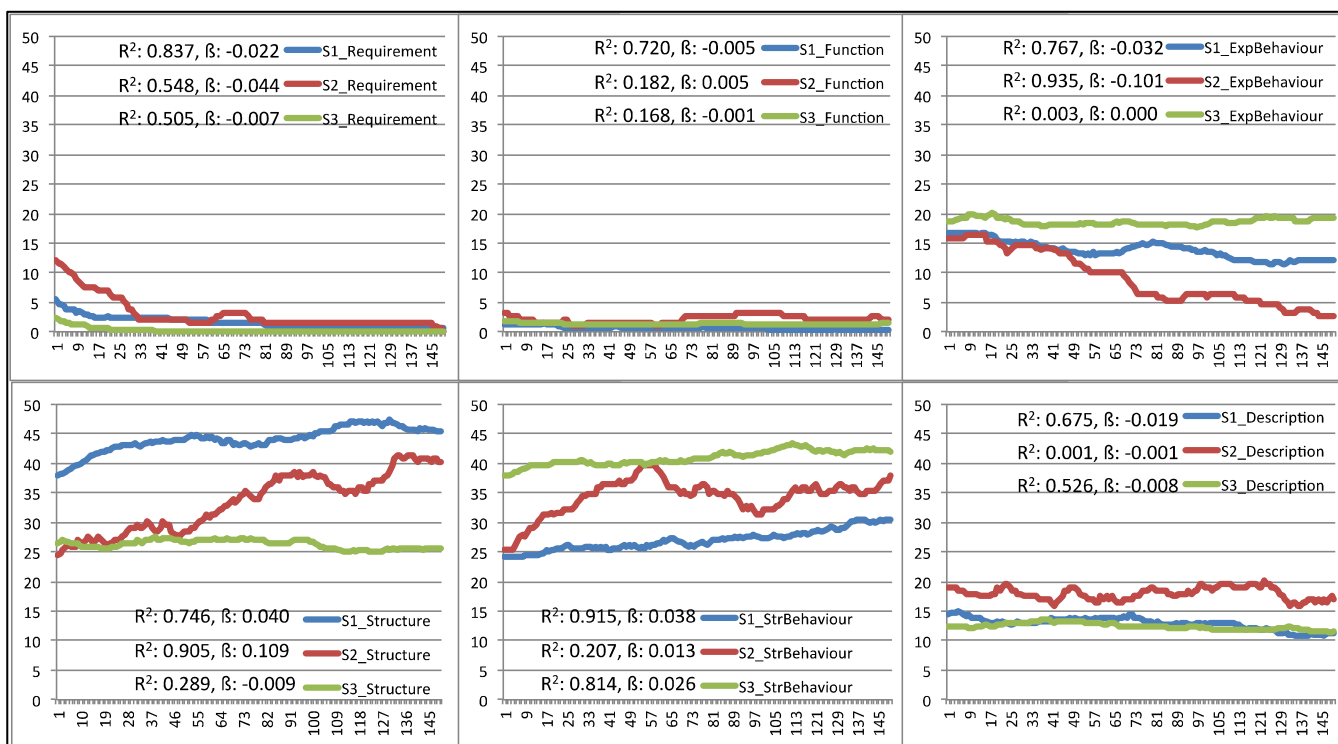


FIGURE 3
ISSUE DISTRIBUTION SLIDING WINDOW RESULTS—EM & MIXED MAJORS

For the design issue of expected behavior, students spent more cognitive efforts in semester 3, followed by

semesters 1 and 2. The amount of cognitive effort remained almost equivalent throughout the design session

in semester 3, while a significant decline was observed in semesters 1 and 2.

For the design issue of structure, students spent more cognitive efforts in semester 1, followed by semesters 2 and 3. Interestingly, the amount of cognitive efforts in semesters 1 and 2 increased as students progressed through the design session, while a slight negative trend of cognitive effort was observed in semester 3.

For the design issue of behavior from structure, students expended more cognitive efforts in semester 3, followed by semesters 2 and 1. Although the slopes for all semesters showed a positive trend, semester 2 showed the most variation throughout the design session, and more similar pattern was identified for semesters 1 and 3.

For the design issue of description, students expended significantly more cognitive effort in semester 2, when compared to semesters 1 and 3. The slopes for all semesters showed a slight negative pattern.

II. Problem-Solution Index

One method to measure meta-level design behavior is to divide all cognitive effort into that focused on the problem or focused on the solution. The ratio of cognitive effort on the problem to cognitive effort on the solution is called the problem-solution index. When the cognitive effort relates to design issues it is called the problem-solution issues index. The method to calculate this index is given in Figure 4.

$$P-S \text{ Issue Index} = \frac{SUM (Requirement, Function, Expected Behavior)}{SUM (Structure, Behavior from Structure)}$$

FIGURE 4
P-S ISSUE INDEX EQUATION

The moving averages of the problem-solution issue index describes the dynamic meta-level behavior and is

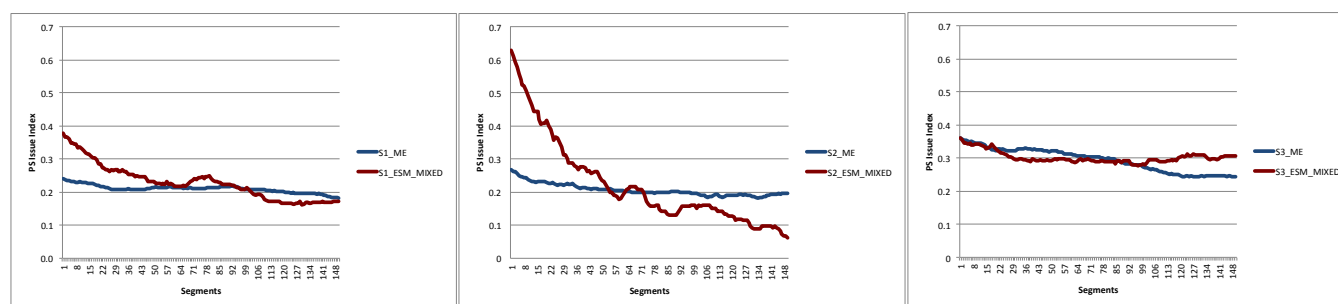


FIGURE 5
PROBLEM-SOLUTION ISSUE INDEX: SEMESTER COMPARISON BY MAJOR

Also of interest is that the control group spends very little time on discussing function. This does not change across the three semesters of experiments, which could relate directly to their curricula's lack of a design focus.

Looking at the two groups' P-S indices in semesters 1 and 2, the students of the control group spend more time

calculated in the same way as for design issues themselves. When graphed these provide the basis for observing the qualitative differences between semester and between majors.

Figure 5 shows the problem-solution issue index moving averages for each of the three semesters by major. Two qualitative differences can be observed. First the behavior of ME and EM students differ markedly in their first two semesters and converge in their third semester of this study. ME students commence with a P-S issue index value that declined only slightly in their first two semesters and dropped noticeably in their third semester. The behavior of CM students was the reverse of this. Second the P-S issue index of ME increases in their third semester.

DISCUSSION

Due to the lower number of participants in the control group, it is not feasible to quantify differences between the teams using descriptive statistics. However, qualitative observations can be made by comparing the two student groups' design issues and P-S indices. From these observations, we can note that there are differences between the two groups' behaviors.

Regarding design issues, it is interesting to note how the design cognition of the experimental group changes according to their involvement in design-related courses. For example, there is a large positive increase in the amount of time spent on function related issues from Semester 2 from Semester 1; however, the time reduces in Semester 3. The increase corresponds to the students' time in a design course focused in problem scoping and definition.

focused in problem definition than those in the experimental group (as seen by the higher P-S value). This is slightly surprising, given that the experimental group has received distinct instruction on the importance of, and strategies for, problem scoping.

While the control groups' P-S value changes sporadically across the three experiments, the experimental groups' P-S value regularly increases. As higher P-S values correlate to more expert-like design behavior, this is a positive progression for the experimental group. This progression is also evident in comparing the slopes of the experimental groups' sessions in semesters 1 and 3. A P-S slope indicates the rate of change of focus, and should be negative as the problem solving process progresses. The experimental groups' P-S slope is more negative during each semester.

In future work, the authors will close their longitudinal study by capturing the data following the students' senior years. This dataset will offer valuable insight as both groups will have concluded their capstone design courses and projects. We look forward to exploring how these formative experiences (and the two majors' varying interpretations) affect student behavior.

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GLOBAL ENGINEERING: CYBER SECURITY, BRICS, AND CULTURE

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Abstract—This paper discusses our approach to a global engineering course at Bucknell University in the Spring semester of 2010-2011. The format or course-plan for the course is presented, along with suggested improvements for an expanded version covering two semesters. The course takes a multidisciplinary approach, drawing on the resources of several academic departments at Bucknell University, and presents its content in a series of stand-alone sessions or modules. These sessions were not necessarily connected to each other regarding content; instead, they were meant to provide knowledge outside of engineering which the global engineer of the 21st century needs to be aware of, but would not normally encounter in the usual course of the engineering curriculum.

Keywords—Global Engineering; Cyber Security; BRICS.

I. INTRODUCTION

A. The Need to take a Broader View

The engineer of the future will need to have the ability to navigate a multinational environment and collaborate with people with different cultures and background. Information and transportation networks, trade and economic alliances, international business and labor mobility, and humanitarian and environmental concerns have linked the world together. Engineers will need more than just core engineering skills and knowledge in order to succeed. The global nature of collaboration and work means that engineers have to interact with colleagues hailing from unfamiliar cultures and backgrounds who have different styles of working, different expectations of the work-place, and different views on how things should be done. In other words, the engineering graduate of the 21st century is likely to be faced with a number of unfamiliar situations, or with some amount of uncertainty unrelated to the technical aspects of his or her job, but stemming from the global dimension of engineering work.

To be properly prepared to work and compete globally, engineers will need to draw on knowledge from a variety of academic areas in addition to their core specialty. Taking a cue from the “Triple Bottom Line” concept in business, which measures organizational performance in terms of “People, Planet, and Profit” [1], and modifying that idea for the

purposes of this course, engineers will need a better understanding of the following.

- **People:** In order to coexist and collaborate with people from different countries and backgrounds, both inside and outside of the work-place, engineers will need to recognize similarities and differences in people, realize there may be multiple valid perspectives and approaches to problems, be able to both teach and learn cultural norms, and understand that positive contributions can come from differing points of view.
- **Planet:** Engineers will need an awareness of the social and environmental impacts attendant to work and business, in addition to the importance of both community satisfaction and approval of the solutions involving finite natural resources. Responsible action demands acknowledging these concerns in decision making.
- **Profit:** In addition to engineering expertise and experience, a basic understanding of business, management, and economics is crucial to success. Since work happens in the context of a business, this is meant to help engineers navigate their work-place better, and to develop a more thorough understanding of their business environment and the macro-level factors which impact it.

Together with their core engineering specialty, the expanded knowledge base will increase engineers’ awareness of global and cultural differences, making them more readily adaptable to their environment, and will give them greater confidence in tackling new challenges. In short, it will properly equip them to ride the waves of globalization.

B. Global Engineering Education at Other Institutions

The importance of a global dimension to engineering education has been emphasized repeatedly in the related literature; what that global dimension should actually consist of and how to implement it in the engineering curriculum have also been debated. Generally, global engineering programs

will consist of foreign-language study along with the engineering major, and will involve a study-abroad with an internship-abroad component [2]. For instance, the well-known global engineering program at the University of Rhode Island [the International Engineering Program or IEP] follows a 5-year dual-degree format, where students earn Bachelor's degrees in both engineering and in a foreign language[2]. Students study abroad and complete an internship abroad for their fourth year. Another example is Purdue University's Global Engineering Alliance for Research and Education (GEARE) program which follows a student exchange format and involves foreign language study, internships in both domestic and overseas locations for the same company, and a study-abroad component during which students begin an engineering design project at the overseas university [3].

While larger universities may possess the necessary resources to successfully run dedicated global engineering education programs, for smaller institutions, a separate program may not be feasible. Given size and resource constraints, the presentation of the global dimensions of engineering is a bigger challenge.

II. BUCKNELL UNIVERSITY AND GLOBAL EDUCATION

Bucknell University is primarily an undergraduate institution. Although a liberal arts university, Bucknell has a College of Engineering and is noted for the strength of its engineering programs. Approximately 3,500 undergraduate students attend Bucknell [4], and roughly 600 of those students choose to major in Engineering [5]. Our students have a number of opportunities for international exposure such as:

- **Bucknell-in Programs:** These offer Bucknell students the opportunity to spend a semester or an entire year abroad in Spain, France, or England, taking courses in the overseas location [6].
- **Bucknell Approved Programs:** A semester or full academic year study-abroad programs offered by non-Bucknell institutions in various locations around the world [7].
- **Engineering 290 (ENGR 290) – Engineering in a Global/Societal Context:** ENGR 290 is a summer program, three weeks in length, during which selected engineering students travel abroad and visit industrial sites, office locations, educational institutions, and other points of interest in the foreign country, while gaining exposure to the local culture. Previous trips have included locations in England, Brazil, Sweden, and Norway, and a trip to China is scheduled for the summer of 2012 [8].

In the classroom, Bucknell offers an elective course titled “The Global Engineer”, designated ENGR 291; the course is for a quarter-credit, meets once a week for two hours, and is taught in both the fall and spring semesters. Students will typically take the course multiple times (four times) to accumulate one course credit, which can then be used to fulfill Bucknell University's global and societal perspectives requirement for graduation. ENGR 291 has usually been taught with an engineering-related topic or theme in mind; previous themes for the course have included: Infrastructure and the

Global Economy (Fall 2009-2010), The Global Engineer and the Green Economy (Spring 2009-2010), and The Economics and Ethics of Global Energy Production (Fall 2010-2011).

III. OUR APPROACH TO ENGR 291: THE GLOBAL ENGINEER

We started with the assumption that students receive sufficient instruction in engineering from their engineering courses, and therefore, ENGR 291: The Global Engineer would focus on the “global” aspect of the curriculum. We focused on providing students with exposure to topics that would facilitate an understanding of peoples, cultures and the business environment and less on engineering content. A similar approach to global engineering education is taken by Lehigh University as part of their Global Citizenship Program (GCP) [9].

Since Bucknell does not have a separate global engineering program, it was a real challenge to fit all the desired material into one course. Therefore, courses which are commonly included in a global engineering program were compressed into eleven two-hour sessions, which comprised a single global engineering course. The remaining three sessions were devoted to an introduction to the course, an international dinner featuring food from the Brazil, Russia, India, and China (BRIC countries), and student presentations. Each session was designed to be a stand-alone module and was not necessarily connected to the others with regard to content; instead, each was intended to provide knowledge that the engineer needs to know. The aim was to introduce students to the topics, make them aware of the established tools and frameworks for specific interactions, and provide them with a starting point from which they can continue learning in the future.

The ENGR 291 course was divided into the following components:

- **A technical component relating to communications and security (3 sessions):** The first session focused on the use of wireless communication and information networks in China; the second session dealt with internet crime and cyber-attacks, and the third session covered computer and network security measures. Each of the three sessions was presented by a different guest speaker, from both on and off campus.
- **A country-specific component (4 sessions):** Each of the four sessions focused on one of the BRIC countries: Brazil, Russia, India and China. The term “BRIC” was coined by Jim O'Neill, an economist at Goldman Sachs, in a paper titled “Building Better Global Economic BRICs” in 2001 [10]. The paper postulated that the economies of the four BRIC countries would become a more significant part of the global economy, symbolizing the rising economic strength of the developing world, as opposed to the developed G7 countries (U.S.A., U.K., France, Germany, Italy, Japan, and Canada). Each of the country-sessions was led by a guest speaker from that respective country, who gave an overview of the country from a historical, political, economic, and cultural point of view, and also facilitated classroom discussion based on assigned readings for that particular class. All the readings were sourced from Harvard Business Publishing (<http://hbsp.harvard.edu/>). There were two readings for each country: “Brazil Under Lula:

Off the Yellow BRIC Road” and “Vale: Global Expansion in the Challenging World of Mining”; “Russia: Revolution and Reform” and “Gazprom (A): Energy and Strategy in Russian History”; “Leadership Lessons from India” and “Infosys: A Profile of One of India's Pioneering Multinationals”; “China: Building Capitalism with Socialist Characteristics” and “HNA Group: Moving China's Air Transport Industry in a New Direction”.

- A business and management component (2 sessions): The first session covered negotiation techniques, including Geert Hofstede's cultural dimensions - psychological dimensions, used to describe cultures. Professor Hofstede is a well-known social psychologist whose research delves into national cultures and their effects on organizations. Hofstede's cultural dimensions consist of: power-distance, individualism, masculinity, uncertainty avoidance, and long-term orientation [11]. The second session covered industry analysis using the research of Michael Porter, professor and leading authority on management strategy and competition. Specifically, we used his five forces framework (competition or rivalry within the industry, barriers to new entry, availability of substitutes, bargaining power of supplies and bargaining power of customers [12]), to examine industry attractiveness. In addition, we highlighted scenario planning, which is a strategic planning and forecasting method used by organizations to facilitate long-term decision making [13].

- A cross-cultural communications component (1 session): This session focused on how perceptions, decision-making, and approaches to problem-solving may differ from culture to culture, with China and Germany serving as examples. One of the guest speakers for this session was the International Student Services director at Bucknell University, who introduced the Intercultural Competence Model developed by Dr. Darla Deardorff, which provides a framework for interacting with other cultures successfully [14]. The other speaker for the session was from Exxon Mobil and had traveled abroad extensively on job assignments. He shared his experience in dealing with other cultures in the context of international business and how culture affects business communications. The reading assigned for this session was “Cultural Shock: Adjustment to New Cultural Environments” by Kalervo Oberg [15].

- An expatriate experiences component (1 session): This session discussed what qualities make for a successful expatriate. The guest speakers were two Bucknell professors who had lived and worked in Japan for a number of years. They recounted how they had gradually acclimated to a new country and shared their advice on living abroad. The assigned reading for this session was “Up or Out: Next Moves for the Modern Expatriate”, a report from the Economist Intelligence Unit about the state of expatriate assignments in the 21st century [16]. Given the fact that students may go abroad while at college or in the course of their professional careers, addressing the challenges of overseas assignments and the requirements for success are particularly important.

IV. IMPROVING ENGR 291

Building on the experience of our first ENGR 291 attempt, improvements are suggested for the content of the sessions, for the assigned readings, and for the course as a whole. Since ENGR 291 is a quarter-credit course and almost all students who take it will do so multiple times to earn one full credit hour, we believe enough material can be added to develop two courses to be offered in the fall and spring semesters. The technical component could be reduced or eliminated, since that material is covered in other courses. Following is a suggested plan for the two-part ENGR 291 course, with the contents of the sessions updated in order to improve upon our implementation.

A. For the fall semester (part 1 of the course)

- Drivers of Globalization (1 session): Globalization is a fact of the modern world and the better understanding students have of its origins and its impact, the better they will be able to compete in their professional careers and to successfully negotiate their own futures. A number of formative world events occurred in the closing decades of the 20th century, which helped bring about globalization [17], and because everything cannot be covered, we have chosen to highlight events of the 1980's and 1990's, including:

- Technological events: Advances in microprocessor capabilities leading to the rise of personal computers and mobile computing devices; the rise of fiber-optic communication systems to enable large volumes of information flow across the globe, and the rise of the World Wide Web [17].

- Financial events: The deregulation and liberalization of international financial markets, and the emergence of private international banking and credit services, which made global capital transfer easier and quicker, and powered the growth of international business [18].

- Political and Economic events: The dissolution of the Soviet Union in 1991; the disintegration of Yugoslavia in 1991 – 1992; the reunification of Germany in 1990; the end of apartheid in South Africa in 1994; the emergence of China as a superpower due to economic reforms in the 1980's and 1990's; the economic liberalization of India in 1991; the establishment of the European Union in 1993; and the establishment of the World Trade Organization in 1995 to promote more liberal international trade policies.

- Environmental events: International environmental treaties such as the Montreal Protocol of 1987 aimed at addressing the depletion of the ozone layer and the Kyoto Protocol of 1997 aimed at mitigating global warming.

It is important to emphasize to students that while “globalization” has received a lot of press of late, the phenomena is not new: different peoples and different cultures have been interacting with each other for purposes such as trade, exploration, or conquest for hundreds of years.

- **Macroeconomic Principles (1 session):** Engineering students may have gleaned a cursory exposure to certain topics in macroeconomics through news media, but do not have a working knowledge of the concepts. To provide them with the necessary background in this area, we give them a primer on measures of national income and output, unemployment, inflation, and instruments of monetary and fiscal policy.

- **Environmental Studies (1 session):** The addition of this topic is to address the lack of an environmental component (the “Planet” aspect in the previously mentioned desired areas of knowledge) in the first version of the ENGR 291 course. It will cover issues regarding water, energy, food production, population growth, land use, pollution control, and sustainability.

- **Country-specific sessions (4 sessions):** Brazil, Russia, India, and China will remain as the focus of the country-specific sessions. However, only one reading can be assigned for each session instead of two, specifically: “Brazil under Lula: Off the Yellow BRIC Road”, “Russia: Revolution and Reform”, “India on the Move”, and “China: Building Capitalism with Socialist Characteristics”. The readings are all purchased by the students from Harvard Business Publishing.

- **Business and Management sessions (2 sessions):** There is no need to make any significant changes to either the readings or the emphasis for this portion of the course; it could have the same content as before: negotiations and Hofstede’s cultural dimensions for the first session, and industry analysis and scenario planning for the second session.

- **Cross-cultural communications (1 session):** Greater emphasis could be placed on the dimensions of cultural orientation, such as the different perceptions of environment, time, action, and communication; the presenter(s) can also illustrate cross-cultural communication issues in the business world and during trips abroad so that students can better understand the relevance of the topic. The suggested reading for this session is an article titled “Cultural Differences in Business Communication” by Professor John Hooker of Carnegie Mellon University’s Tepper School of Business [19].

- **Expatriate Experiences (1 session):** As before, this session will discuss what qualities make for a successful expatriate, and will also cover the phenomenon of culture shock as one arrives in a new country for the first time, and tries to adjust to living there. The suggested readings for this session are “Making It Overseas” from Harvard Business Publishing, and “Cultural Shock: Adjustment to New Cultural Environments” by Kalervo Oberg.

B. For the Spring Semester (Part 2 of the Course)

- **Philosophy and Ethics (1 session):** The basics of Western philosophical thought will be explored, starting with rationalism (the idea that knowledge is derived from pure thinking and reason) and empiricism (which holds that knowledge is derived from sensory input and experience) [20], moving on to deontological or rule-based ethics, contrasted

with utilitarianism or consequence-based ethics, and ending with a look at contemporary ethical theory.

- **Psychology (1 session):** As an introduction to this topic, the basic concepts of psychology will be presented, followed by the aspects of both social and cultural psychology, with an emphasis on theories of social interaction and the effect of cultural traditions on human behavior.

- **Political Science (1 session):** This review of the important international events and changes since WWII will include the topics of national decision making, conflict resolution, diplomacy and war.

- **World Religions (2 sessions):** Religion and culture are inextricably intertwined and exert an influence on the behavior of individuals and societies. The three major monotheistic faiths of Christianity, Islam, and Judaism will be covered, followed by other major world religions, including, Buddhism, Confucianism, Hinduism Shinto, and Taoism.

- **Country-specific sessions (2 sessions):** Two countries will be examined in detail, Mexico and South Korea. Mexico’s proximity to the United States, along with its unique relationship and history with the U.S. makes it an interesting candidate for study. South Korea warrants a look because of its economic history as one of the Four Asian Tigers, its technological and industrial strength, and its continued exceptional growth despite being a developed country. The suggested readings are “Mexico: Crisis and Competitiveness” and “Transforming Korea Inc.: Financial Crisis and Institutional Reform”; both readings are from Harvard Business Publishing.

- **Accounting and Finance Basics (1 session):** Given that all organizations need to keep accounts of how they fund themselves and what they spend their money on, it follows that having an elementary understanding of accounting is important. This session will introduce the basic accounting statements – the income statement, the statement of cash flows, and the balance sheet – and will also cover financial ratios used to mathematically assess the financial health of a business.

- **Marketing and Selling (1 session):** A knowledge of marketing and selling techniques would be beneficial, firstly because engineers are generally not trained in such techniques, and secondly because, regardless of where careers paths may take our engineers, it is highly probable that somewhere along the line, they will have to engage in some form of promotion or selling, be it for a product that they helped to develop or for a service. This session can cover marketing concepts such as the marketing mix or the Four P’s (Product, Price, Place, and Promotion), aspects of brand management, and personal selling techniques.

- **Operations Management (1 session):** A business’s operations can all be broken down into processes which can be analyzed and optimized in order to improve the business’s performance and to give it a competitive advantage over its rivals [21]. This session will introduce the basic concepts of Process Analysis, and will involve a case-study to give the engineering students a better grasp of the topic. The suggested case for this session is “Benihana of Tokyo” from Harvard Business Publishing.

- Business, Government, and Society (1 session): A case-study involving stakeholders from business, government, and society will be the basis for discussion and debate. The objective of this session is to introduce engineering students to the thorough nature of case discussions, and to the complexities created when conflicting interests, perspectives, and beliefs collide, which is often the case in the real world. The suggested case-study for this session is “Royal Dutch/Shell in Nigeria (A)” from Harvard Business Publishing. This session is modeled on and named after a management course offered at Bucknell University titled “MGMT 312: Business, Government, and Society.

V. CONCLUSION

We presented our approach at Bucknell University to the course “ENGR 291: The Global Engineer” followed by suggested improvements for future offerings. It is our belief that having a more diverse academic background will make engineers more open to new experiences, more comfortable handling uncertainty, and more well-rounded as individuals.

As the world becomes increasingly interconnected and different countries rise up to participate in the global economy, it is not possible to train our engineers to handle each and every culture and unfamiliar situation they may encounter. Perhaps the single most important result a global engineering course can achieve is for its students to possess an awareness of the complexities of the future and the confidence to face them. It is our hope that this objective has, at least to some extent, been realized through the global engineering course discussed in this paper.

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Work in Progress: An International Engineering Certificate: Incentivizing Engineering Students to Pursue Global Experiences

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Abstract—An innovative, easy to implement International Engineering Certificate is introduced in this work-in-progress, innovative practice paper. The certificate enhances a four year engineering or computer science major without delaying the time to graduate. Other benefits include low cost, flexible structure, appeal to diverse audiences and potential for external support opportunities. The certificate is compared to four international opportunities provided by other engineering programs.

Keywords—international engineering certificate, international engineering education, global experiences

I. INTRODUCTION

As the world's economy becomes increasingly integrated, the marketplace demands engineering and computing graduates who have more sophisticated international knowledge and skills. It is important for the engineering education community to help its students prepare for work in a global context and the challenges of the globalized world [1].

To help meet this demand, the Montana State University (MSU) College of Engineering (COE) created an International Engineering Certificate [2] that was approved by the Montana Board of Regents in September 2011. To earn the certificate, a computer science or engineering student must (1) select a country or region of focus, (2) earn 15 credits of relevant coursework and (3) spend two weeks or longer in that country or region as part of a study abroad, work abroad or service abroad experience. If MSU offers a relevant language, the first three language courses must be completed.

II. RELATED WORK

University of Rhode Island – International Engineering Program. URI's program [3] allows a student to earn two majors simultaneously; one in engineering and one in a language. The program takes five years to complete and requires the fourth year to be a study abroad year.

In contrast, the MSU certificate can be completed in four years with less stringent language and international experience requirements. The MSU certificate is thus less demanding as would be expected when comparing the requirements of a

second major to the requirements of a certificate. Consequently, the MSU certificate is more accessible to a larger population of students.

Purdue University – College of Engineering Global Minor. Purdue's program [4] requires a student to demonstrate proficiency in a second language, study engineering abroad for one semester, undertake an internship for a global corporation (three months domestically plus three months abroad), and participate in a two semester project that involves a co-located global team for a portion of the project.

Purdue's Global Minor is similar to the MSU certificate in that it requires a student to focus on a non-native country or geographic region. However, Purdue's Global Minor requires living abroad for at least six months whereas the MSU certificate requires living abroad for a minimum of two weeks. Not surprisingly, there are more requirements to earn a minor than to earn a certificate. Once again, the MSU certificate is more accessible to a larger population of students.

University of Colorado – International Engineering Certificate. UC's program [5] requires a student to earn at least 15 relevant credits pertaining to one of the following six languages: German, French, Spanish, Italian, Chinese or Japanese. An international study or co-op experience is encouraged, but not mandatory.

The Colorado and MSU certificates are comparable with respect to the number of credits required and the number of language courses required (when relevant). The Colorado certificate is easier to earn if a student chooses not to engage in an international experience. However, there is much value in requiring a student to be immersed in another culture. In addition, the MSU certificate provides more flexibility by enabling a student to choose any non-native country as a focus.

MIT International Science and Technology Initiatives (MISTI). The MISTI Program [6] provides both undergraduate and graduate students with paid internships and research opportunities around the world. The requirements to participate in an internship vary slightly from country to country. In general, students need to complete two years of

language study (if the language is offered at MIT) and a relevant culture course. MISTI also provides global seed funds to help faculty jump-start international projects.

Although the MISTI program does not confer additional degrees upon a student, it is exemplary in providing guaranteed internship opportunities as well as seed funds for faculty. MSU strives to develop such opportunities.

III. CONTRIBUTIONS

Diversity. Women comprise 15% of the students in the COE. Yet, 34% of the 68 students who have expressed an interest in pursuing the IEC are women. The certificate could prove instrumental in attracting more women to study engineering.

Ease of Attainment. With careful planning, the certificate can be earned alongside a COE degree in four years. Once a country or region of focus is identified, many of the 15 credits can be earned in the context of university core requirements.

Low Cost of Implementation. The certificate does not require any new courses to be developed. It takes advantage of existing courses that are offered by departments that range from Modern Languages to History to Economics. The costs incurred thus far include the time to develop the certificate, the time to keep the certificate updated with respect to current opportunities, the time to advise students and the time to certify that students have earned the certificate.

Flexibility. The certificate caters to both domestic and international students by allowing any non-native country to be chosen as a focus. Thus, international students could focus on the United States and automatically satisfying the study abroad requirement. Furthermore, because a student can choose any non-native country or region as a focus, the world is literally each student's oyster!

Advancement Opportunities. The certificate provides advancement (development) opportunities for both individuals and corporations. As one example, scholarships would help make the study abroad or service abroad requirement more affordable to a greater number of students. As a second example, corporations might be engaged by asking them to provide guaranteed work abroad opportunities to qualified students.

Enhanced Student Skill Sets. A student who earns the certificate should be more marketable upon graduation, as well as a better global citizen.

IV. FUTURE WORK

Assessment. We must determine how we will assess the success of the certificate once significant numbers of students begin to earn it. Certain information is easy to obtain such as

the gender of the student, the major of the student, the country or region chosen, and whether the student chose to study abroad, work abroad or perform service abroad. We need to identify learning outcomes and develop an assessment method for these outcomes.

Work Abroad Opportunities. If a student wants to work abroad, she is responsible for finding the opportunity. Because this is difficult for a student to do, the COE strives to identify guaranteed opportunities in diverse locations. For example, it would be beneficial to offer an automotive internship in Stuttgart, Germany. MIT's MISTI Program [6] is an exemplary model of providing such opportunities.

Service Abroad Opportunities. The COE has a vibrant chapter of Engineers Without Borders (EWB) that enables students to perform service in Kenya each year. COE students may also affiliate with the Montana Tech chapter of EWB to perform service in El Salvador. We need to identify more service opportunities in diverse locations.

Study Abroad Opportunities. In addition to the standard study abroad opportunities, the COE strives to offer more short-term, faculty led study abroad opportunities for its students. These opportunities appeal to a segment of our student population who are not yet ready to venture forth on their own. An example of this occurred last summer when an MSU computer science professor led nine computer science students on a six week study abroad trip to Kyoto University.

Advancement Initiatives. The certificate provides ample opportunities to engage individuals, corporate partners and our advisory board. We must formulate and execute a plan to provide travel scholarships, work abroad opportunities, etc.

Student and Faculty Awareness. Because the certificate is at the college level as opposed to the departmental level, it presents special challenges in terms of making students and faculty aware of its existence. Students should ideally learn of the certificate early in their academic careers so that they can earn it without delaying graduation. Faculty need to be aware of it for advising purposes. Strategies are under development to accomplish these goals.

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Factors Influencing STEM Teachers' Effectiveness in the UAE

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Abstract— New studies in the United Arab Emirates (UAE) have delved into investigating the factors why students do or do not appreciate Science, Technology, Engineering, and Mathematics (STEM) courses. Many indicators point mainly to the effectiveness, or ineffectiveness, of teachers. The main purpose of this paper is to identify significant factors that affect a teacher's effectiveness. This is done through an analysis of the results of a twenty-four-question survey, developed by the authors, given to 200 Science, Technology, and Mathematics teachers, from Kindergarten to Grade 12, in public and private schools across the country. A literature review consisting of comparable studies in other countries served as a backdrop to the many trends discovered in the analysis of teachers' responses. Furthermore, the authors provide additional critical interpretations to address the unique nature of the findings in the UAE educational system. Overall, the findings point to the dire need to address teachers' dissatisfaction with the teaching profession in the UAE. Specifically, addressing monetary compensation, improving the curricula, lack of resources and providing professional guidance via development courses and seminars is necessary if teachers are to be more effective in the classroom.

Keywords- Grade K-12; STEM; Teacher Effectiveness; UAE.

I. INTRODUCTION

Extensive research has been conducted globally by many academic entities into what proves to be an effective educator in knowledge-based economy. In the previous UAE studies presented in [1,2], analysis of secondary and post-secondary students in the UAE provided useful information about why students choose or do not choose to enroll in Science, Technology, Engineering, and Mathematics (STEM) programs. These studies revealed that the most important factor that determines a student's desire to like or enroll in STEM is based on the capability of the STEM teacher. In other words, the studies [1,2] urge a strong need to increase the capability of STEM teachers in order to get students to like STEM classes and therefore significantly increase the likelihood that they will enroll and graduate from STEM academic programs. Thus, this paper seeks to identify the factors that enable and prevent teachers from being capable educators.

Investment in human capital, teachers and administrators, is one of the cornerstones of the UAE's educational overhaul [3]. So far, the UAE's school systems have opted to hire licensed educators from surrounding

Arab countries, and in the past 3 years, from Western, English-speaking countries. Governmental agencies, such as the Abu Dhabi Education Council (ADEC) and the Ministry of Education, have taken measure to help ensure that they are hiring and retaining teachers who are qualified to carry out the task of preparing the Emirati young generation to create and sustain a knowledge-based economy [3,4]. Given that STEM is the centerpiece for jumpstarting and maintaining a knowledge-based economy, an importance has been placed on ensuring that STEM teachers and programs are given much attention [3,4]. However, it is almost commonsensical to understand that even though a teacher may be qualified to teach, the environment surrounding these qualified professionals is also crucial.

In all, students in the UAE have already provided a glimpse of what motivates and demotivates them to join STEM programs [1,2]. Seemingly, at the center of their choice is the capability of the teachers. This paper serves as an investigation into the minds of STEM teachers in the UAE dissecting what they are doing or attempting in their classrooms and what they believe are factors that are aiding and hindering their abilities to be capable educators. In the subsequent sections, this paper will discuss results and conversations from other similar research, present the methods used to collect the data for the research and provide a deep analysis of the research results. Finally, this study will provide a conclusion that compares this research with previous ones discussed in the literature review and provide suggestions for potential research projects to advance the understanding and effective implementation of this topic.

II. RELATED WORK

Similar studies on determining factors that affect teachers from optimally performing have been conducted in other countries. However, considering the different contexts and variables due to culture, religion, etc., research specific to the UAE is necessary. Nevertheless, using the findings from these earlier scholars is still useful as a backdrop to this research. The following is a review of prominent academic research and commentary of what makes teachers feel that their work is effective.

Many international studies show that job preparation and skills development are vital factors in the recruitment and retention of professionals. For teachers, this usually means

the foundational learning of modern pedagogy and frequent updates to the changes in the field. According to previous research conducted in the USA [5,6] and Canada [7], the lack of preparation and professional development has led to high levels of teachers' incompetence. In addition, another study [8] declared that a considerable amount of first-year educators in New York commented that teacher preparation institutions did not effectively prepare them for their first-year of teaching; thus, professional development and mentoring are key.

Furthermore, the lack of input teachers have in the school's decision-making and professional development adds to the feeling of lack of autonomy. Experienced teachers in the USA are concerned with how autonomous they feel and the value of their input [9]. Moreover, a significant number of teachers in the USA would sacrifice the higher wages of other professions to work in a school where there is a positive environment [10-14].

Thus, this assertion may neutralize the age-old debate and assumption from the USA and the UK studies that state relatively low wages offered to teachers are why "talented" professionals do not choose to become teachers or do not stay in education. For example, in a 2002 survey, California educators, who were prepared to leave the teaching profession, listed "salary considerations" as the number one reason that led to their decision [15]. Salary compensation was also ranked in [16] as a highly influential factor that Washington male and female teachers will consider for remaining in the profession or leaving. The comparative study [17] found out that poor salary was the major reason behind the teacher demotivation or attrition in the UK.

Moreover, the inadequate amount and/or access to resources such as textbooks and computers, adds to teachers' job dissatisfaction according to some research carried out in the USA [8]. Moreover, the physical quality of the school facility is another important predictor of teachers' motivation, satisfaction and success. The research conducted in Sweden [18], and different USA studies [19-22] link facility quality to learning outcomes and teacher morale.

Additionally, stability and coherence of government education policies like curriculum professional standards and certification procedures play a major role in a teacher's job satisfaction. In a New York study [8], many teachers vented their anger toward the fickle nature of education policies and the lack of clear and accurate information. The study, conducted in rural middle schools of North Carolina [23], affirmed the assertion that curriculum changes, such as adoption of new standards or procedures, added to factors that affect teachers' performance and competency.

In addition, the number of students in classrooms is a major factor that dictates what type of teaching method an educator employs. Essentially, class size weighs heavy on teachers' pedagogical styles. The research conducted in the Netherlands [24], the UK [25] and the USA [26] suggested that the smaller the student to teacher ratio is, the more flexible the teacher could be. Basically, smaller class sizes

allow the educator to take heed to the individual needs of his/her pupils more than larger ones.

Finally, according to research conducted in the USA [15] and Australia [27], the dual perception that people have of the teaching profession also affects the effectiveness of teachers. These two studies demonstrate that public perception of the profession as relatively easy (because of its vacations, preferable hours, etc.) means that teachers are treated as a lower caste in the professional rung and this tends to alienate educators. In all, teachers may become mentally fatigued with having to battle negative stereotypes about the "ease" of their job and low social status of the profession in the eyes of the community. This may also lead to teachers' frustration and low esteem.

Overall, worldwide academic studies about what has led to teachers feeling effective in their profession vary to certain degrees. Literature from the past three decades from different countries point to factors that affect an educator's effectiveness such as low wages, undesirable work conditions and incoherent governmental policies which lead to frustration and attrition. Additionally, the social stigma that some societies have towards their educators sometimes has an effect of creating a professional inferiority complex. In all, these prominent studies will serve as a background to facilitate a comparison with the information that will be presented in this research's findings.

III. RESEARCH METHODS

This research project started with a survey, developed by the authors, given to Science, Technology, Engineering and Mathematics (STEM) track teachers in the K-12 public and private school sectors across the UAE. In all, 200 teachers took the questionnaire. The survey was distributed in Arabic or English, according to the preference of the teacher, and was completely anonymous in order to ease teachers' anxieties over possible reprisals for their responses. Of these 200 teachers, 102 currently teach in public schools while 98 are in private schools. The gender breakdown of the participants consisted of 93 males and 107 females. In terms of nationality, 100 identified themselves as UAE nationals and 100 as non-UAE nationals. This survey collected the ethnic, gender, and professional identities of the participants in order to compare the results and understand if these factors altered the responses given.

The questionnaire itself contained 23 multiple-choice questions and one open-ended question. The first thirteen questions were split into five categories:

1. Teachers autonomy in their classroom.
2. Curriculum changes made by policymakers.
3. Role of the administration in the classroom.
4. Teacher's influence in the school's curricular decisions.
5. Job satisfaction.

Response options for these 13 questions ranged from strongly disagree, disagree, neutral, agree, to strongly agree. These questions were formed with the intention of

pinpointing the factors that may be enhancing or hindering the teacher's effective performance in class.

The remaining 10 multiple-choice questions gauged the frequency of an action that the teacher has done in the span of a school year. These questions tried to identify how often basic effective methods were used by the participant. Four categories also comprised this section of the questionnaire. They included

1. Sharing of pedagogical knowledge with colleagues.
2. Direct instructional strategies used with regard to students and their parents.
3. Assessment and data evaluation.
4. Attendance of professional development workshops.

Response options for these 10 questions ranged between 1-3 times a year, 4-6 times a year, 7-9 times a year, 10 or more a year, and never.

Finally, the open-ended question was: "*In your opinion, what are the effective strategies you would recommend for your school to improve students' achievements in STEM subjects?*" This final question was used to gauge teachers' most impending need to become more effective in the classroom.

IV. RESULTS AND DISCUSSION

The UAE's policy of drastically improving its education system include actions such as building new schools, incorporating technology into classrooms and revamping its educational workforce. The latter tactic needs special attention because the educator labor force and its effectiveness can significantly determine whether a school is successful or not. Considering that the UAE is in pursuit of establishing a respectable and competitive innovative economy, strengthening STEM is foundational. However, in order to achieve this goal, understanding whether UAE teachers, in public and private sectors, feel effective as educators is essential. In the following sections, we analyze how UAE teachers responded to the survey that aimed mainly to understand what factors affect K-12 STEM teachers' performance. We will discuss the aggregated data, i.e. the nine categories, as main points of discussion and point to specific questions in the categories when necessary.

Autonomy, or the feeling of self-governing or control over something or someone, can be a reality that some teachers want and others do not. Essentially, the concept of autonomy in the school context is the idea of being independent in one's work and classroom rules, procedures, etc. and not being hassled by higher ranking authority figures. For the 200 teachers in the study, 92% agreed to the fact that, as a teacher, they receive autonomy over their classes (as shown in Fig. 1). However, the concept of autonomy can be mapped to a spectrum of total trust in one's professional wherewithal from the school administration (and thus allowing the educator to do what he/she sees fitting) or sheer neglect. The questions asked in the survey probed the limits of teachers to use creativity and

their own teaching strategies. This appears to show that the schools are not insisting on any specific methods or strategies of teaching and instead put the burden on the teacher. Some teachers may welcome this approach because it may give the educator a sense of being trusted and a complete ownership of his/her class. Furthermore, if teachers, more than likely veterans, interpret autonomy given to them from their superior colleagues as "I trust your skills" then this may give the teachers a positive perception of the profession.

On the other hand, new teachers, specifically young ones, may see this "autonomous" approach as another word for "indifference" toward the educator. If perceived in this negative light, the educator may feel neglected and unguided; consequently, this could lead to teachers performing below effective levels and eventually resigning. But overall, 92% of the respondents stated that the schools leave them to use their own creativity and strategies to reach the students.

The following category in Fig. 1 deals with curriculum changes. This pertains to the issues of whether the teacher keeps up with new mandates from school policymakers and whether the curriculum is appropriate for the age and interest-levels of students. In general, this second category is seen in a negative light. Only 30% of teachers state that curriculum changes are monitored for their effectiveness and fit students' performance levels and interests. However, 60% of the respondents believe that entities in charge of creating a certain curriculum do not follow-up on whether it is effective and whether the material is in-touch with students' abilities or not.

Major disconnections between the curriculum and the students' levels of ability and interest have the potential of resistance from students who may see the curricular material as difficult or oppressive. In response to student unrest over "esoteric" curricula, teachers may feel frustrated given that they must deal with the fallout of students who are weary of an unpopular curriculum. Furthermore, it is difficult for teachers to feel effective in their students learning process if the curriculum is seen as irrelevant or disconnected.

The role of administrators, their philosophies, attitudes and decisions pertaining to the classroom can alter one's outlook on the classroom environment. Administrators are the leaders of the school and can have positive or negative influence on the teacher. In this portion of the questionnaire, the role of the administration in regards to setting high standards for STEM and providing enough resources for STEM teachers were questioned. While 30% of teachers agreed, 58% of the respondents disagreed and strongly disagreed with the idea that their administration provides enough materials and curricular standards for STEM. Some teachers can interpret this as a lack of support and/or a lack of a central vision from their leaders. If a leader does not give the materials needed to the ones he/she leads, then the followers may not trust or even want to work for the leader. Possessing a feeling of not being supported alienates workers and can easily lead to negative feelings toward the job.

The most nuanced responses came from the fourth category presented in Fig. 1 which is teacher's influence. The two questions that comprise this category received opposing responses. While teachers overwhelmingly stated that they had no influence in selecting the type of professional skills they need or want, almost the same number of respondents claimed that they have an influence in choosing the books that will be used in STEM courses. It seems that while there is agency given in one area (choosing books), it is void in another (skill development courses). The latter poses a potential problem because teachers may feel that their pedagogical needs are not being addressed. These pedagogical deficiencies will remain unless the teacher takes the extra time to address them on his or her own. As a result of not being able to improve deficiencies that are known to the teacher, their effectiveness may stagnate or even regress. In all, 42% of teachers agreed while 50% disagreed that they had some influence in choosing STEM supplementary books and the content of skills' development programs. The majority of those who agreed believed that teachers have an advantage in choosing supplementary resources for the STEM classes, however, most teachers feel that they do not have a say in what type of professional development needs to be issued by the school.

The response scale pertaining to job satisfaction was the most negative and resolute of all the categories. Overall, while 32% of participant answers to this category expressed dissatisfaction with their current profession, 58% were strongly dissatisfied. The respondents overwhelmingly expressed their discontent with the class sizes and salaries. Furthermore, they expressed their willingness to change profession if offered a better salary. The sheer number of negative responses to questions in this category is alarming. According to the respondents, teachers' pay is too low, while class sizes are too large. Furthermore, the large number of participants who said they would leave the profession to go to another industry points perhaps to a lack of identity and/or professional bond to the teaching profession itself as if it is just a temporary occupation to hold over until something better comes along.

Responses to the next four categories presented in Fig. 2 are not based on opinions or feelings of the respondent but on the frequency of strategies used by the participating teachers. The sixth category breaks down how often collaboration with other teachers occur. These collaborative efforts range from sharing teaching methods to assessing the scope of STEM topics taught in school. Approximately 39% of teachers responded that sharing knowledge with other teachers happens more than 10 times a year (this is the most frequent of all the responses). Thus, teachers frequently collaborate in pedagogical matters.

Since many of these same respondents claimed that they do not get much support from their administration, these teachers may have become closer knit and open to helping each other professionally as a result of this lack of support. Overall, sharing teaching methodologies seems to be very common among the teachers who responded.

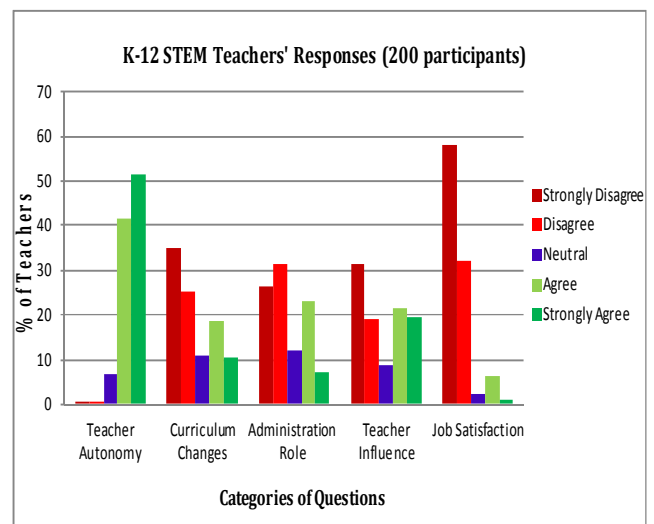


Figure 1. STEM Teachers' Responses - Questions Categories 1 to 5.

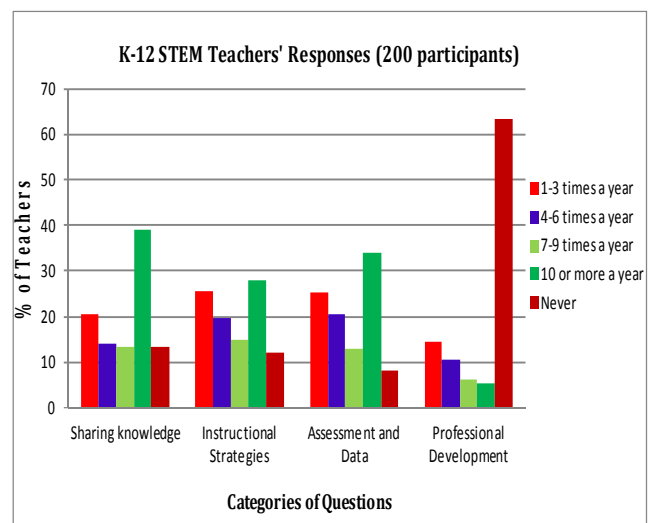


Figure 2. STEM Teachers' Responses - Questions Categories 6 to 9.

The seventh category examined in Fig. 2 displays the frequency of teachers contacting parents about the STEM curriculum and how they could help their children academically, use heterogeneous groupings and help struggling students. This category produced mixed results because while many teachers shared information with parents quite infrequently, the surveyed teachers conceded that they overwhelmingly help struggling students and use mixed achievement groups in order to boost peer-to-peer teaching.

Nevertheless, the low frequency (12%) is largely due to the fact that outside tuition is not offered by most teachers. The responses to these questions could be skewed due to the fact that many education employers do not allow teachers to give after-school tuition and the large number of "never" answers may be defensive answers in order to save their jobs. Moreover, the relatively high number of "1-3 times a

year” responses which is around 25%, could be due to the large number of responses for teachers contacting parents. Considering that many schools have “parent night” at least once per trimester, this could serve as a large bulk for parent contact. In essence, the surveyed teachers may not be taking the initiative to seek out parents and share instructional strategies but could simply be passively waiting for them to attend parent nights and discuss instructional information with them.

Assessment and data category consisted of two questions, evaluating students’ progress with administration and participating in STEM grade-level meetings for curricular improvements. This category had the lowest frequency of “never” responses with only 8%. 34% of teachers stated that they assess data with administration and other STEM colleagues at least 10 times per year. However, 25% responded that evaluating students’ progress and participating in STEM meetings occurred “1-3 times” a school year. The “1-3 times” option may be high because of mandated administration-teacher conferences for job review; however, teachers should be meeting at least once per week. Therefore, the 25% of teachers in the “1-3 times” option, along with the 8% in the “never” option, are an anomaly that needs to be addressed. Essentially, these respondents are not, or are barely, meeting with colleagues or administrators to improve the STEM curriculum data. This could be because they have already reached an “indifference” stage of teacher burnout.

Finally, the professional development category in Fig. 2 holds a very eye-opening statistic. This category only had one question: “did the respondent attend professional development activities on or off campus to improve STEM pedagogies?”. A disturbing 64% answered that they never attend professional development. This is very alarming because not developing the professional expertise of teachers makes their skills regress. In fact, the lack of attendance of professional development sessions may be the foundation of why teachers feel neglected by administrators, frustrated with new curriculum changes, and overall, dissatisfied with their job. Professional development may not be given in many UAE schools because there is an absence of professional development centers, as school districts in other countries have, provided by the schools or by subcontracted entities. Furthermore, although there are many online opportunities to attend professional development activities, teachers’ ignorance of these opportunities, lack of desire to do them outside of school hours or even pay out of their pocket, may be reasons why they do not utilize them. In all, school administrators and teachers largely ignore professional development. Ignoring the development of pedagogical skills, especially for academically important subjects such as STEM, can be very detrimental. When STEM teachers are professionally left behind, their students will suffer.

V. CONCLUSION

In conclusion, the categories of Figs 1 and 2 show many determining factors on gauging the effectiveness of teachers. The most significant categories seem to be: teacher

autonomy, job satisfaction and professional development. Although teachers are autonomous entities in the school, this may not be by deliberate design. Furthermore, an overwhelming number of teachers did not like their jobs due to poor pay and class size. Moreover, the lack of professional development may be at the core of this discontent among the participating teachers.

Overall, the 200 STEM teachers who participated in this study provided some very insightful information about what is hindering or promoting their effectiveness in class. The collection of responses exposed many critical barriers that need to be addressed. For example, many teachers complained of low salary. This perception has led to their job dissatisfaction similar to the findings in studies done in the USA and the UK [15-17] as discussed earlier. However, higher wages is not the sole answer to the problem even though “throwing money” at the problem may be the solution as many may believe. Even with higher salaries, if professional realities in the other troublesome realms of the profession, do not occur, issues such burn out, indifference, and “doing just enough for regulators in order to get by” will continue. The high discontent among participants also correlates with the findings in the Netherlands, the UK and the USA [24-26]. It is positive to note that the teachers have stated that they try to help struggling students frequently and use the heterogeneous grouping method, smaller classes, as according to the study; this may help facilitate the critical thinking needed in STEM classes and alleviate job stress for the teacher.

Curriculum changes committed by school policymakers are also a barrier for teacher effectiveness. Very few of the respondents answered that the new curricula meet students’ interests and/or are feasible challenges for the students’ comprehension levels. The feelings resulting from these curricula changes appear in studies done in the USA [8,23] that claim teachers grow angry at these changes and feel discontent with their profession. Furthermore, a large percent of teacher participants stated that they are not properly equipped with necessary school resources. This deficiency hinders teachers from performing at their highest levels of effectiveness. Research in Sweden and the USA [8,18-22] also concludes that this problem leads to teacher attrition due to the frustrating inadequacies of their school.

Lastly, professional development, according to the respondents, is clearly neglected on the part of the schools and the respondents themselves. Without the ability to keep up with the ever-changing pedagogical methods of STEM teaching, educators may become frustrated and essentially obsolete because they may not be able to meet students’ needs as they change with time. Professional development keeps teachers relevant in the minds of learners and it provides teachers a platform to collaborate with other professionals (whether at the same school or not). Research in Canada and the USA [5-8] already proves that proper professional development and mentoring can help improve teachers’ capability and retention rates. Hopefully in the UAE context this can also occur and thus raise job satisfaction among teachers in order to help increase their effectiveness at work.

ACKNOWLEDGMENT

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A cross-cultural comparison study: The effectiveness of Schema Training modules among Hispanic students

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Abstract - Previous studies indicated that misconceptions related to heat transfer, fluid mechanics, and thermodynamics, persist among engineering juniors and seniors even after they completed college-level courses in these subjects. Researchers have proposed an innovative instructional approach, the ontological schema training method, which helps students develop appropriate schemas or conceptual frameworks for learning difficult science concepts. Three online training modules were designed to help engineering students develop appropriate schemas in heat transfer, diffusion and microfluidics. The effectiveness of these modules was examined with two different student populations from two different universities (US and Hispanic). At each institution, participants were assigned randomly to a control or experimental group. The treatment for each group at both institutions was exactly the same. Preliminary results indicated a mixed effectiveness of the training modules among these populations.

Index Terms – Cultural Differences, Ontological Schema Training, Quantitative Analysis

INTRODUCTION

Previous studies conducted by Streveler and Miller [1] indicated that misconceptions related to heat transfer, fluid mechanics, and thermodynamics, persist among engineering juniors and seniors even after they completed college-level courses in the subjects. Researchers argued that in order to repair and correct student's misconceptions, it is critical to facilitate conceptual change through training students in the appropriate mental framework or schema for some difficult concepts. [2] Chi and her colleagues proposed an innovative instructional approach, the ontological schema training method to help students develop appropriate schemas or conceptual frameworks for learning difficult science concepts. [3] Chi's studies are grounded in the assumption that students learn new concepts by assimilating or encoding new information into an existing schema or framework. This assimilation allows students to make inferences about and assign attributes to a new concept or phenomenon. Furthermore, an incorrect inference, based on an incomplete or incorrect schema, affects negatively students' understanding of a new and difficult concept by making

common errors associated to the targeted concept[2]. In addition, social cultural characteristics factors of learners, such as race and ethnicity, language, social environments are believed to affect students' conceptual change and their approaches to construct meanings[4].

Based on Chi and her colleagues' work, three online training modules were designed to help engineering students develop appropriate schemas, which are needed to understand some key engineering concepts, such as heat transfer, diffusion, and microfluidics. To tests the efficacy of these learning modules, researchers tested and compared performances of two populations at different institutions: a public engineering institution in the Midwest (MPI) and a Hispanic engineering serving institution (HSI). Thus this paper presents results from a study whose objective was to compare the performance of two different populations on the effectiveness of the Schema Training Modules (STM) developed to assess conceptual understanding. The research question that guided this study was: **Are there differences in student conceptual understanding of concepts in thermal and transport sciences based on their cultural backgrounds?**

BACKGROUND

I. Theoretical Framework – Ontological Schema Training Method

Previous studies reported students' difficulty understanding concepts related to heat transfer, fluid mechanics, and thermodynamics. Furthermore, the presence of misconceptions has been identified, even after students have completed college-level courses in the domain subjects [1], [5],[6]. These misconceptions have been proven to be robust and resistant to traditional instruction because the correct understanding requires students to not only acknowledge the presence of the misconception, but also to "conceive" them differently [3]. Chi and her colleagues have proposed an innovative instructional approach to repair misconceptions among students. This approach is referred to as the ontological schema training methods (STM). STM focuses on helping students develop appropriate schemas or conceptual frameworks for learning difficult engineering concepts [3], [7]-[9].

Chi has identified Emergent Processes as those "properties of a system that result from its constituent

elements interacting over time, often in conjunction with equilibration” [1]. Research has shown that Emergent Process misconceptions are particularly resistant to traditional instruction because they are made at the ontological level – where students ascribe a fundamental characteristic to the concept that is at odds with the scientifically normative view [1],[3]. In order to help students learn concepts of the Emerging Process ontology, instruction should first identify the ontology and provide them with some rich examples and properties of that ontology [3],[7], [9]. This would help students develop a “schema” or mental model for that ontology which would make subsequent examples easier to understand. Referred to as “schema training,” this instructional methodology has been successful with both middle school students and undergraduate psychology students [3], [7], [9]. Previous work has identified difficult concepts in heat transfer, diffusion and electricity as emergent processes [5], [10].

II. Description of Ontological Schema Training Modules (STM) in Thermal Sciences

A group of researchers developed the STM following the work done by Chi and her colleagues. As shown in Figure 1, the experiment design uses both experimental and control groups of students matched for equivalent levels of engineering education.

| Day | For Control Group | For Experimental Group | Expected Completion Time |
|-------|--|--|--------------------------|
| Day 1 | Nature of Science | Sequential and Emergent Processes: Part I | 3 – 4 hours |
| | Demographic Survey | | |
| | Heat Transfer Concepts Assessment (Pre Test) | | |
| | Scientific World View Instruction | Processes Instruction | |
| | Diffusion Instruction <i>Not described as an emergent process</i> | Diffusion Instruction <i>Described as an emergent process</i> | |
| | Diffusion Concepts Assessment (Post Test only) | | |
| Day 2 | Sequential & Emergent Processes: Part II | | 2 hours |
| | Heat Transfer Instruction | | |
| | Heat Transfer Concepts Assessment (Post Test) | | |
| | Microfluidics Instruction | | |
| | Microfluidics Concepts Assessment (Post Test only) | | |

FIGURE 1
SCHEMA TRAINING MODULES

Specifically the modules consist of a pre-test in heat transfer concepts, used as a further measure of the “equivalence” of the two groups’ prior knowledge. The experimental group completed a training module describing the characteristics of two kinds of processes (sequential and emergent processes), which was intended to facilitate students’ conceptual change. The training modules for the experimental group also describe why diffusion concepts are an emergent process. The control group completed an approximately equivalent module that describes the nature of science. Diffusion is described but no mention is made of emergent processes. Then, both groups completed the same instruction module on heat transfer principles. Later, post-test concept questions were answered by both groups. The

post-test was followed by a far transfer experiment in microfluidics instruction and concept assessment. The far transfer experiment was designed in such way because the concept of microfluidics represents an ideal application of emergent process principles, which the participants were unfamiliar prior to the study. This paper discusses quantitative analyses performed on the shaded activities presented in Figure 1.

METHODS

Specifically, we conducted an experimental study with junior or senior engineering students at two universities, a Public Institution located in the Midwest (MPI) and a US Hispanic Serving Institution HIS. A description of the institutions and participants is presented in the following section.

I. Descriptions of participating populations

1. Midwestern Public Institution (MPI)

The selected MPI is a Land Grant institution founded in 1869 and enrolls over 40,000 students across campus. It has been identified as an institution with the largest international student population of any U.S. public university. The undergraduate enrollment for 2011 had a total of 30,776 with 57% male and 43% female. From these students 60% are state residents, 26% other U.S. states, 14% other countries and 13% minority domestic student population. From the total enrollment of undergraduate students approximately 20% are pursuing engineering degrees. Engineering programs at the MPI consist of a four-year curriculum with 12 engineering programs including Aeronautics and Astronautics, Agricultural and Biological, Biomedical, Chemical, Civil, Construction Engineering and Management, Electrical and Computer, Industrial, Materials, Mechanical and Nuclear. The undergraduate engineering program is positioned in ninth place among the national rankings.

In total 60 participants were selected for this study. They were typical college junior and senior students who majored either in mechanical, chemical, or material science engineering. Also, the majority of participants were male and their primary language was English, which is representative of the engineering population at the MPI.

2. Hispanic Serving Institution (HSI)

The College of Engineering (CoE) of the selected HSI is among the largest engineering institutions in the U.S., ranking fifteen in the nation in undergraduate enrollment, about 5000 students (approximately 98% are Hispanic), 67% males and 33% females [11]. Because of this, researchers have an excellent opportunity to impact both Hispanics and women, who are traditionally underrepresented populations in engineering. The HSI’s engineering programs were initiated in 1913, two years after the campus was founded as a Land Grant Institution in 1911. As of today, there are six broad ABET-accredited undergraduate programs as well as strong graduate programs in Civil, Chemical, Computer, Electrical, Industrial, and Mechanical Engineering.

Moreover, this institution has played a critical role in the training of future Hispanic scientists and engineers in the U.S. Some key national rankings as described by the ASEE Profiles of Engineering and Engineering Technology Colleges [12] published in June 2010 include:

- # 1 in Engineering Bachelor's degrees awarded to Hispanics (614)
- # 3 in Percentage of Bachelor's degrees awarded to women (39.6%)
- # 3 in Engineering Bachelor's degrees awarded to women (243)
- # 15 in Engineering Undergraduate Enrollment (4,981)
- # 26 in Engineering Bachelor's degrees awarded (614).

The sample size of this study consisted of forty-five students, from which 65% of them were male. These participants were primarily junior (26%) or senior (70%) students who majored either in chemical (35%) or mechanical engineering (63%). Refer to Figure 2.

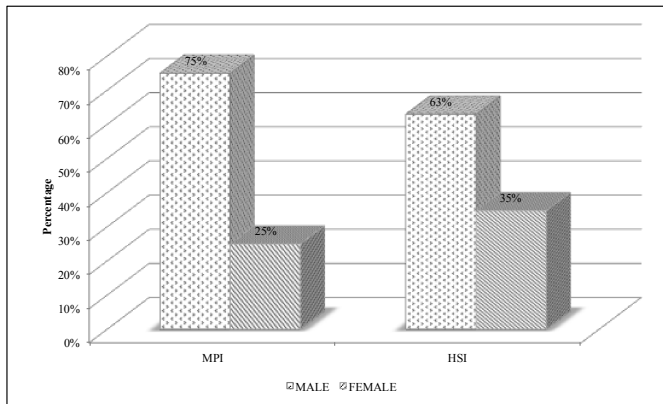


FIGURE 2
GENDER DISTRIBUTION

II. Participant Selection Process

Engineering students were invited to participate in the study via email. Participants had to have completed at least one of the following courses: thermodynamics, fluid dynamics, or heat transfer. At each institution, selected participants were assigned to either a control or experimental group according to their gender, major, grade point average (GPA), and total courses approved. The objective was to have a uniform distribution amongst both groups, control and experimental, within each institution.

Participants were recruited primarily from the chemical and mechanical engineering programs. Students were required to have approved at least one course in thermodynamics, heat transfer and/or fluid dynamics; being 18 years of age or older; being fluent in written English; and haven't previously participated in the study. They were invited by e-mail, which were provided by HSI's Office of Institutional Research and Planning. A description of selected participants is presented in Tables 1 and 2.

TABLE I
DESCRIPTION OF PARTICIPANTS FROM MPI

| | | MPI | | | |
|---------|----------------|---------|-----|--------------|------|
| | | Control | | Experimental | |
| Gender | Male | 27 | 82% | 21 | 68% |
| | Female | 6 | 18% | 10 | 32% |
| Year | Sophomore | 1 | 3% | 1 | 3% |
| | Junior | 13 | 39% | 18 | 58% |
| | Senior | 19 | 58% | 12 | 39% |
| GPA | 4.00 - 3.50 | 13 | 39% | 7 | 23% |
| | 3.49 - 3.00 | 7 | 21% | 14 | 45% |
| | 2.99 - 2.50 | 11 | 33% | 9 | 29% |
| | Other | 2 | 6% | 1 | 3% |
| Major | Chemical | 4 | 12% | 5 | 16% |
| | Mechanical | 17 | 52% | 13 | 42% |
| | Other | 12 | 36% | 13 | 42% |
| Courses | Thermodynamics | 31 | 94% | 31 | 100% |
| | Fluid Dynamics | 15 | 45% | 11 | 35% |
| | Heat Transfer | 6 | 18% | 4 | 13% |

TABLE II
DESCRIPTION OF PARTICIPANTS FROM HSI

| | | HSI | | | |
|---------|----------------|---------|------|--------------|-----|
| | | Control | | Experimental | |
| Gender | Male | 14 | 45% | 15 | 65% |
| | Female | 9 | 29% | 7 | 30% |
| Year | Sophomore | 0 | 0% | 1 | 4% |
| | Junior | 8 | 26% | 4 | 17% |
| | Senior | 15 | 48% | 17 | 74% |
| GPA | 4.00 - 3.50 | 7 | 23% | 5 | 22% |
| | 3.49 - 3.00 | 11 | 35% | 9 | 39% |
| | 2.99 - 2.50 | 5 | 16% | 8 | 35% |
| | Other | 0 | 0% | 0 | 0% |
| Major | Chemical | 9 | 29% | 7 | 30% |
| | Mechanical | 14 | 45% | 15 | 65% |
| | Other | 0 | 0% | 0 | 0% |
| Courses | Thermodynamics | 31 | 100% | 23 | 74% |
| | Fluid Dynamics | 11 | 35% | 22 | 71% |
| | Heat Transfer | 4 | 13% | 17 | 55% |

Specifically, the percentage of women participating in the study was higher for the HSI than for the MPI. This tendency was expected since the number of women enrolled

in engineering is higher for the HSI. Also, the HSI had more participation from senior students as compared with the MPI that had more junior students. An exception occurred for the experimental group at the MPI that had more senior than juniors. In terms of GPA, the majority of the students had a GPA of 3.0 to 3.49, except for the control group at the MPI that had more students at the highest range (3.5 to 4.0 GPA). At both institutions, the majority of the students belonged to the Mechanical Engineering department. Finally, students from the HSI had more courses approved from the thermal and transport sciences (either thermo, fluids mechanics, or heat transfer). A summary of the course distribution is depicted on Figure 3, which shows a bigger variability for the samples at the MPI within each of the groups (control or experimental).

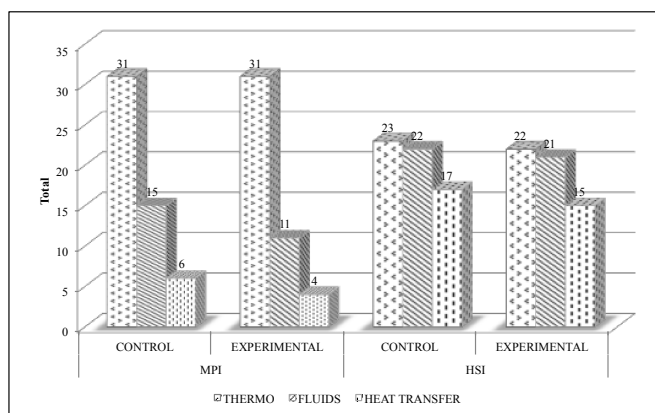


FIGURE 3
COURSES APPROVED

In summary, there are similarities and differences among these populations (HSI vs. MPI). Some of the similarities are as follows. First, participants were primarily from mechanical or chemical engineering. Second, both group were traditional engineering students in terms of age. Finally, participants have taken one, two or three courses in thermal sciences. The main differences include: (1) different ethnicity (Hispanic vs. non-Hispanic participants), (2) primary language differences (Spanish vs. English), (3) type of institution (undergraduate education vs. research intensive institutions), (4) program duration (5-yr vs. 4-yr academic programs).

III. Data Collection Process

Once participants were selected, at each institution, and randomly assigned to either the control or experimental group. They were given a user name and password to access and complete the learning modules available on-line through Blackboard. During the first day, participants completed the activities corresponding to Part 1, which required 3 to 4 hours to complete. The following day, they completed activities corresponding to Part 2. These activities required approximately 2 hours of time to complete. Participants were asked to take their time while completing the modules and researchers were asked to identify those who took less time and expected. Participants' confidentiality was

protected according to IRB requirements. Participation was voluntary and they received a compensation of \$60 after they completed the modules.

DATA ANALYSIS AND RESULTS

Quantitative comparisons for HSI and MPI participants were conducted on the pre- and post-test of heat transfer and post tests on diffusion and microfluidics. The shaded sections of Figure 1 represent the activities that were analyzed quantitatively, Table 3 depicts the mean gain for the experimental and control groups and Table 4 depicts the summary of the p-values that resulted from comparing significant differences between pre-test and post-test. Firstly, in terms of the mean gain for the experimental and control groups for both student populations (MPI and HSI), results show a significant average gain for the experimental group at the HSI as shown on Table 3.

TABLE III
MEAN GAIN

| | Group | Count | Average Gain | Std. Dev. |
|-----|--------------|-------|--------------|-----------|
| MPI | Control | 33 | 0.030 | 0.133 |
| | Experimental | 31 | 0.029 | 0.132 |
| HSI | Control | 20 | 0.050 | 0.139 |
| | Experimental | 20 | 0.105 | 0.101 |

Secondly, the p-value obtained for MPI's control group was equal to 0.500 (greater than 0.05), meaning that the difference between the average results of the pre-test and the average results of the post-test is not significant. Similar results were obtained for the MPI's experimental group (p-value = 0.510) and the HSI's control group (The p-value = 0.172). On the contrary, the p-value obtained for the HSI's experimental group was equal to 0.006, which means that the difference between the average results of the pre-test and the average results of the post-test is significant.

Thirdly, a two-way ANOVA was conducted to examine if either the group differences (control or experimental) or the test differences (pre- and post- Heat Transfer tests) had any significant influence over participants' results. The two-way ANOVA Test for the MPI population produced p-values of 0.128 and 0.467 for the group and test, respectively. This shows that neither the group (control or experimental) nor the test (pre- and post-) had significant influence on students' performance. For the HSI population results indicated that the group difference did not have an influence on students' results (p-value = 0.068), but on the contrary, the pre- and post-tests indicated an impact on participants' results (p-value = 0.021). Some students were eliminated from the ANOVA analysis because their post-test was incomplete.

Finally, a two-sample t-test was performed to determine if there is significant difference on students' performance on Diffusion, Microfluidics, and Heat Transfer items. Table 4 shows all the p-values obtained for both group of

participants (MPI and HSI) for the two-sample t-test. Results indicated a significant difference between average group results (control and experimental) for MPI and HSI for Diffusion items. In Microfluidics items, results from MPI participants showed significant difference between average group results. No significant difference was obtained for Heat Transfer items.

TABLE IV
SUMMARY OF P-VALUE RESULTS FOR T-TESTS

| | Two Sample T-test | | |
|------------|----------------------|--------------------------|--------------------------|
| | p-value Diffusion | p-value Microfluidics | p-value Heat Transfer |
| MPI | 0.044 (Y) | 0.018 (Y) | 0.976 (N) |
| HSI | 0.044 (Y) | 0.305 (N) | 0.0160 (N) |

DISCUSSION AND CONCLUSION

This paper discusses the effectiveness of the STM among populations from two different institutions (MPI and HSI). The outcomes of this study provided some evidence about the variability of performance of the different populations on the STM. Results indicated a greater effectiveness of the STM among the Hispanic population as evidenced from the average gains depicted in Table 3. But as shown in Table 4, in general, participants from the MPI performed better having significant differences in their post-test performance in the Diffusion and Microfluidics concepts. We have previously suggested that one potential explanation of the low effectiveness of the STM on student learning could be that robust misconceptions are resistant to be repaired through traditional teaching methods. For the case of HSI students an additional factor to consider could be the fact that the learning resources were not in their mother tongue—i.e., Spanish.

The main contribution of this study was the comparison of performance on STM with different populations. STM has been designed to help repair robust misconceptions, which are resistant to repair by traditional teaching methods. Further qualitative analyses of students' verbalization of their reasoning are being conducted to determine the role of language in students' conceptual change.

ACKNOWLEDGMENT

The authors would like to thank the National Science Foundation for supporting this project: Developing Ontological Schema Training Methods to Help Students Develop Scientifically Accurate Mental Models of Engineering Concepts (EEC-0550169). We would also like to acknowledge the collaboration with the recruitment and data collection process of undergraduate students Rosaurelis Marín, Laura Nieves, and Paola Pacheco.

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Work in Progress: What do engineering students do with non-academic information as they address authentic socio-technical problems?

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Abstract—This paper focuses on the knowledge construction process in a technology and society course in which engineering students propose solutions to authentic socio-technical problems in India. Student definition and use of non-academic information is examined with the recommendation that documentation practices be further developed to accurately reflect community contribution. Implications for the global engineering workplace are also addressed.

Index Terms—community service-learning, global engineering, information literacy, problem-oriented learning, social context, technical communication.

I. INTRODUCTION

With the call for “high impact, high engagement” activities [1] becoming louder, faculty members across the disciplines are looking for ways to integrate individualized experiential learning opportunities, such as those fostered by Community Service-Learning (CSL) projects, into their classes and assignments. The integration of CSL activities into the curriculum raises many questions that were previously considered irrelevant. Within the context of engineering, several questions arise: How do students value and document non-academic information as they are drawn into the co-creation of a new knowledge base? What implications does this broad approach to knowledge-making and problem-solving have for life-long learning, after engineering students have graduated and may no longer have access to traditional academic databases as they work in a global workplace, where they may work on interdisciplinary teams without direct contact to their clients?

II. CONTEXT

This study explores these questions through the context of a technology and society course subtitled “The Global Engineer” at the University of British Columbia, in Vancouver, Canada. As an elective three-credit course, Applied Science 263 introduces students to the emerging discourse on global engineering [2], [3], [4] and satisfies the

“Impact of Technology on Society” requirement for the Bachelor of Applied Science degree. The course is mainly taken by students in all engineering disciplines but is also open to students in the Faculty of Arts, and interdisciplinary perspectives are strongly encouraged through a variety of assignment genres to open discussion on questions of legitimate knowledge, to encourage critical thinking, and to instill notions of life-long learning: requirements set out by ABET Criteria 3 [5].

As a variant of CSL, this course enables students to address authentic socio-technical problems identified by rural artisans in India without travelling to India. Information about the problems is sparse, mainly photographic in nature, and transmitted through a social entrepreneur (Maiwa Handprints Ltd.) based in Vancouver and active in the organic textile and crafts sector in India. Many of the 3000 Maiwa-affiliated artisans are part of the “Dalit” or “untouchable” caste and have little access to public resources.

Although students have no direct contact with the artisans themselves, they have informally reported that they are motivated by the impact their assignments may have. With a focus on social context, the course requires students to expand their research skills and explore a broad range of resources, spanning academic and non-academic information, in order to develop culturally appropriate, technically feasible and sustainable solutions to the given problems. As Barsky et al point out, students in this kind of course have learned the value of broadening their traditionally defined disciplinary knowledge by acknowledging that “other” people may hold useful knowledge and insight that may not be documented in double-blind, peer-reviewed journals [6]. Several students have also commented on the intersection of written and oral cultures in the course. Students are encouraged to engage in “contextual listening,” as posited by Lucena et al [7], but what does this mean if students cannot, for various reasons, communicate with the artisans? How then can students gain access to contextual information needed to develop socially appropriate, feasible, and sustainable technical solutions?

III. METHODOLOGY

This study consists of quantitative and qualitative data, the implications of which are part of a larger ongoing research project on multimodal literacy practices among engineering students across five cohorts of Applied Science 263 at the University of British Columbia. Of the 2012 class (the fourth cohort), 31 students volunteered to participate in an anonymous survey of six questions on their use of non-academic sources to gain insight into the social context of the given technical problems. After final grades had been released, the identity of the participants was revealed, so that the survey results could be reviewed in relation to the sources referenced in the respective Recommendation Reports and Formal Reports. Survey results were tabulated in quantitative terms and compared with the quantitative use of academic and non-academic sources listed in the reference sections of their Recommendation Reports and Formal Reports.

The Recommendation Reports constituted integrative literature reviews of the Formal Reports submitted by previous cohorts (used with permission) to generate new perspectives and frameworks for further investigation of the problems. Students in the 2012 cohort then used their Recommendation Reports as a basis for their own investigation documented in the Formal Reports, “concluding” with recommendations for further investigation for the incoming cohort in 2013.

IV. FINDINGS

A. Quantitative Results

This paper will focus on the first, fifth, and sixth questions in the survey. Firstly, to define what “non-academic” might mean, students were provided with an open-ended checklist of possible sources that included the following: “blogs, industry newsletters, magazine articles, photographs, podcasts, radio and television shows, websites from government organizations, websites from private-sector companies and corporations, YouTube videos, other_____.” Twenty-nine percent of the students checked off all sources, with one student stating “anything not published in a journal” and another student checking off none, commenting that “it depends on who produces the material and how it is referenced.” Of the remaining 71% who did not check off everything or nothing, YouTube videos received the largest vote, with 48% considering information derived from this source to be “non-academic.” Blogs, photographs, and websites from private-sector companies and corporations also received a clear “non-academic” vote at 45% each. While these results may seem conservative in their implications, they reveal a significant shift in thinking that is expressed more clearly in the final question.

In the final question, students were asked to what extent they think the use of non-academic sources is important “to understand the socio-cultural context of any technical problem anywhere” and were given four possibilities: not important, somewhat important, very important, and essential. Unexpectedly, the “essential” and the “very important” categories received approximately 2/3 of the responses. No one responded “not important.”

B. Qualitative Results

Reviewing work by previous cohorts demonstrated to students that “solving” (i.e. addressing) authentic socio-technical problems is a work in progress that extends beyond student timetables, academic calendars, and university classrooms. The Recommendation Reports were difficult to gauge in light of the above findings. Slightly over half the Recommendation Reports contained citations to additional sources, which were primarily non-academic in nature, in the critique of the sources used by previous cohorts.

With regard to the Formal Reports generated from the Recommendation Reports (integrative literature reviews), 23% of students reported in the fifth survey question that slightly 3/4 of their research for the Formal Reports was based on information from non-academic sources, with 45% stating roughly 1/2 and 26% indicating approximately 1/4 of their research for the Formal Reports was. While the information referred to in the Formal Reports suggests that the majority of students underestimated their actual use of non-academic sources, this becomes difficult to ascertain given the above shift in definition of “non-academic” and, in some cases, the incomplete documentation of sources.

V. PRELIMINARY CONCLUSIONS

The cumulative layering of knowledge across cohorts for a problem-oriented CSL course illustrates the complex nature of addressing, if not solving, authentic socio-technical problems in a global environment; it also demonstrates that instructors and students need to clarify together how to value and document the use of non-academic sources in such an endeavor.

Further work in this study involves strengthening the link between quantitative results and qualitative assessment. Student self-reports on their estimation of how much of their research was based on academic and non-academic sources need to be more closely tied to the type and quality of research coverage in their Formal Reports rather than simply using the Reference section of the Formal Reports as an indicator of the use of academic and non-academic sources. To increase awareness and ownership of students in the knowledge creation process, next steps involve working with students to further develop content analysis expectations. Further work is also required in the re-mapping of documentation conventions, as they pertain to the broader ramifications for information access and ownership by the community, with a view to indigenous scholarship [7].

As universities become more engaged in community work, non-academic voices will gain in participatory parity and the use of non-academic sources will become increasingly legitimate. Students will need to learn how to negotiate boundaries and definitions of academic and non-academic information for the benefit of engineering in service to the non-academic community. The need to uphold both student and professional codes of ethics also presents the challenge of knowing how to document non-academic sources in a manner that accurately reflects the contributions, information access and ownership of the non-academic community. These

challenges hold far-reaching implications for student development of critical thinking skills and life-long learning values, as required by the 21st-century engineer in a complex and dynamic global workplace [2], [8].

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Eliciting Yucatan Peninsula Teachers' Images of Engineering and Engineers

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Abstract—Data were collected using the *Draw an Engineer* test followed by unstructured informal interviews to determine individual conceptions of engineering and what engineers do, as well as to make a comparison between teachers' conceptions from two states of the Yucatan peninsula. Drawings and open-ended responses were analyzed following an inductive data analysis approach. Four main categories emerged: 1) engineers in action, 2) characteristics of an engineer, 3) gender, and 4) work context. The majority of participants in this study perceive engineers as male individuals that perform activities related to construction (in the case of Quintana Roo) or oil (in the case of Campeche) industries. Interviews supported main findings while helping researchers gain insight into individual reasoning behind the interviewed teachers' drawings and answers. Our results suggest differences on how Yucatan peninsula teachers perceive engineering and engineers based on the state where they are from, their gender, and grade in which they teach.

Keywords—*Draw an Engineer; images of engineering and engineers; Yucatan*

INTRODUCTION

Mexico is one of the countries with the largest percentages of students performing below the baseline Proficiency Level 2 in mathematics and sciences among the *Organisation for Economic Co-operation and Development* (OECD) nations [1].

Given the crisis that Mexico faces in mathematics and science education in the P-12 levels, *Universidad de las Américas Puebla* started a research program to develop solutions to help overcome this situation. This investigation is part of a broader project funded by the Campeche State Council for Science and Technology (*Consejo Estatal de Investigación Científica y Desarrollo Tecnológico de Campeche*). Its goal is to promote an early approach to engineering and science among the student population at the upper elementary, middle and high school levels of the State of Campeche by creating high quality learning environments that promote interactive classrooms and contribute to a better understanding of science and mathematics while promoting careers in science, engineering and technology [2].

In general, Mexican teachers have an incomplete understanding of engineers and engineering as a profession [3]. Images shape the way individuals view the world [4], thus, eliciting and understanding the image teachers have of engineers and engineering is extremely important in order to

develop programs and curricula that encourage engineering teaching and learning at the P-12 school levels [3-13].

Subject-produced drawings offer a simple and unique way for researchers to assess individual conceptions. These individual-produced drawings offer a window into human sense making that is often beyond description using mere words [5]. Psychologists, scientists, sociologists, anthropologists, and education researchers, among others have used and continue to use subject-produced drawings in their research. In the 1950s, the famous anthropologist, Margaret Mead, asked US students to draw pictures of scientists [6]. The "Draw a Scientist (DAS) test" has been widely used to assess students' attitudes about scientists [7], even with Mexican students [8]. To help assess students' ideas about engineering a "Draw an Engineer test" was developed [4, 9, 10] derived from the DAS test. In order to explore and document teachers' perceptions about engineering and engineers, the following sections describe a study conducted in the Yucatan peninsula using drawings and open-ended questions as the primary data collection tools. The primary goal of this study is to provide an original account of the sort of images teachers from two states from the Yucatan peninsula have of engineers. From this overarching goal, this study attempts to answer the following research question: how do gender, grade level, and state where they are from influence Campeche and Quintana Roo teachers' images of engineers?

METHODS

Data were collected using the *Draw an Engineer* (DAE) test followed by unstructured informal interviews [2-3, 6-8]. 179 teachers participating in the study were given the DAE test at the beginning of two unrelated workshops in the Yucatan Peninsula, one in the state of Campeche (45 participants) and the other in the state of Quintana Roo (134 participants). The purpose of the DAE test was to determine individual conceptions of engineering and what engineers do as well as to make a comparison between teachers' conceptions from two states of Yucatan Peninsula.

Teachers were given 10 min to draw an engineer (previously they were asked to close their eyes and imagine an engineer at work) and then 10-15 min to answer three question prompts related to what they had drawn: 1) Describe what the engineer is doing in your drawing. Write at least two sentences. 2) List at least three words/phrases that come to mind when you think of an engineer. 3) What kinds of things do you think

an engineer does? A copy of the test worksheet is provided at the Appendix. It is worth noting that Spanish language places nouns into gender classes; therefore, the instructions mentioned both a male (*ingeniero*) and a female (*ingeniera*) engineer to ensure gender neutrality in the test directions [2].

Workshop facilitators were careful not to talk about engineers or engineering during the administration of the DAE test. Facilitators offered help to clarify directions and question prompts, but they did not offer any ideas or assistance that would influence teachers' original conceptions of engineers or engineering [2, 3]. Thirty informal interviews (which were videotaped) were performed during the DAE test and consisted of one-on-one discussions between a facilitator and teachers (10 from Campeche and 20 from Quintana Roo) to further investigate reasoning's behind his/her drawing and responses.

Drawings and open-ended responses were analyzed by three researchers (i.e., the last author and two doctoral students, which are the first two authors). Following the procedure described by Oware *et al.* [13], an inductive data analysis approach was utilized to code the drawings and written responses. After reading and re-reading the questionnaire responses and discussing their impressions of the entire data set, the researchers created a coding scheme that included four main categories to describe the data. Using this coding scheme, researchers coded each participant's response at the same time. This procedure allowed the researchers to resolve any discrepancies during the coding process [2].

RESULTS AND DISCUSSION

Gender detailed information regarding the demographic status of the teachers' population is presented in Table 1. Approximately 42% of the teachers were from elementary school (grades 1-6 in Mexico), 25% from middle school (grades 7-9 in Mexico), 15% from preschool and kindergarten, 12% from high school (grades 10-12 in Mexico), while the rest were university teachers.

TABLE I. PARTICIPANTS BY GENDER

| GENDER | QUINTANA ROO | | CAMPECHE | |
|--------|--------------|--------|----------|-------|
| MALE | 27 | 20.1 % | 28 | 62.2% |
| FEMALE | 107 | 79.9 % | 17 | 37.8% |
| TOTAL | 134 | | 45 | |

In this section we will use the term *drawing* to represent a teacher's drawing and question responses. Interviews supported main findings while helping researchers gain insight into individual reasoning behind the 30 interviewed teachers' drawings and answers.

In the case of Quintana Roo, as previously reported [3], analysis of the teachers' drawings and answers to question prompts indicated the emergence of three main categories: 1) Engineers in action, 2) Occurrence of gender, and 3)

Engineering tools. Key elements that depicted engineers in action included drawings of engineers building, repairing, designing, supervising, or experimenting. Drawings recorded as Repairing-Building represented 22% and portrayed mainly engineers working on a construction site. Further, 83% of the drawings were recorded as Designing-Supervising-Experimenting, depicting individuals who are mainly supervising others work. Engineering tools corresponded to the activity depicted in the pictures and included specific tools, equipment, and clothing, such as helmets, blueprints, drafts, cranes, and shovels. The most common activities related to engineering were supervising, designing, and directing a construction, process or people; some Quintana Roo teachers draw other activities and tools including some engineers experimenting, laboratory materials, lab coats, glasses & goggles, in these particular drawings were depicted female engineers doing research [3].

Many figures from Quintana Roo teachers displayed images of an engineer focusing on the mental aspects of engineering. The fact that so many teachers portrayed engineers with high level of mental functions (explaining and/or experimenting) is very interesting. It reveals that many Quintana Roo teachers' perceived an engineer more as a "thinker" rather than a "doer" which represents a lack of perception instead of an inaccurate perception [3].

In the case of Campeche (Figure 1), four main categories emerged from teachers' drawings and open-ended responses: 1) engineers in action, 2) characteristics of an engineer, 3) gender, and 4) work context. 62% of Campeche teachers describe engineers in action (engineers working in oil related activities, construction related work, or office related work as depicted in Figure 2).

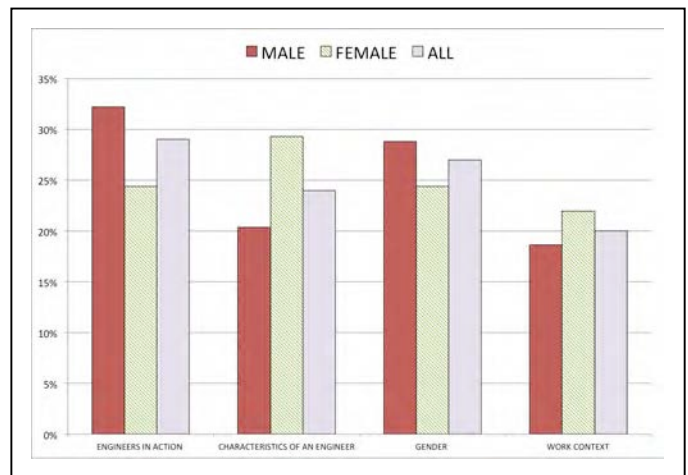


Figure 1. Distribution of images in Campeche teachers' drawings of engineers.

It is important to point out that close to 39% of Campeche teachers mention a category that does not come up in the case of teachers from Quintana Roo, i.e., an engineer working in the corresponding area of expertise of the teacher (drawing of his/her profession, i.e., university professor drawing of himself in Figure 3). 53% of teachers mention that among the characteristics of an engineer are the wit, intelligence,

enthusiasm for mathematics, as well as abilities for design, administration, planning, and supervision. Furthermore, 60% of Campeche teachers refer to an engineer working in a specific context, like at the Mexican oil company (PEMEX: *Petróleos Mexicanos*).

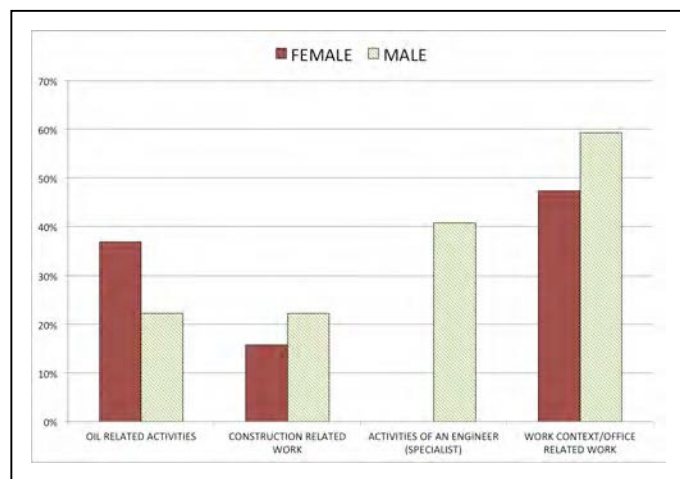


Figure 2. Distribution of images for the category "Engineers in Action" in Campeche teachers' drawings of engineers.



Figure 3. Examples of an engineer drawn by a university professor (top) and a middle school teacher (bottom).

With regards to gender, Yucatan peninsula teachers' responses were classified into one of three categories (i.e., female engineer, male engineer, or unknown-gender engineer) according to the characteristics depicted in their drawings as

previously reported [2]. Pictorial representations were categorized observing stereotypical features associated to a specific gender; for instance, long hair was associated to a female engineer (see top of Figure 5) and short hair to a male engineer. Drawing descriptions also helped to figure out the characters' gender. Furthermore, some participants made explicit the gender of their character using the nouns *ingeniera* or *ingeniero* for a female or male engineer, respectively. In those cases with no clear indication of a specific gender, characters were coded as unknown-gender (both/neutral figure) engineers.

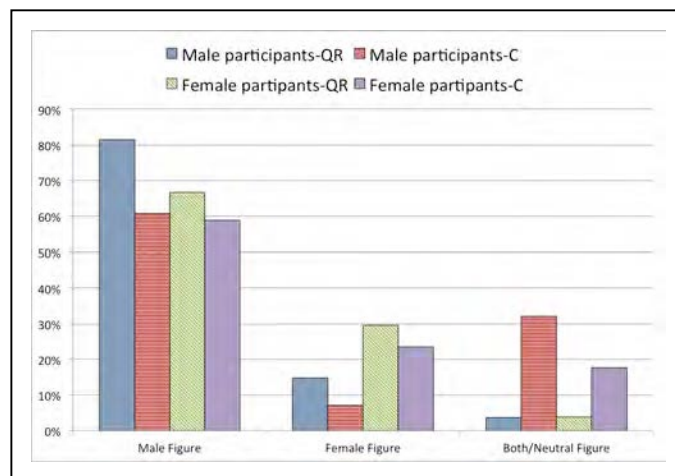


Figure 4. Occurrences of gender among male or female participants' drawings from Quintana Roo (QR) or Campeche (C) teachers.

Even though the female participants (124) were almost three times the number of male participants, the majority of Yucatan peninsula teachers perceived engineers as male individuals (Figure 4) that perform activities related to the construction (in the case of Quintana Roo) or oil (in the case of Campeche) industries as depicted in Figure 5. Female participants displayed a stronger tendency to draw female engineers than their male counterparts (Figure 4).

Perceiving science related fields as male-dominated arenas is the stereotypical image among the general population across borders [14], including Latin American countries [8, 15]. In the particular case of engineering, recent studies based on the DAE test have shown that the male-dominated stereotype is the predominant view held by P-12 United States [4-5, 9-12] as well as Mexican [2, 3] students and teachers.

Living in a state where the oil industry is the economic driver of the region, most Campeche participants' drawings depicted what they see in their everyday life near Ciudad del Carmen (where the Campeche workshop took place): oil rigs and jumpsuits from PEMEX; while living in the Mexican state where most building is taking place, the majority of Quintana Roo participants' drawings depicted construction sites as representative of what is usual nearby Playa del Carmen (where the Quintana Roo workshop took place). Results from this study confirm that cultural models to which Yucatan peninsula teachers are exposed can contribute significantly to their mental schema, as suggested by Gardner [16].

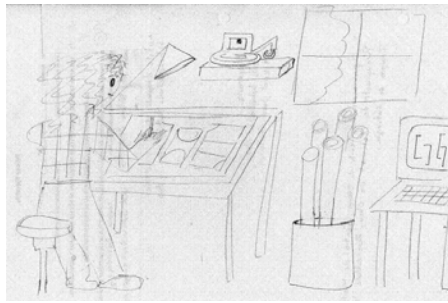


Figure 5. Drawing examples of an engineer from Quintana Roo (top) and Campeche (bottom).

It is important to mention that the two subcategories that more frequently appeared in this study exhibited some variation by gender. 30% of the men from the study in Quintana Roo mentioned features related to the oil industry, while 21% of the women mentioned aspects regarding this subcategory. In contrast, 21% of the men from Campeche mentioned characteristics related to oil industries, while 41% of the women did it. With regards to the subcategory related to construction work, 28% of the teachers in Quintana Roo mention it, but 36% women stated aspects related to it. The percentages by gender of Campeche teachers in this category were similar (21% of men vs. 17% of women).

Very few Quintana Roo or Campeche teachers had accurate perceptions of engineering. Selected answers to the question “Describe what the engineer is doing in the picture” probe an accurate knowledge about what an engineer does as can be seen in Figure 6. However, most of them are far from actually depicting an engineer in action [3]. This means that if Yucatan peninsula teachers’ perceptions of and attitudes toward engineering are not accurate, they could play a significant role in perpetuating incorrect perceptions about engineering [3, 17]. This could be reflected into their curricula and in the way they deliver messages about the nature of engineering to their students. As already stated, images shape the way individuals view the world [4], thus, eliciting and understanding the image Quintana Roo and Campeche teachers have of engineers and engineering was deemed extremely important in order to help the development of programs and curricula that could encourage engineering learning in the Yucatan peninsula.

FINAL REMARKS

Outcomes from this study confirm that cultural models to which humans are exposed can contribute significantly to their mental schema. Our results suggest differences on how Yucatan peninsula teachers perceive engineering and engineers based on the state where they are from, their gender, as well as the grade in which they teach.

Given that teachers’ ideas, knowledge and attitudes towards engineering and science might influence their students’ perceptions toward these fields, it was considered necessary to explore the conceptions held by Yucatan peninsula teachers to prevent (or correct) potential misconceptions. Addressing potential misconceptions is of critical importance since it has been established that student’s negative images and stereotypes about engineers and engineering can influence their career choice, making them less likely to pursue a career in this field [2, 18]. Therefore, we are implementing a program to encourage engineering learning at the P-12 school levels in the Yucatan peninsula, which consists of engineering teaching kits (ETKs), corresponding lesson plans, and professional development workshops in order to help teachers learn about engineering as well as implement the ETKs in their classrooms where their students are learning science and mathematics through guided inquiry, conceptual change, and engineering design [19, 20].

- She is carrying some blueprints to show her colleagues the projects that she has planned, since these blueprints are a lot, a friend comes down to help her.
 - *Está llevando los planos para mostrarle a sus compañeros los proyectos que tiene planeados, como son bastantes un amigo baja para ayudarlo.*
- He is supervising the construction work of a school, he is comparing his notes to the work that has been done by the workers and he is indicating how to perform the work.
 - *Supervisando los trabajos de la construcción de una escuela, comparando sus apuntes con lo que hacen los trabajadores e indicando cómo hacer las cosas.*
- Directing a construction, verifying that all the workers are carrying out their function and supervising.
 - *Dirigiendo una construcción, verificando que todos los trabajadores estén realizando su función y supervisando.*
- The engineer is collecting rubble from the construction.
 - *El ingeniero está recogiendo escombros de una obra.*
- The engineer thinks and works making models of buildings, physical and natural phenomena.
 - *El ingeniero piensa y trabaja en la elaboración de modelos de obras, fenómenos físicos y naturales.*
- He/she is thinking about how to relate his/her knowledge with new technological applications.
 - *Está pensando como relacionar sus conocimientos con las aplicaciones tecnológicas.*
- The engineer is working offshore in an oil rig.
 - *El ingeniero se encuentra trabajando en altamar en una plataforma.*
- The engineer is making blue prints, solving technological problems for oil extraction.
 - *El ingeniero está haciendo planos, resolviendo problemas tecnológicos para la extracción de petróleo.*

Figure 6. Selected quotes as examples of accurate perceptions from Quintana Roo and Campeche teachers.

The *Draw an Engineer* test used in this study proved to be a useful tool to identify Yucatan peninsula teachers' perceptions about engineering and engineers as previous studies suggested for students and teachers [2-5, 9-12]. However, the particular characteristics of the study context, the sample size, and some limitations related to the instrument utilized to collect the data [14], prevent us from making generalizations from our findings. In future studies, we will explore the suitability of the DAE checklist developed by Fralick *et al.* [21] and its flexibility to identify perceptions heavily based on a particular context [2].

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APPENDIX

Draw an Engineer Test Worksheet

Género: hombre ____ mujer ____
Estado ____
Grado en el que imparte clase: ____
Años de experiencia docente: ____

LOS RESULTADOS DE LA ENCUESTA SE MANEJARAN DE
FORMA AGREGADA Y CONFIDENCIAL

DE ANTEMANO MUCHAS GRACIAS POR SU
RETROALIMENTACIÓN

Ponga su nombre, teléfono y dirección de correo electrónico
SOLAMENTE si desea participar de forma voluntaria en una entrevista
posteriormente.

Teléfono:
Nombre:
e-mail:

1. Describa qué está haciendo el (la) ingeniero(a) de tu dibujo. Utilice al menos dos frases
2. Enliste tres palabras o frases que vengan a su mente cuando piensa en un(a) ingeniero(a)
3. Desde su perspectiva, ¿qué tipo de actividades piensa que son propias de un(a) ingeniero(a)?

Gender: male ____ female ____
State ____
Grade(s) in which you teach: ____
Years of teaching: ____

RESULTS FROM THIS SURVEY WILL BE HANDLED AS
AGGREGATES AND CONFIDENTIALLY

THANK YOU VERY MUCH IN ADVANCE FOR YOUR FEEDBACK

Write your name, phone, and e-mail ONLY if you are willing to
voluntarily participate in a follow- up interview.

Phone:
Name:
e-mail:

1. Describe what the engineer is doing in your drawing. Write at least two sentences
2. List at least three words/phrases that come to mind when you think of an engineer
3. What kinds of things do you think an engineer does?

Introducing “Stickiness” as a Versatile Metric of Engineering Persistence

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Abstract—A new metric, “stickiness,” is proposed, tracking longitudinally all students who have contact with a discipline to determine the likelihood those students will “stick” to that discipline and graduate in it. This metric has the versatility to be relevant for students making contact with engineering through a variety of pathways. Stickiness exhibits significant disciplinary differentiation. Whereas earlier work has shown that Industrial Engineering is the most successful at attracting and retaining students, the disciplinary distribution of stickiness shows that Industrial Engineering is exceptional. Disaggregating by race/ethnicity and gender, much larger variations in stickiness are observed (as much as 48 percent), and positive and negative outcomes are identified where students in particular subpopulations are more or less likely to stick than expected. Aggregated by race/ethnicity and gender, the stickiness of transfer students ranks the disciplines in the same order as the stickiness of first-time-in-college students, but transfer stickiness exhibits less disciplinary variation and transfer students in all disciplines exhibit higher stickiness than first-time-in-college students.

Keywords—retention; persistence; metric; transfer students; longitudinal

I. MEASURING PERSISTENCE IN ENGINEERING EDUCATION

A review of approaches to measuring persistence in engineering education has been presented by Ohland, Brawner, Camacho, Layton, Long, Lord, and Wasburn [1]. That work catalogued measures of persistence, characterized philosophical differences in the assumptions underlying those metrics, and described how the choice of metric results in underestimating or overestimating persistence in certain populations. That earlier work does not discuss in detail how the choice of a metric affects the population that can be studied. A discussion of various study designs and metrics follows. The population restrictions imposed by each are discussed along with the effect of those restrictions on the interpretation and impact of the results. These approaches are used by many researchers, but

our goal is to focus on methodological issues, so the examples here are drawn from earlier work using the same data source.

A. Graduation rate of a matriculating cohort

One of the most common research designs is a cohort study in which persistence of a cohort matriculating at the same time (or at least approximately the same time) is computed at various points, typically culminating with a six-year graduation rate. This is consistent with results that are submitted for accountability to external bodies [2, 3]. Cohort studies are primarily limited by who is included in the cohort. Since 1997, “Graduation Rates (GR)” from the Integrated Postsecondary Data System (IPEDS) [3] have been used to satisfy the terms of Student Right-to-Know legislation. These report the fraction of full-time, first-time, degree / certificate-seeking undergraduate students in a particular year (cohort), by race/ethnicity and gender completing a program in 150 percent of normal time. Because these rates are used to satisfy that legislative mandate, they are among the most commonly known and cited measures of an institution, yet this definition fails to consider part-time students and transfer students. Each of these populations poses challenges to the determination of “normal time”. The expected graduation time of part-time students can only be guessed. Inferring the cohort of each transfer student based on the number of credits transferred not only risks overestimating the contribution of those credits toward each student’s degree program, but also results in a cohort size (denominator) that changes with time, which can result in confusion or suspicion. These populations are left out of most studies [1, 4, 5, 6], which results in a lack of understanding of an educational pathway that is used by a large and growing number of students, particularly students from low socioeconomic backgrounds. Community colleges enrollments are 45 percent minority students, 42 percent first-generation students, and 46 percent students receiving aid (though there is certainly overlap among these groups) [7].

B. Cohorts of students in a single discipline

Studying persistence of disciplinary cohorts results in similar challenges to studying matriculation cohorts, but poses some additional challenges as well. If the study population (the denominator) is the number of students enrolled in a particular discipline at matriculation, then students who graduate in that discipline but who matriculated in other disciplines are removed from consideration. This overestimates the negative impact of the department in which the student matriculates, because it counts all students who switch majors as a loss, and also underestimates the contribution of the discipline that attracts and graduates the student. Particularly in engineering education, the diversity of matriculation models [8] poses problems for disciplinary cohort studies. A disciplinary cohort that is formed after students have completed a first-year engineering program will naturally have a higher graduation rate than a cohort formed at matriculation. Variation in time to complete the first-year engineering program adds further confusion to the establishment of disciplinary cohorts. In some cases, cohorts are formed from students enrolled in a particular discipline in the third semester (with the limitation that this represents varied levels of curricular progression) [1], and in other cases, institutions with first-year programs are excluded from study [6].

C. Composition of a graduation cohort

Focusing on the composition of the students graduating in a year or other time period is also valuable. This converging design provides a profile of the completers, which is therefore a description of the alumni of an institution. Comparing graduation cohort profiles to matriculating cohort profiles identifies populations that are not being successful to graduation. Further, comparing graduation cohort profiles to the institution's target population (the state population in the case of a public university) reveals the degree to which that target population is being served. The biggest risk in studying graduation cohorts is that the researcher is required to notice who is missing from the population.

D. Criteria for developing a new metric

Thus, there is value in developing a metric that can be used to study part-time students, transfer students, students who switch disciplines, and students who choose a discipline after entering in a non-disciplinary pathway (first-year engineering, or various "undeclared" or "undesigned" pathways). Transfer students are of particular interest because community colleges are more diverse than four-year institutions, both in terms of race/ethnicity and in a socioeconomic sense [7]. A new metric should minimize the effect of pooling students from multiple cohorts, who may be different in important ways as population changes occur over time. Satisfying these criteria will increase the size of the populations available for study, increase the applicability of the findings to populations of interest, and include a more diverse group of students and institutions.

II. INTRODUCING "STICKINESS" AS A NEW METRIC

We propose a new metric, "stickiness," that permits considering all these subpopulations with a single, unifying assumption: selecting a major indicates intent to graduate in that major. The stickiness of a major describes how likely students are to "stick" to a particular major once they choose it—regardless of what other majors they have had previously, what other institutions they have attended, or how long they have been in college when they first enroll in that major. The term "stickiness" is derived from Gladwell's use of the term in *The Tipping Point*, in which stickiness is defined as the specific content of a message that renders its impact memorable [9]. In the case of a disciplinary degree program, it is the specific content (or culture) of a program that makes students stay through to graduation.

A. Mathematical definition of stickiness

Specifically, the stickiness of a major is calculated as the number of students who graduate in that major divided by the number of unique students who have ever been enrolled in that same major, so it is a number between 0 and 100 percent. If this number is the "specific stickiness" of a major, two corollary numbers can be calculated: the "group stickiness" of a major is the percentage of students ever enrolled in that major who graduate in a group of related disciplines (engineering is the disciplinary group of interest in our work, although Science, Technology, Engineering, and Mathematics (STEM) more generally is of broader interest to the National Science Foundation and other national groups). Similarly, the "university stickiness" of a major is the percentage of students ever enrolled in that major who graduate from the university in any major. In our work, all these graduations occur in six years or fewer from when the student first matriculated to the institution from which they graduated.

B. What stickiness really measures

The assumption that students who select a major intend to graduate in that major leads to a corollary assumption: *when a student is allowed to major in a degree program (through any pathway), a commitment has been made by the institution and/or program that the student will be supported to succeed and graduate in that major*. Thus, stickiness is not just a measure of attractiveness to students, but it is fundamentally a measure of the degree to which a degree program (or group of degree programs, or university) makes and lives up to that commitment. Because stickiness is focused on measuring this degree of commitment, the effect of pooling students matriculating in different cohorts that may change in various ways over time is not perceived as an issue. In other words, even if there is variation among the populations that are pooled, we do not believe this introduces a bias in the measurement of interest. Stickiness allows direct comparison of majors, groups of majors, or universities. While the stickiness per se may not be that important, the relative stickiness of one group compared to another gives an indication of how that group is faring. This can be done at the level of major, race, gender, groups of majors, institution, or entry point (FTIC vs. transfer). This minimizes biases because the same metric is applied to all so if all have the same treatment, all should have the same result.

III. A DATASET FOR TESTING THE STICKINESS METRIC

The stickiness metric is tested using the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD). MIDFIELD comprises a census of undergraduate students that attended eleven public institutions in the U.S. between 1988 and 2009. Accounting for 11 percent of U.S. engineering graduates, MIDFIELD institutions represent public universities that educate large numbers of engineering students. A detailed description of the MIDFIELD database is available elsewhere [4]. From the records of 977,950 students in MIDFIELD, we restricted our sample to those who (a) were domestic students identifying as Asian, Black, Hispanic, or White (927,350), (b) entered the data set early enough to have the possibility of graduation within six years (662,736), and (c) ever declared a major in engineering or otherwise expressed an intention to study engineering (145,579). Race/ethnicity is based on student self-reporting from among institutional choices. Three of the institutions have first-year engineering programs while the rest permit direct matriculation into an engineering discipline. Note that all institutions can be included in analyses with the stickiness metric. At FYE schools, students must wait to declare a specific engineering discipline as their major. However, each discipline at these schools is in the same situation so useful comparisons can be made.

We wanted to explore a range of disciplines that are likely to have different cultures and variation in student outcomes. Majors with large populations and higher-than-average percentages of women were included. Electrical (EE) and Mechanical (ME) each contribute to more than 20 percent of the engineering students in our dataset. These are the only majors offered at all 11 MIDFIELD institutions. Chemical (ChE), Biomedical (BE), and Industrial (IE) engineering all have more than 30 percent women at graduation. Computer Engineering (CpE) was also included for several reasons. It is often combined into a single department with Electrical, has a very similar curriculum to Electrical but our prior work has already seen different outcomes for students, and it has the smallest percentage of women of any engineering major [6]. All disciplines included were offered at a minimum of 8 schools in our dataset for at least four years.

To enable us to illustrate the usefulness of the stickiness metric with various populations, we have chosen to use dot plots and multiway plots. These are tools for visualizing, exploring, and presenting categorical data [10]. Here, we consider the stickiness metric for different engineering disciplines, disaggregated by race/ethnicity and gender, as well as different matriculation pathways. Thus the six engineering disciplines are the rows and the horizontal axis is the stickiness in percentage. Each dot represents the stickiness of a particular population in a specific engineering discipline.

IV. DISCIPLINARY DIFFERENCES IN STICKINESS

In introducing this new metric, we show that stickiness varies more than 20 percent among engineering disciplines, that the stickiness of a particular major varies by race/ethnicity and gender, and that transfer students are “stickier” than FTIC students. Here we focus on the specific stickiness of engineering disciplines rather than groups or institutions.

A. The Specific Stickiness of Six Engineering Disciplines

Figure 1 illustrates the variation of specific stickiness among six engineering disciplines. As described earlier, the stickiness of each discipline is the number of students who graduated in that major divided by the number of students who ever declared a major in that discipline (N^e). Here, stickiness is expressed as a percentage. For example, in IE, the stickiness is about 55 percent, meaning 55 percent of the 9532 students who ever declared a major in IE graduated in IE in six years. In contrast, the stickiness of CpE is much lower with only about 33 percent of those students who ever declared a major in CpE obtaining a degree in CpE. EE, with its similar curriculum to CpE, also has relatively low stickiness. However, ME, which has the larger number of students, has the second highest stickiness. Thus stickiness is not a function of program size. It appears that there is a continuous distribution of increasing stickiness for CpE, BE, EE, ChE, and ME. IE has particularly high stickiness.

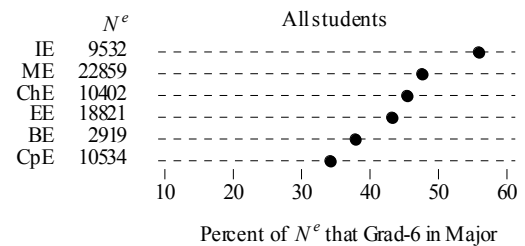


Figure 1. IE has the highest stickiness: variation in stickiness of six engineering disciplines. N^e is the number of students who ever declared a major in that discipline.

B. Variations in Disciplinary Stickiness by Race/Ethnicity and Gender

Does this success of IE apply to men and women? Does this vary by race/ethnicity? When studying underrepresented students in engineering, it is important to adopt an intersectional lens and consider race/ethnicity and gender [11, 12] as shown in the multiway plot in Figure 2. Here each panel displays the variation in stickiness for six engineering disciplines for a particular race/ethnicity and gender. For example, the top left panel shows the results for Asian women while the bottom left panel shows the results for Asian men.

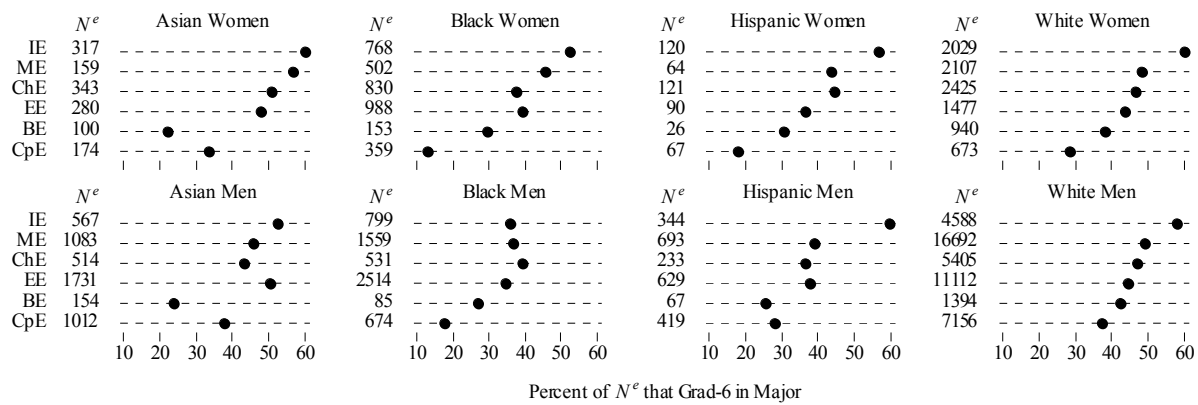


Figure 2. Stickiness of six engineering disciplines disaggregated by race and gender. N^e is the number of students who ever declared a major in that discipline.

Several interesting stories emerge from Figure 2. As expected, the overall shape of Figure 1 is best represented by the panel for White men, the largest population in engineering. The order of majors changes for several subpopulations. For Asian men and women and Hispanic men, BE, not CpE, has the lowest stickiness of any discipline. For Black men, ChE, not IE, has the highest stickiness. Asian students have overall high stickiness, with unexpectedly high stickiness in EE and CpE for Asian men. Women of all races appear to have particularly low stickiness in CpE and high stickiness in IE. Other poor outcomes include Hispanic men and women in ME, Hispanic men in ChE, and Black men in all disciplines with the possible exception of ChE. On the positive side, Black women have higher stickiness in EE than expected and Hispanic women and men appear to do quite well in IE. What are these programs doing well that helps these students “stick”?

C. Variations in Disciplinary Stickiness by Matriculation Pathway

If we disaggregate Figure 1 by matriculation pathway rather than by race/ethnicity and gender, Figure 3 results. Figure 3 shows the variation in stickiness for the six engineering disciplines for students who matriculated as first-time-in-college (FTIC) students and those who transferred (XFR) from another institution.

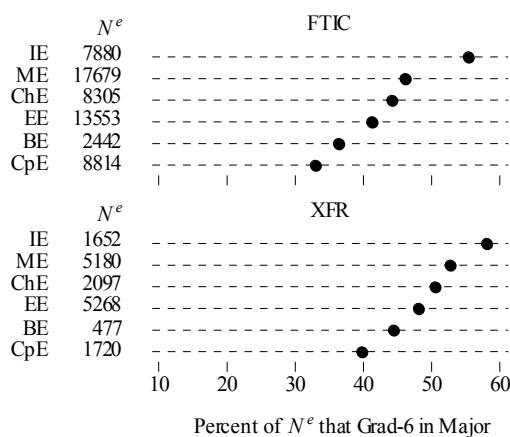


Figure 3. Stickiness of six engineering disciplines for FTIC and transfer (XFR) students. N^e is the number of students who ever declared a major in that discipline.

Figure 3 shows that the matriculation pathway makes a difference. The stickiness of transfer students ranks the disciplines in the same order as the stickiness of first-time-in-college students shown in Figure 1. However, transfer stickiness exhibits less disciplinary variation than FTIC stickiness (18 percent vs. 22 percent range). This might be expected since transfer students declare their major after some preparation at their prior institution suggesting a stronger commitment to their declared major at their four year institution. For all disciplines, transfer students have higher stickiness than FTIC students ranging from about 6 percent higher for ChE to 8 percent for BE. Again, IE appears to exhibit different behavior. Note that the stickiness for transfer students in IE is about 2.5 percent higher than that for FTIC students. This is much closer than for any other discipline.

V. CONCLUSIONS

The proposed stickiness metric has been shown to be effective in comparing outcomes for FTIC, transfer, FYE, and other populations that were difficult to include in the same study previously. It distinguishes among disciplines and provides new information that could not be inferred as easily from other metrics. We will continue to explore the use of stickiness, and encourage other researchers to use it.

As earlier work has shown, industrial engineering has remarkable characteristics [13, 14]. Qualitative work has helped explain its unique role among the engineering disciplines [15]. The authors continue to encourage other engineering disciplines to learn from industrial engineering. Other disciplinary findings from this work—both positive and negative—suggest that further investigation is warranted through both quantitative and qualitative study.

Because the stickiness metric can explore the outcomes of students in such diverse pathways, it holds promise as a metric that can be used to study the entire enrolled population in a single study. This elusive study design would be valuable in understanding the collective experience of all the students enrolled in a particular degree program at the same time. Thus, stickiness has the potential to relate persistence to climate (as expressed by conditions experienced by students taking classes at the same time) and program demographics (to explore whether a critical mass of a population affects outcomes).

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On Deployment of Effective Instructional Strategies: Students' Engagement through Cooperative Learning

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Abstract - Engineering education in the Arab Gulf States (the Region) faces significant challenges as it seeks to meet the demands on the engineering profession in the twenty first century. This paper focuses on classroom-based pedagogies of engagement, and *cooperative learning strategies* in particular. The paper is a follow up to previous work by the author, on viable strategies to improve the classroom environment of engineering colleges in the Region. At the start, the paper provides an overview of relevant benchmarks of engineering education in the Region. Then, relates author's preliminary findings on *teaching/learning* practices in Region's colleges, sheds light on the *pros and cons* of the *lecture format*, and examines the literature on substance of different *active learning* protocols, focusing on *cooperative engagement strategies*. Next, it identifies barriers to *reformation* in general, and to the use of modern pedagogical skills in particular. The paper also argues that any meaningful change in Region's classroom practices (dominated by traditional lecture-based methods) should be supported by the university administration. What is necessary to create a change, is for the department or college, to have a comprehensive and feasible set of plans: articulated expectations, opportunities for faculty to learn about new pedagogies, and an equitable reward system.

Index Terms –Arab Gulf States, Lecture format, Active learning protocols, Cooperative learning.

Introduction

“To teach is to engage students in learning.” This quote, from *Education for Judgment* by Christenson et al,⁽¹⁾ captures the meaning of the art and practice of pedagogies of engagement. The theme advocated here is that student involvement is an essential aspect of meaningful learning. Also, engaging students in learning is principally the responsibility of the instructor, who should become less an imparter of knowledge and more a designer and a facilitator of learning experiences and opportunities. In other words, the real challenge in college teaching is not trying to cover the material for the students, as many of us believe and

practice today; but, rather uncovering the material with the students. This is a call for all faculty involved with teaching engineering courses, and as members of faculty teams who develop, maintain and implement engineering programs, to consider not only the content and topics that make up an engineering degree but also how students engage with these materials. It is primarily a call to consider how students engage in their college experience, and what tools can be deployed to stimulate learning.

There are numerous tools available to select from, including the models predicated on cooperation; i.e., working together to accomplish shared goals. Within *cooperative* activities, individuals seek outcomes that are beneficial to them and to all other group members.^(2, 3, 4)

Cooperative learning researchers and practitioners have shown that positive peer relations are essential to success in college. The positive interpersonal relationships promoted through *cooperative learning* are regarded by most as crucial to today's learning communities. They reduce uncertainties about college attendance and increase integration into college life. Isolation and alienation do, often, lead to failure. Two reasons for dropping out are: failure to establish a social network of classmates, and failure to become academically involved in classes.^(4, 5, 6)

In the Arab Gulf States (Saudi Arabia, Bahrain, Kuwait, United Arab Emirates, Qatar, and the Sultanate of Oman) traditional methods of teaching/learning dominate the classroom environment. Calls by some academics to introduce *engagement pedagogies* have not been effective in changing the “mind set” of most involved. Therefore, the traditional mode of lecture where the information passes from instructor's notes to students' notes (without passing through the mind of either) continues as “the norm”.

The paper renews the call for deployment of effective instructional strategies in the classrooms of the Region, stressing on *cooperative learning* practices as a viable alternative to the traditional (low-interaction lecture-based) environment that has gripped the engineering education of Region's institution for decades. The paper sheds light on: research support, current practices, and ways of redesigning classes to stimulate interaction to help break the lecture dominant pattern, using *cooperative learning* protocols.

A number of relevant questions do come to mind, including: What needs to be done to move the process forward? What are the key components of successful deployment of *active learning* in general and *cooperative learning* in particular? How to foster and expand the community of faculty who decide to use *cooperative learning*? Achieving the change needed across the Region requires collective effort by all involved, namely: the institution, the faculty, and the students.

An overview of engineering education in the Region

Engineering education in the Arab Gulf States (the Region) started, in earnest, during the early to mid sixties. Initially, colleges of engineering were founded in Riyadh, Jeddah, and later, in Dhahran, Saudi Arabia. In the other states of the Region, engineering colleges were founded soon after these states have gained their independence.^(7, 8)

The strong political and economic ties between the States of the Region and western countries - the USA in particular - has helped enormously in setting up, manning, and providing needed guidance to these fledgling institutions during their early years. The dramatic increase in oil revenues during the 70s, and 80s, coupled with lack of skilled professionals in areas deemed necessary for growth and development of oil-related industries, has been pivotal in the start-up of higher education in general and engineering in particular. There are today eight main public colleges of engineering in the Region (Table 1) in addition to several, recently established, private and semi private colleges and/or universities that offer engineering degrees.

These eight public colleges (shown in Table1), have since their inception, been guided by advisory committees drawn from US colleges. Previously, the Grinter's Report⁽⁹⁾ and the Goals Report⁽¹⁰⁾ have guided the educational process forward. Recently, ABET Engineering Criteria 2000⁽¹¹⁾ has been the subject of seminars and workshops, intended to assist colleges of the Region in making use of the EC2000, whenever possible. Indeed, the EC2000 has generated a lot of interest and challenges in the Region.

Admission policies, for all eight colleges, are based on grades obtained in an examination sanctioned by the Ministry of Education, upon completion of the 12th grade. Additionally, an entrance exam and evidence of proficiency in English, a requirement imposed by many of these colleges, may exempt the applicant from a pre-engineering "prep year", administered as a separate unit from the college. Statistics have shown that over 80% of first year engineering students do attend the "prep year", during which students embark primarily on improving their English skills. The author has proposed to reform the "prep year" by making it two years, and widening the scope of the subject matter to include (in addition to building up English language skills to a pre-set level):(i) math and science courses-to prepare for engineering "gateway" courses;(ii) hands-on "pre-college" training period; and,(iii)

fostering a "proper learning environment", to help students acquire desirable attributes such as: analytical skills, creative thinking, and social skills⁽⁷⁾

TABLE 1
THE EIGHT MAIN ENGINEERING COLLEGES OF THE ARAB GULF REGION.

| Country | COLLEGE OF ENGINEERING | Year Established |
|----------------------|---|------------------|
| Saudi Arabia | King Saud Univ, Riyadh | Early sixties |
| Saudi Arabia | King Abdul-Aziz Univ, Jeddah | Early sixties |
| Saudi Arabia | King Fahd Univ of Petroleum and Minerals, Dhahran | Late sixties |
| Bahrain | University of Bahrain, Manama | Mid seventies |
| Kuwait | Kuwait Univ, Kuwait City | Mid seventies |
| Qatar | Univ of Qatar, Doha | Early eighties |
| United Arab Emirates | UAE Univ, Al-Ain | Early eighties |
| Oman | Sultan Qaboos Univ, Muscat | Mid eighties |

In a recent **survey** directed at graduates of engineering colleges of the Region on: the *pros and cons* of the engineering education they have received, and any advice they may be willing to offer? **Fifty seven** out of a total of **sixty five** respondents were critical of the classroom environment and teaching styles practiced during their college years. Majority of the respondents were between 25 to 30 years of age, citizens of the Arab Gulf States, and either employed or practicing engineering on their own.

The **Survey**, aimed at getting first hand information from the graduates on a number of topics, including: (i) curricula, classroom environment, and *teaching-learning issues*; (ii) alumni-college relations; and, (iii) industry-academe relationships, as perceived by the graduates. Of particular interest here are the remarks made by the respondents, on the need to replace *traditional teaching* that has persisted with better and more effective methods of course delivery⁽⁸⁾. Some of respondents have come to the realization, after having finished college, that learning is not an automatic consequence of pouring information into student's head. The process should have an enduring value beyond the classroom! It was also a call for the colleges of the Region to begin transforming learning and teaching, by sponsoring new initiatives that will promote and encourage faculty to adopt "classroom-based *pedagogies of engagement*". This raises a general question: How can the Region, as one entity, promote systematic change to the education process, taking advantage of the wealth of

available information on *teaching and learning*? There is no easy answer. But, developing a new cadre of faculty who are comfortable using novel *engagement strategies* would be a step in the right direction.

Teaching and learning practices in the Region: preliminary findings

To get first-hand information on teaching practices and classroom activities in the colleges of the Region, the author traveled - during the spring of 2008- to the Region and was able to meet with faculty members and administrators from three engineering colleges, in an effort to learn about current teaching and learning practices, and instructors' views on ways to improve the classroom environment in the Region. A total of 24 faculty members responded voluntarily – on a rather short notice - and expressed their views, supplemented with written statements. The main headings/questions raised by the author, during the interviews, were:

- Have you been exposed to *active teaching/ learning strategies*? Have you kept up with recent developments in the arena of *pedagogies of engagement*?
- Are you willing to deploy any of those strategies (*pedagogies of engagement*) when the need arises?
- Preliminary information reveals that *engagement strategies* are not currently utilized in the Region, at any level, why not?
- Do you believe that *active learning* should be deployed in your department, and if so, what are the barriers?
- Based on your experience, what would you suggest to improve the classroom environment?

While answers to the above noted questions varied considerably from one member to the next; there were, nonetheless, some agreements amongst many, on certain issues that would be worthy of consideration. The general consensus of views/opinions expressed by the majority of the interviewed faculty asserts and/or amplifies the following points: **First**, nearly all have been exposed to one form or another of *active learning* through work shops and seminars offered at their universities' Learning Centers. Some have acquired the knowledge on their own, i.e., through their own personal endeavors. **Second**, all have expressed their wish to learn more about *active learning strategies*; and most do not believe that they are sufficiently competent to deploy an *active learning strategy* as yet. **Third**, many have expressed their wish to improve their classroom strategies within the framework of traditional methods, arguing that there is a great deal of room for improvement within the traditional lecture approach. **Fourth**, some members have stressed that the success of any *active learning strategy* requires students' participation, raising the question whether students are ready and willing to become active participants in the process? **Fifth**, most members were mindful of the time and effort needed to

become a more effective instructor; and concerned that teaching is undervalued in comparison to research.

The interviewed faculty members have been teaching undergraduate classes at their present institutions for a minimum of five years. Most of the classes taught by the aforementioned faculty are small size, seldom exceeding 35 students per class. The lecture format dominates the seen. Students listen, take notes, and are allowed to ask questions at the end of the lecture or during office hours. There seem to be less interest (by most of the interviewed faculty) in the process by which the course content is delivered, and more of a concern whether the rate of delivery would allow the instructor to finish the course on time. The views expressed by the faculty and the impression(s) arrived at by the author, leads one to believe that it is highly unlikely that new more effective *teaching-learning strategies* would be deployed any time soon, unless drastic measures are undertaken⁽⁸⁾. The author is more convinced now than ever, that classroom reformation, including deployment of *active learning strategies*, would happen only if the institution mandates it!

The pros & cons of the lecture format

Lectures have a number of characteristics that does make them, for the right subject matter, desirable in the classroom^(2, 12, 13). It depends on the abilities and experience of the lecturer. An able and committed lecturer can accomplish the following:

1. Relate the material proficiently and effectively, in a manner that reflects lecturer's personal conviction and grasp of the subject matter;
2. Provide students with a thoughtful, scholarly role model to emulate;
3. Supplement the subject matter with current developments not yet published, or interject lecturer's own views derived from his/her own experience;
4. Organize material in ways to meet the particular needs of a given audience;
5. Efficiently deliver large amounts of information when the need arises, without confusing his/her audience; and,
6. Underscore key points, simplify complexities, illustrate with facts and figures, and arrive at well "thought-out" conclusions.

In addition, lectures are presumably cost-effective, in that they can reach many listeners at one time; also, provide an advantage for those students who find learning by listening enjoyable⁽¹²⁾. As most students will attest, not all lectures or lecturers achieve these goals. Also, the effectiveness of the lecture varies inversely with the difficulty of the material presented, and listeners retain factual material better when presented in short sentences. Speaking extemporaneously is more effective than reading from lecture notes, and it is desirable to change the pitch, intensity, and the timbre of one's voice⁽¹²⁾. These characteristics presume that the lecturer is an enthusiastic and knowledgeable scholar. But we realize that most campuses have a few that fit this description, and can be

labeled as gifted practitioners who could keep most students interested during the formal 50-minute lecture. Even if it is assumed that most engineering lecturers possess these necessary characteristics, research has shown that *the exclusive use of the lecture in the classroom constrains students' learning*.^(12, 13, 14)

One of the most important problems associated with *total* reliance on the lecture method is the inability of most students to listen effectively to any lecturer, no matter how skillful, over a sustained period. Ten to 20 minutes into the lecture, confusion and boredom sets in and assimilation falls rapidly, remaining at a low state until a brief period toward the end of the session when students are revived by the knowledge that the lecture will soon be over.⁽¹⁵⁾

If a faculty member is hesitant about selecting one or more of *active learning strategies*, because some questions exist about its comparative effectiveness with the lecture method, he or she should consider the following: research has shown, beyond the shadow of doubt, that these strategies do deliver content as well as lectures while providing diverse presentations that enhances students' motivation and achievement, and helps in building up desirable personal traits.^(14, 16, 17)

Examining the literature on meanings and substance of active learning

Active Learning is generally defined as any instructional method that *engages* students in the learning process. It is widely accepted that *active learning* requires students to take part in "pre-planned" learning-related activities, believed to spark and stimulate their learning, while in the classroom. It is understood that during *active learning*, less emphasis is placed on transmission of information and more on developing students' skills. Additionally, during an *active learning* cycle, emphasis is placed on students' exploration of their own abilities, including: their thinking process, their value system, their intellect, and their courage to express themselves orally and in writing.⁽¹⁸⁾

Collaborative Learning refers to any and all of the instructional methods where students work together in small groups towards a common goal.⁽³⁾ It can be viewed as encompassing all group-based instructional methods, including *cooperative learning*.^(5,13) Some researchers view *collaborative* and *cooperative learning* as having two distinct historical developments and differing philosophical roots. Despite differences and similarity of the two approaches (*collaborative* vs. *cooperative*), the fact remains that the core element of both is the emphasis on student interactions, as the primary source of learning, rather than learning as individuals. *Cooperative Learning* is a formalized active learning structure where students work together in small groups to accomplish shared learning goals and to maximize their own and each others learning. The most common model of *cooperative learning* in engineering is that of Johnson, Johnson and Smith⁽¹⁶⁾. This model has five elements: mutual *interdependence*,

individual *accountability*, face to face *interaction*, *interpersonal* and small group *skills*, and individual *assessment* of group *functioning*. Although different cooperative models exist, the core element in all is the emphasis on cooperative incentives rather than competition in the promotion of learning. Before adopting a specific method of *active learning*, faculty members need to become familiar with the literature and, in particular, the various strategies that promote *active learning* in the classroom. Despite familiarity with the literature, ambiguity and confusion may result, at times, from reading the literature; particularly when the effectiveness of any instructional method is examined and/or compared with another method. Assessing "what works" requires looking at a broad range of learning outcomes, interpreting results carefully, and quantifying the magnitude of any reported improvement. To assess critically "what works" for a given set of conditions, the reader has to attain sufficient knowledge and familiarity with the subject matter. This should not, by any means, discourage faculty from moving toward *active learning*; but rather intended as a "precautionary" observation, to new instructors: Not "to make too much" out of what they have read unless it is credible, and substantiated with facts and figures. Despite some pitfalls, faculty should be encouraged to examine the literature on *active learning*, including the common barriers that may arise as a consequence of its application.

Promoting student engagement using cooperative learning structure

The positive interpersonal relationships promoted through *cooperative learning* are regarded by most as crucial to today's learning communities. They increase the quality of social adjustment to college life, reduce uncertainties about attending college, and increase integration into college life. Isolation and alienation, on the other hand, often lead to failure. Two major reasons for dropping out of college are: failure to establish a social network of classmates and failure to become academically involved in classes.^(14, 17)

Cooperation is more than being physically near other students. It is actually a state of mind. A willingness to open up to others, exchange information and views with others, and accept the fact that working together is more beneficial to all involved in the exercise. For a *cooperative learning* experience to be successful, it is imperative that the following be integrated into the class activity:^(13, 14)

- Positive Interdependence- Students should perceive the need for one another to complete planned activity.
- Face to Face Interaction- Students should work together in planning, executing, and arriving at conclusions. They should share the work load, and share the credit, thus promoting each others learning.
- Accountability- Each student's role and performance is to be assessed, and the results are those of the group (and for the group). Keeping track of the contribution and knowledge gained by each could be monitored, as

well, by either testing each and every student in the group, or by randomly selecting a group member (or members) to be tested and thus proxy for the group.

- Sharing known skills- Students who possess certain knowledge or skills (examples: computer skills, laboratory skills, data reduction skills, presentation skills) should be willing to pass it on, and/or share it with their group members.

As noted earlier, relying solely on the traditional lecture approach, no matter how competent the lecturer is, fails to *engage students in learning*, thus indirectly depriving students of learning experiences and opportunities that could only materialize utilizing *engagement strategies*. Under the umbrella of *engagement strategies*, there are numerous models available to select from. The work by Johnson, Johnson, and Smith ⁽¹⁶⁾ indicates that students exhibit a higher level of individual achievement, develop more positive interpersonal relationships, and achieve greater levels of academic self-esteem when participating in a successful *cooperative learning* environment.

Barriers to change in the classroom

To address adequately why most faculty in the Arab Gulf region have not embraced recent calls for educational reform, it is necessary first to identify and understand some common barriers to instructional change that seems to apply in America and elsewhere, and have been reported on in the literature ⁽²⁾. Many of these barriers seem applicable to the institutions of the Region, including:

- The powerful influence of educational tradition,
- The discomfort and anxiety that change creates,
- The potential problem/difficulty that may result from not covering adequately the assigned course content in the limited class time available,
- The increase in the amount of preparation time, and
- Lack of needed resources to proceed with the new method, when applicable.

Perhaps the single greatest barrier of all, is the fact that faculty members' efforts in employing a new approach would involve risk - the risk that students would not participate, or learn, the fact that faculty members may feel a loss of control, lack necessary skills, or be criticized for teaching in unorthodox ways. Faculty universally "know" that their institution expects excellence in teaching, but few campuses have critically examined and discussed explicitly how "excellence" is best achieved and assessed. Research has shown that faculty perceptions about the underpinnings associated with "superior teaching", almost always, place "knowledge of the subject matter" well above all others.

Faculty members see few incentives to change for several common reasons. **First and foremost**, is the pervasive belief that "we are all reasonably good teachers?" **Second**, there is very limited financial incentive, if any, to devote the effort acquiring alternatives to traditional approaches of teaching. **Third**, the perception shared by most faculty that time and effort spent pursuing research and research

money, is more rewarding, from an institution point of view, than time spent improving one's teaching skills.

Looking forward?

A root question: What is an engineering education for? – should be on the table for an evolutionary debate, referring, in particular, to the future of engineering education. What engineering students need to learn, and **how** can they best learn it, as well as **how** can engineering schools best teach it? are among the "questions" to be considered. The "**How**" is at the crux of the matter. Changing the *status quo* is never easy, but time has come for Region's colleges to turn a "new leaf" and begin moving in the direction of *active learning strategies*, in general, and *cooperative learning* environment in particular.

The author believes that in addition to mandating the "change", an effort should be made to create a climate for improvement in classroom instruction by changing the social and cultural norms that have prevailed for decades. Such an effort should permeate throughout the academic arena, re-defining the role of teaching faculty, underscoring the fact that learning is a consequence of students' engagement with the subject, and emphasizing that the simultaneous presence of interdependence and accountability are essential to learning. The specifics of such an effort ought to include the following:

- Rid classroom teaching environment from prevailing passive approaches to learning, and plant the seeds for active learning protocols throughout the public education system.* Propagate the idea that: student-teacher interactions are a "priori" to stimulate learning at all levels.
- Provide the manpower and support necessary to "in-house" education units and/or centers that define, promote, and encourage the art of appropriate teaching, including active learning protocols.* Scholarly research about teaching, should be encouraged, and openly discussed.
- Provide instructors with clear and consistent communications about expectations regarding teaching.* Faculty become frustrated and confused when told that teaching plays a vital institutional role, but to find out that rewards are for research. Effective teaching should also be rewarded, and poor teaching needs to be remediated.
- Encourage instructors, when using alternative instructional strategies, to try to meet the specific needs of students' different learning styles.* Students are inherently different, and so are their learning styles.
- Target new instructors, in particular, and help them to make the transition from traditional methods to active learning strategies.*

Invariably, different scenarios may be arrived at, and faculty members who have had some prior experience in deploying *engagement practices* should be given the opportunity to lead in this effort. However, leaving change up to individual faculty members without a supportive culture that values effective teaching/learning pedagogies for classroom reformation and educational development, doesn't work. Piecemeal efforts - an initiative here or a

success story there - could result in pockets of improvements but will not change the *status quo* within the Region as a whole. What is necessary to plant the seeds and sustain the “change” is for the university (i.e., the department and the college) to arrive at a comprehensive and integrated set of plans: clearly articulated expectations and a reward system aligned with these expectations.

Concluding remarks

To keep pace with fast changing global marketplace, engineering education in the Arab Gulf States has to undergo major “reformation” including revitalization of the classroom environment. There is concern among students, faculty, and graduates of Region’s institutions- arrived at through a survey targeting new engineering graduates & the feedback from Region’s faculty interviewed recently - that current teaching practices (traditional teaching) appear to have adversely affected outcome. There is an urgent need to adopt new and innovative approaches in teaching.

The paper reviews the *pros and cons* of the traditional lecture approach, defines common forms of *active learning* relevant for engineering faculty in the Region, and argues that the introduction of classroom-based pedagogies of engagement can help break the traditional lecture-dominant pattern. One way to get the students actively involved is to adopt a *cooperative learning strategy*: getting them to teach one another, dig below superficial levels, learn “to learn”, get to know their classmates, and build a sense of community with them.

This is a call for Region’s faculty to learn the new ways of teaching, and strive to reach a high level of pedagogical knowledge and competence. In the dialogue between administrators and faculty, needed to bring about the change, faculty will rightfully identify barriers including the time and resources needed to embark on the change. Also, should request authorization to experiment with new ways of teaching without risking low teaching evaluations.

With regard to implementations, author’s findings assert that classroom practices today have remained, by and large, very traditional. And none of the novel approaches to teaching, including *pedagogies of engagement*, are deployed anywhere in the Gulf region. Therefore, unless the “change” is mandated by the institution, it is highly unlikely that the classroom environment would witness any noticeable shift toward *classroom engagement practices* any time soon. If and when the “change” is mandated, the challenge then will be: how to infuse the new pedagogies without causing disruptions or trigger some undesirable consequences? Said another way, is there an optimum balance between maintaining traditional lecture-based practices and the deployment, of an *active learning pedagogy*? If so, what does the balance depend on? (Type of course? Students’ background? Instructor’s skills?).

Implementation of said “change” may have to be carried out in phases and /or steps over time. It may take years before it reaches optimum condition. Change will only be brought about through the determination of the leadership

(deans, department heads, etc.), appropriate support and resources, and faculty members’ willingness to learn and change their current classroom practices. The myth expressed by some faculty that “*I am willing but they won’t let me*”, is a common response from faculty members to calls for reform in education. To the contrary, and as eloquently expressed by Combs⁽¹⁹⁾: “*Teachers may not be able to change the educational system, but the variations possible within the classroom are almost limitless.*”

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Increasing student commitment in introductory programming learning

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Abstract— High failure rates are common in many programming courses worldwide. Many causes for the learning problems have already been identified and different solutions have been proposed. However, the situation remains mostly unchanged. So, new pedagogical approaches are necessary, looking to create learning contexts that motivate students, increase their involvement with course activities, and maximize their learning possibilities. In this paper we present the changes made in the structure of a non-majors introductory programming course, and discuss the results obtained. We also present the results obtained in the first implementation of the new course structure.

Keywords: *learning to program; non-majors; motivation; pedagogy;*

I. INTRODUCTION

Introductory programming courses at the Department of Informatics Engineering from the University of Coimbra suffer from high failure and dropout rates as reported in many other high educational institutions [1, 2, 3]. This is a situation that affects mostly novices as those courses are usually placed at the beginning of the curricula [4, 5, 6]. Many authors suggested possible causes for students' difficulties, such as the nature of programming, the students' background and study attitudes as well as the pedagogical strategies commonly used in introductory programming courses [1, 2, 7, 8].

In many higher education institutions, introductory programming courses are offered not only to computer science freshmen, but also to students in other degrees. Consequently, courses normally have many students with different backgrounds, needs and interests. The high number of students that fail or drop out worsens the situation. All these factors prevent teachers from giving individualized attention to each student (or even group of students). The same has happened with the first programming course (called IPRP, a Portuguese acronym for Introduction to Programming and Problem Solving), at our Department. This course is common in Informatics Engineering, Industrial Engineering and Design and Multimedia. As the results were not satisfactory, with high rates of failure and drop outs, the Department decided to make several changes in the teaching structure and strategies, aiming to improve the students' results. This decision was reached after some successful experiments that were made in the three previous years in a small introductory programming course

directed to Design and Multimedia Master students, who had very limited or no previous programming experience [9, 10]. The new structure was introduced for the first time in the first semester of the academic year 2011/12.

In this paper we present a detailed view of the changes made and their pedagogical consequences in the context of a non-majors introductory programming course directed to Design and Multimedia students. To assess the results we use official information, like the drop out and failure rates of the last few years including this year and the students' answers to the official pedagogical surveys regularly made by the University. We also use the results of another survey, directed only to students that were repeating the course (they had dropped out or failed in the previous year), which was explicitly focused on the changes made. These students followed the course in the two formats, so their views are important to assess the changes made.

In the next section we present the changes made and the rationale behind them. In the following section we present the results obtained, both in terms of failure rates and the students' opinion. We finalize with some conclusions.

II. WHAT CHANGED

The changes decided at management level were essentially organizational: to create separate courses for students following different degrees and to modify the course class structure. These decisions created the opportunity to make crucial changes at the pedagogical level, especially in the case of the course to Design and Multimedia students (we will call it IPRP-LDM from now on).

The Design and Multimedia degree was offered for the first time in the academic year 2008/2009. Since then, the introductory programming course adopted a weekly 2 hour lecture with all the students together, 3 hours of lab classes in groups of 24 students and 2 hours of free tutorial classes in groups of about 60 students. The new class structure includes only one type of class, with students divided in groups of about 24 students. Each group has 5 hours of classes per week, divided in two different days, one with 2 hours and the other with 3 hours. The same teacher is responsible for all classes of a particular group during the semester. Each class consists of

both the introduction of theoretical concepts and practical assignments.

The rationale behind the changes made included a better use of class time, as traditional lectures were not as useful as they should be (class rhythm, examples, and activities were not suited for many students due to the dimension and the very heterogeneous nature of the group). Also, this new class structure would allow the presentation and immediate practice of the different concepts, eliminating problems due to the split between lectures and the different lab groups (even more clear in the case of students who missed lectures and arrived to the lab without a clue about the relevant concepts for that day).

The separation of students following different degrees in separate courses reduced the number of students in IPRP-LDM to 103, 45 freshmen and 58 repeating the course after previous failure or drop out. More importantly, the separation allowed us to shape the course considering the interest most Design and Multimedia students had in design and digital art issues. This was the main reason for choosing the Processing language for the course, instead of Python that was previously used in the joint course. The reason was not language simplicity (on the contrary), but its ability to easily support the development of applications that display drawings, animations and art works. Most course activities had a visual nature, while involving programming concepts common in introductory courses (e.g. selection, repetition, arrays, and an introduction to object oriented programming).

A recurrent question of IPRP-LDM students in previous years was: Why should we learn to program? Many of them did not have any motivation to face the difficulties inherent to learn to program. They felt it was not useful for their professional future. As motivation is very important for student involvement in learning activities the teachers addressed this question in the first class. However, instead of telling them how important programming can be, they asked each student to make a web search about Processing made projects. Each of them had to select a project to present in the next class. The teachers noticed a positive impact in the second class because students wanted to know how those projects were made and also to be able to create their own projects.

The possibility of working with small groups of students and the increase of time availability (5 hours of class per week), allowed the teachers to better know each student, her difficulties, preferences and reactions to teacher interactions. To reinforce the teacher – student relationship we used a less conventional activity in programming courses: students were asked to write about their learning experience every two weeks. Reflections were written in the course Learning Management System (Moodle) and were accessible only to the teacher. This activity allowed teachers to know better each student, as many of them seemed to find easier to write about their problems than to speak about them. It was possible to identify and address some learning issues that were causing difficulties to some students, and also prevent some drop outs through direct interventions with the specific students.

To keep students as committed as possible was one of the teacher's main objectives. To achieve this, some other strategies were used:

- In several assignments students were allowed to include a more creative component. For example, the teacher defined the minimum visual requirements for the assignment (e.g. it has to include a windmill with rotating sails), but the rest of the specification was left open, allowing each student to design and program other components that she/he felt interesting;
- Teachers often tried to encourage students to recognize their efforts and achievements. Errors were always presented as learning opportunities, showing that all programmers make mistakes (including the teacher). It was important to make students conscious of their own progresses, so that they understand that learning is possible if they commit enough;
- Assignments given to a particular student took into consideration her current level as much as possible. This means that in the same class different students could be working on different assignments;
- Students were made aware of their role in learning and the necessary attitude and commitment to be successful. The teachers frequently reminded students about the importance of an active and pro-active attitude towards learning;
- Teachers closely followed students' progress, trying to early detect any difficulties. This allowed teachers to provide early corrective actions, both to small groups sharing similar problems and at an individual level.

Although the changes made in the course structure were essentially organizational, their consequences were mostly pedagogical. There was a better learning context, more suitable to the students' characteristics, and a higher degree of consideration of individual difficulties. All this resulted in more motivation and a deeper student involvement that had a positive impact in their final results, as presented in the next section.

III. THE RESULTS

The results accomplished with the new course structure in the introductory programming course for Design and Multimedia students were measured using three different sources of information: the students' final grades, the results of the university official pedagogical survey, and the results of a questionnaire directed to the students that were repeating the course.

A. Final grades

To evaluate the impact of the innovations introduced in the course, we compared the course final information with the two previous years. The data is presented in Table I. This table shows, for each year, the number of enrolled students, the number of students who followed the entire course (including the final exam), the number of approved students, the rate of assessed students (assessed/registered), the success rate (approved/assessed), the approved rate (approved/registered) and the average of the final marks (expressed in the scale 0 – 20 as used in Portugal).

TABLE I. COMPARATIVE DATA IN THE THREE ANALYSED YEARS

| ALL STUDENTS | | | | | | | |
|--------------|-------------------|-------------------|-------------------|------------------------|--------------|---------------|---------------------|
| | Enrolled students | Assessed students | Approved students | Assessed students rate | Success rate | Approved rate | Final marks Average |
| 2011/12 | 103 | 82 | 59 | 79.6% | 72.0% | 57.3% | 12.9 |
| 2010/11 | 91 | 78 | 18 | 86.8% | 23.1% | 19.8% | 12.1 |
| 2009/10 | 64 | 57 | 17 | 89.1% | 29.9% | 26.6% | 12.0 |

It is possible to observe that there was a very positive evolution in most figures, especially in success rate and approved rate. The evolution of the last indicator can be seen in Fig. 1.

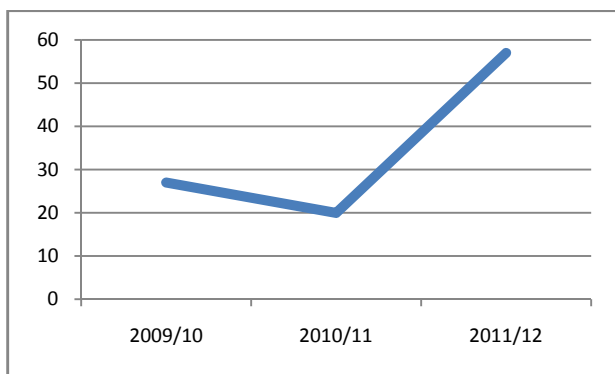


Figure 1. Percentage of approved students

The percentage of approved students increased from 26.6% and 19.8% in the previous years to 57.3% in 2011/12. Considering only the students that were in the final exam, the approved percentage increased from 29.9% and 23.1% to 72%. We performed the same analysis considering freshmen and non-freshmen separately. The results can be consulted in Tables II and III.

TABLE II. COMPARATIVE DATA FOR FRESHMEN IN EACH YEAR

| FRESHMEN | | | | | | | |
|----------|-------------------|-------------------|-------------------|------------------------|--------------|---------------|---------------------|
| | Enrolled students | Assessed students | Approved students | Assessed students rate | Success rate | Approved rate | Final marks Average |
| 2011/12 | 45 | 36 | 22 | 80.0% | 61.1% | 48.9% | 13.3 |
| 2010/11 | 48 | 41 | 9 | 85.4% | 22.0% | 18.8% | 12.6 |
| 2009/10 | 38 | 37 | 9 | 97.4% | 24.3% | 23.7% | 12.7 |

TABLE III. COMPARATIVE DATA FOR NON-FRESHMEN IN EACH YEAR

| NON-FRESHMEN | | | | | | | |
|--------------|-------------------|-------------------|-----------------|---------------------|--------------|-------------------|-------------|
| | Nr of enrollments | Nr of assessments | Nr of approvals | Rate of assessments | Success rate | Rate of approvals | Global Mean |
| 2011/12 | 58 | 46 | 37 | 79.0% | 80.0% | 64.0% | 12.8 |
| 2010/11 | 43 | 37 | 9 | 86.0% | 24.0% | 21.0% | 11.7 |
| 2009/10 | 26 | 20 | 8 | 77.0% | 40.0% | 31.0% | 11.3 |

The resulting curves are similar to Fig. 1, although the results were slightly better with non-freshmen than with freshmen (64% approved students versus 48.9%). This is consistent with the idea that learning to program needs time and maturation.

Although average grades also increased, the difference was not so impressive, as it was 12.9 (in a 0-20 scale) this year versus 12.0 and 12.1 in the two previous years (approximately 0.9% increase from previous years). The same analysis separating freshmen and non-freshmen shows that freshmen average grade was higher in the three years.

The percentage of students in the final exam decreased from 89.1% and 86.8% in the two previous years to 79.6% in the last year. This situation causes some concern, as it means that a number of students consistently register for the course, but do not follow it or drop out before concluding it. Further investigation is necessary to understand the reasons for this decrease.

Comparing the percentage of students that got approved in the three years, it is possible to say that the evolution is very positive. The overall approved rate had a sharp increase, supporting the teachers' view that the changes made were benefic for most students.

B. Official pedagogical survey

At the end of the semester the University pedagogical services conducted an anonymous survey about every course offered at the University. The survey included questions about the general conditions of learning (spaces, library, and so on) and particular questions about the student's enrolled courses.

The survey used a Likert type scale with five points (1 to 5), where higher marks mean a better opinion.

The first point to mention is the fact that 90% of IPRP-LDM students answered the survey (a high number when compared with other courses).

The survey consisted of 11 questions about each course followed by the student, such as:

- Appreciate the average quality of learning in the course
- Classify her own learning
- Rate her own participation in learning activities
- Globally classify her own performance in the course

The average marks to each question were between 4.0 and 4.3, reflecting a positive view about the course. Considering that the highest possible mark was 5, this means that most students had a positive view about the course and what they were able to learn.

It is noteworthy to compare IPRP-LDM results in this survey with the global results for the Design and Multimedia degree (considering all courses). In this case the average results in the survey questions went from 3.7 to 3.9. This means that IPRP-LDM was rated above average in all questions included in the survey. This is a very relevant result considering that many other courses could be more appealing to the students, as they are more design and multimedia oriented.

It is also significant to note that in 2010/11 the same survey had already been used, and the average of the student answers about IPRP-LDM were between 2.9 and 3.8, clearly below 2011/12 results.

The University survey also included some questions that allowed the students to give their opinion about the teachers. The results were coherent with the course results, as all averages were between 4.0 and 4.7 for the three course teachers. This means that most students appreciated the efforts the teachers made to promote learning.

C. The Non-Freshmen Questionnaire

To have a deeper insight on the way students reacted to the changes made in the course, we asked the non-freshmen to answer a specific questionnaire, as they had experienced both models. The questionnaire included 10 questions. It was put online and the teachers sent an email to the 58 non-freshmen asking them to give their answers anonymously. Only 30 students answered the questionnaire (17 male and 13 female). Answers were given before students knew their final grades.

The first question asked the students whether they consider the activities in class more adequate or not than those in the previous year. It was a free text answer, but the answer was unanimous. In a way or another, students expressed their agreement with the changes made. They appreciated the use of Processing and considered visual oriented programming activities more interesting and adequate to them. Some also wrote that it was easier to understand the effect of the programming instructions due to the visual impact of the programming language. Finally, some students appreciated the fact that teachers often allowed them to progress at their own pace, giving different exercises to students in different learning stages.

The survey asked students to indicate how often they attended the different types of classes (lectures, labs and free tutorials) in the previous year and classes in the current year. The results are shown in Table IV (in percentage of the total number of classes).

TABLE IV. ATTENDANCE BY CLASS TYPE AND YEAR

| | <i>Lectures 2010 - 2011</i> | <i>Labs 2010 - 2011</i> | <i>Free Tutorials 2010 - 2011</i> | <i>Classes 2011 - 2012</i> |
|--------------|---|-------------------------------------|---|--|
| [0-25%] | 26.67% | 0.00% | 53.33% | 16.67% |
| [25%-50%] | 30.00% | 13.33% | 30.00% | 6.67% |
| [50%-75%] | 30.00% | 40.00% | 10.00% | 16.67% |
| [75%-100%] | 13.33% | 46.67% | 6.67% | 60.00% |
| Total | 100.00% | 100.00% | 100.00% | 100.00% |

From the table it is possible to reach some conclusions about these students' class attendance:

- Most of these students did not attend the free tutorials, as more than 80% of them attended less than 50% of those classes.
- More than half of the respondents (56.67%) attended less than 50% of the lectures.
- Most students (86.67%) attended 50% or more labs.

Therefore, it is possible to conclude that the labs were more appealing for the students. As they had difficulties in learning to program, one could expect that they would take advantage of all classes to improve their situation. However, that was not the case, maybe because they did not feel that lectures and free tutorials were useful for them.

On the contrary, in 2011/12 60% of the students attended more than 75% of classes, showing that they felt them useful for their learning.

The questionnaire also included a question to identify drop out situations. The number of students that did not drop out increased from 33.3% in 2010/11 to 96.7% in 2011/12.

For those students who did drop out, the questionnaire included a question about the reasons for that decision. The students mentioned several reasons. The most frequent one was related to failure to achieve the minimum allowed grade in the course project or in some mini-tests that existed in the course evaluation schema. Some students mentioned that they found the course uninteresting, especially lectures. They found them difficult to follow, and useless to clarify doubts, as there was an excessive number of students. The separation between lectures and labs was also mentioned. The teachers at the labs were expecting that the students had understood the concepts and examples presented in the lectures. When that did not happen labs were not very useful, as students could not solve the exercises or even understand the solutions presented by colleagues or the teacher. The time between lectures and labs was also pointed out as a reason for drop out, as some students mentioned it as an added difficulty (when they came to the labs they could hardly remember lectures). Some students simply said that they dropped out because they could not keep up with the course pace.

Analyzing the students' justifications for dropping out in the previous year, we may think that the course structure and activities failed to motivate students to get involved and make

the necessary effort to learn. This lack of commitment is obvious when students mention the time between lectures and labs. Of course, teachers expected some autonomous study in that time, but that simply did not seem to have happened in the case of the respondents.

The questionnaire included a question that asked students to express their opinions about the advantages and disadvantages of the new course structure. Some statements were given and the students had to classify each of them in a five points scale: -2 = "strongly disagree", -1 = "disagree," 0 = "neither agree nor disagree," 1 = "agree" and 2 = "strongly agree". The statements were:

- a) *There was a better connection between theory and practice.*
- b) *There was a higher proximity between student and teacher.*
- c) *The teacher monitored students more closely.*
- d) *There was more time to clarify doubts.*
- e) *The teaching was more personalized.*
- f) *There was more time to practice programming.*
- g) *It was more tiring due to more practical and intensive work.*
- h) *Time was better organized.*
- i) *The reduction of contact hours (7 hours per week in 2010/11 to 5 hours in 2011/12) was disadvantageous.*
- j) *There was more motivation to program.*

The results obtained are presented in Table V. We can conclude that the students had a very positive opinion about the changes. In statements a) to f), h) and j) almost no student expressed disagreement, and even neutral positions were a small minority. This means that for the respondents there were clear advantages in the changes made.

The statement g) got more disperse answers, as 40% of the students were neutral, 46.6% expressed disagreement (saying it wasn't more tiring) and 13.4% expressed agreement. We see this as natural, as the new approach requires a much more active attitude from the students, both in classes and outside classes. Possibly some students see this as tiring, while others like it, since they are learning better than before and think the extra work was worthwhile.

The new model implied a reduction of the number of contact hours. Previously, there were 7h per week (2h lectures, 3h lab and 2h free tutorials), while in the new model the number was reduced to 5h (mostly due to staff constraints, as in the new model all classes were in small groups, creating the need to use more staff hours). Anyway, considering the answers to statement i) 56.7% of the students did not consider this to be a problem, while 33.3% were neutral. So, it seems that, for these students, the changes in the pedagogical strategy compensate the reduction of contact hours.

TABLE V. NEW MODEL ADVANTAGES AND DISADVANTAGES

| | -2 | -1 | 0 | 1 | 2 | Σ |
|----|-------|-------|-------|-------|-------|----------|
| a) | 3.3% | 0.0% | 16.7% | 43.3% | 36.7% | 100% |
| b) | 0.0% | 0.0% | 10.0% | 26.7% | 63.3% | 100% |
| c) | 0.0% | 0.0% | 16.7% | 23.3% | 60.0% | 100% |
| d) | 0.0% | 0.0% | 20.0% | 36.7% | 43.3% | 100% |
| e) | 0.0% | 0.0% | 13.3% | 40.0% | 46.7% | 100% |
| f) | 0.0% | 0.0% | 16.6% | 36.7% | 46.7% | 100% |
| g) | 23.3% | 23.3% | 40.0% | 6.7% | 6.7% | 100% |
| h) | 0.0% | 0.0% | 23.3% | 50.0% | 26.7% | 100% |
| i) | 30.0% | 26.7% | 33.3% | 10.0% | 0.0% | 100% |
| j) | 3.3% | 0.0% | 13.3% | 36.7% | 46.7% | 100% |

The students were also allowed to mention other advantages and/or disadvantages of the new model. Apart from the issues already covered in the statements a) to j) the students also mentioned as advantages:

- The change to the Processing programming language, as it allowed more interesting activities and is a language used in the creative industries;
- The separation of the Design and Multimedia students from the Informatics Engineering students, as they felt that previously the course was essentially designed for the latter students;
- The students felt more motivated with the learning context, as some of them explicitly mentioned the quality of the teachers and the supportive environment in classes.

As disadvantages, some students mentioned:

- As each group only has one teacher, it is possible that different teachers have different assessment criteria;
- It is possible that different programming issues are presented and practiced differently in the various groups, creating an unbalanced situation when those issues appear in the final exam.

Finally, the questionnaire gave each student the possibility to include any other remark not covered before. Some students used that possibility to reinforce some ideas previously mentioned. Others wrote that this experiment and its pedagogical approach should be extended to other courses in the degree. One student expressed the hope that the better programming knowledge acquired in the course would be helpful in other courses. Some students stressed the pedagogical difference between the current and the previous year.

IV. CONCLUSIONS

This paper describes a pedagogical experiment designed to create better learning conditions for a non-majors introductory programming course.

As the students' results in previous years were far from satisfactory, the Department decided to support a change

proposal made after some experiments in a small size course. There were two main modifications: The separation of students following different degrees in separate courses, and a modification in the class structure. The main idea behind these changes was the creation of a context that improves student motivation and learning support.

We presented the results obtained in the first implementation of the new course structure. To verify the differences we compared the students' results with the two previous years. We also used information obtained from the official pedagogical survey, and from a questionnaire we asked all non-freshmen to answer.

All information available points to the success of this approach in the course. There was a clear increase in the success rate, both considering all students together and freshmen and non-freshmen separately. The official survey brought also positive results, as the students' evaluations on the course were well above the previous year, and also above the average of all courses in the degree. The views of the non-freshmen, that had followed the course in the previous year, were also very positive, stressing the motivational and supportive context created in the course.

The positive evaluation leads us to continue this experiment in the next academic year. The course will have fewer students, due to this year success rate. From the Department point of view this is good news, as less teaching resources will be necessary. The teaching staff is considering some small improvements, but the approach will be similar.

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Students' experiences and attitudes towards learning Computer Science

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Abstract—Low enrollment and high drop-out rates in computer science (CS) have led to an alarming decrease in number of graduates in western countries. What are students' learning experiences, how do these affect their attitudes towards learning CS? This question was explored by investigating diverse students, of a broad study program with courses in humanities and technology, at the end of an introductory course in CS (CS1), which has been designed to enhance students' engagement. The results of a first questionnaire were remarkably positive: All students reflected their experiences as overall positive. Almost half of the students stated, that they had been skeptical towards learning CS before the course. All of these students described positive transformations of attitudes. These results provided an interesting starting point for further research using interviews: What exactly have these students experienced and how do they reason about future engagement? We point out students' experiences that were crucial for a positive transformation of attitudes as well as critical aspects in students' reasoning on future engagement in CS.

I. INTRODUCTION

Computer science (CS) has become a driving factor for the development of today's society. Why is it that the number of students that engage in learning CS is so low? Could it be due to unfortunate learning experiences or perceptions of CS?

A survey of research reveals gaps in the understanding of students' engagement. The Review Task Force, a working group of the IEEE and ACM, reviews low engagement in the latest CS curriculum in 2008, referring to the "computing crisis" [1]. The authors state that the curriculum seems to be unattractive for students and that it is vital to engage with the students to improve recruitment and retention [1, p. 29]. Several recruitment projects exist to attract students at upper secondary school [2]–[4]. However, non-completion and drop-out rates at universities are comparatively high [1], [5], [6], and research on drop-out concludes that the problem is very complex [7]. In this study, we focused on students' experiences and resulting attitudes towards learning CS as those have not received much attention in research [8], [9] and appear to be important in the endeavor to enhance engagement in CS.

The following research questions were important and central in this study. What is the role of students' learning experiences, how do they affect students' attitudes towards learning CS? What are students' experiences that lead to positive or negative

attitudes towards learning CS? Are there students who do not decide to (further) engage in CS due to unfortunate learning experiences, perceptions, attitudes etc. – students that would engage if they had only experienced CS differently? Aiming at a better understanding of students' learning experiences that affect students' attitudes towards learning CS, our goal is to be able to plan further research and to inform the endeavor of enhancing students' engagement.

Based on our research questions, we decided to investigate diverse students, who have an interest in IT and technology but who have not decided to major in CS, as they take an introductory course (CS1), which was developed with the explicit goal to enhance students' engagement [10]. The study was carried out in two steps: A first questionnaire aimed to get insights in learners' course experiences and attitudes through collecting data of a greater number of students. Subsequent interviews were carried out with a smaller selected group of students to get a deeper understanding of learning experiences, students have made in the course and beyond.

The report begins with a summary of related research. After that, the first part of the study follows, its research questions, the questionnaire, and the results, which were the basis for the follow-up study. We then state research questions for the second part of the study, describe the selection of students, the interview questions, and results. Finally, we summarize results and conclude with issues for future research.

II. RELATED STUDIES

Students' computer-related experiences before university and resulting attitudes and expectations were studied by Magenheimer, Schulte and Knobelsdorf [8], [11], [12]. Knobelsdorf distinguishes between "users" and "designers" to describe students' experiences and resulting expectations, that are very different for these two groups of students [8]. However, in her summary of related research in 2011, she concludes that the learners' backgrounds, their understanding of the subject, and their individual interests have not received much attention in research so far [8, p. 31].

Why are some students interested and others not? A lot of research has been done with a focus on gender [13] or minorities [14], [15]. A general finding is that conceptions of

CS and attitudes towards learning CS have a major impact on girls' engagement [16]. Overall, CS is often perceived to be a male field [17], [18] and women often perceive themselves as less capable than males while objectively having the same skills [13]. Further findings lead to the following suggestions to enhance womens' engagement: It is important to arrange a positive climate, to foster positive experiences, to convey a broad, relevant image of CS, and to make use of teaching concepts that provide pathways into CS [19].

Providing pathways into CS points towards the theory "community of practice" and the terms "outsiders" and "insiders" [20], [21], that are rooted in social theories of learning. Wenger considers "identity" as one component of learning, which Ulriksen et al. find to be a key aspect to explain students' drop-out [9] and students' decision to choose or not choose engineering as a study program [22]. Holmegaard and Ulriksen state that students do not choose engineering because they do not see opportunities for constructing attractive identities. In contrast, students that do choose the study program see themselves as someone engaging in a cross-disciplinary and innovative subject. However, this is often not conveyed during the first year of education and can lead to drop-out [22].

Kinnunen gives a review of literature on students' drop out in CS and investigates CS minors' reasons for drop out of a CS1 course using qualitative interview research [7]. Her overall conclusion is that reasons for drop-out are complex, thus the most frequent reasons reported by Kinnunen's informants were "lack of time" and "low motivation". Simon et al. furthermore state that non-majors, contrary to majors, more likely experience the course as miserable or pointless [23]. Another important aspect related to students' motivation is "perception of self-efficacy", which is considered in gender studies and also recently by Kinnunen [24]. She gives recommendations on how to enhance self-efficacy and argues that this would likely improve academic performance and persistence. Furthermore, she recommends that more research should be done on how students experience different parts of the course, e.g. assignments and lectures, to understand students' orientation and persistence within their studies.

III. PART 1: AIMING FOR AN OVERVIEW

The aim of this part of the study was to get an overview of students' course experiences and how those affect their attitudes. We purposefully focused on course experiences here, to target interesting related experiences beyond the course in the second part of the study.

A. Research question

A general conclusion from the literature review is that students' experiences are not well understood and that they affect students' perceptions of CS and future engagement. In view of this conclusion and the aim of this part of the study, we state the following research questions (RQ):

RQ 1.1: What do students experience in the introductory CS course that supports or changes their prior attitudes towards learning CS?

RQ 1.2: How do the students' attitudes towards learning CS relate to their broader interests?

The intent of the second research question is to find out about students' interests and how learning CS could be meaningful to them. Are there students that have positive course experiences and attitudes towards studying CS that do not relate to their broader interests? Are there students that have unfortunate negative course experiences or attitudes, meaning that those could be positive, if they had just experienced CS in another way, e.g. more conform to their interests?

B. Data collection

A questionnaire [25] is an efficient method to collect data of a greater number of students. To collect data with which to explore the research questions, we designed a survey consisting of four sections: First, the students were asked for their interests that made them choose their study program. Hereby, we hoped to get broader interests that, through the focus on the study program, are informative to explore RQ 1.2. In the second part of the questionnaire, the students briefly stated their prior programming experiences. This question, contrary to the others, explicitly focuses on programming experiences rather than experiences in CS in general. With this focus, we hoped to get precise information on students prior experiences, that we assumed have a big influence on students' experiences when being introduced to CS, which is commonly done through teaching programming. In the next section, the students were asked to check one of two checkboxes for each contradictory pair of attitudes: Had the students thought that learning CS is rather interesting or uninteresting, boring or exciting, difficult or easy, useful or irrelevant? The idea of this part was to make students decide whether their feelings or attitudes were rather negative or positive. This is helpful for the last section, in which the students were asked to describe two to three of the most important experiences during the course that either supported or changed these feelings or attitudes which aims at exploring RQ 1.1.

C. Sampling

As the goal of this study was to explore different experiences and their affect on attitudes, we decided to investigate diverse students, that have an interest in technology, but that have not decided to major in CS, at the end of an introductory course in CS (CS1). The students of the "Sociotechnical Systems Engineering" program at Uppsala University are an adequate group: Their study program offers courses in both, the humanities and technology. The ratio of male and female students is balanced in that program. The students take CS1 in their second year. About half a year later, they choose whether they want to specialize in CS or energy systems. The CS1 course was designed in recent years, explicitly with the goal to enhance students' engagement, taking into account various results from Computing Education Research [10]: The students work in pairs in the lab. The pairs and assignments change every week. Lab assistants are present to help when it is needed. At the end of every week, the students explain

their results to the teaching assistants who grade the students immediately. There is no final exam. Towards the end of the semester, the students work on a project.

D. Results

Altogether 36 students have filled in the questionnaire using English language¹. Two datasets were excluded because one student did not fill out the last, most informative question and the other student copied the answers from the neighbor. Contact information were provided by 25 students. According to these students' names, 15 of these respondents are male, 10 female. More than two thirds, 26 students, state that they had no prior programming experiences.

In view of the findings reported in related research, the overall impression of the students' experiences is surprising: All of the students have experienced this course as overall positive. Even the students that have experienced the course as relatively difficult, mostly state that it was "fun" and "useful". The most notable result was that all of the 16 students that thought of themselves as rather skeptical before the course (learning CS is rather uninteresting or boring or irrelevant) describe a change towards a more positive attitude. Some statements contain prior stereotypical thinking or prejudices, such as²:

Before, I thought of computer science as very boring and like it was all about sitting in a dark room in front of a computer drinking coca cola. (Anna)³

In other descriptions, this can be found rather implicitly:

Before the course, I thought learning about computer science was difficult and nothing I had done before, thought it was for people who had been programming since they were little, having it as a hobby. (Sofia)

In the last statement, Sofia describes her perception that learning CS is for certain people. It seems as if she doesn't see herself as such a person. Frank expresses this even stronger:

Before the course, I thought learning computer science/IT would be boring, difficult and irrelevant. That it wouldn't fit me. (Frank)

These statements point to "identification", which Ulriksen finds to be an important aspect to explain drop out [9].

Overall, emotions were very often reflected on. Furthermore, the students describe that they now understand how learning CS can be useful or relevant and what CS is all about. The descriptions of students' experiences are relatively short (up to about 100 words). They do not contain details on what exactly the students have done or seen, that made them feel the way they describe it. However, it is possible to categorize the students' descriptions of course experiences using content analysis. Through that, we can distinguish different foci of experiences. Four categories emerged, which can be summarized and further explained through students' statements, mostly

from students that describe a positive attitude transformation. *Emotion*: Experiences are described through emotions, such as CS being "fun", "challenging" etc., as it was also described by Simon et al. [23]. Examples are:

Before, I thought of computer science as very boring [...] But since I started this course, I think it's a lot of fun, though difficult. I think, it's a good feeling to be able to do a program. (Anna)

First I thought, it would be boring, something that only a real geek could enjoy. But I think it's intriguing, it's like a challenge and I get honestly happy when the code is not red. So, I'm positively surprised. (Ulrika)

Usefulness of learning about CS: Experiences of how learning has been useful are described. Such experiences are often pointed out to be important for females [13], [19]. However, in this data seven male students and only three females as well as four students that we don't have information on their gender, write about how they have experienced CS as useful. Examples are:

Even though it's hard and I sometimes feel like crying during the lessons when nothing works out, it's very necessary for my learning experience. (Anneli)

It's still very difficult according to my opinion, but I could really be working with this in the future. I also believe that it can be useful when I'm starting to work to know a little about programming and computers. (Karl)

Before the course, I didn't see courses in computer science as important as I see them now. It's really important to create good programs, that are easy to understand for others to make work easier for the masses. (Andreas)

Understanding of the discipline: The students' descriptions focus on having gained an understanding of the discipline CS as a whole. The fact that we find this focus underpins the recommendation to convey a broad and meaningful image to recruit and retain students [1], [13], [14], [19]

Now, I think computer science is interesting because learning about it has made me understand what it is all about and I know the structure. (Rebecca)

I have noticed that there is a whole world around computer science. It's much wider than I thought and it's interesting to be a part of it. (Emil)

Social aspects doing CS: The students focus on the social setting, in which activities in CS are carried out. Kalle is the only student that states this explicitly. However, according to his choice of checkboxes, he seemed to have had a positive attitude towards CS already before the course.

Before the course, I had the picture of computer science that it was a thing you did on your own, and not in groups. That it only was a non-social job. (Kalle)

E. Summary and Key Aspects for Follow-Up Study

The results of this study are surprisingly positive. Almost half of the students seemed to have undergone a positive transformation of attitudes and no student seemed to have made "unfortunate learning experiences" (see section III-A). Through the different categories, we point out different foci in students' experiences. Overall, the course experiences seemed to have had a relatively strong and positive influence on students' attitudes towards CS. Furthermore, we got the

¹The students' mother tongue is Swedish, but the students are usually relatively fluent in English.

²A few minor spelling corrections were made in the students' statements.

³All student names were changed and chosen in accordance to the respondents' gender. The same names were used for the same student, also for the second part of the study.

impression that the students infer from their specific course experiences, mainly in the area of programming, to more general perceptions of and attitudes towards CS as a whole. Noticeable are the statements in the category *understanding of the discipline*. Both students express that they now know “what CS is all about”. Fortunately, their new image of CS seems to be attractive to them. However, the course is not designed to convey what CS is all about and could thus lead to inappropriate perceptions or attitudes. However, this could have been fostered by the question in the questionnaire, which asked for students’ attitudes towards learning CS/IT.

Unfortunately, the descriptions of experiences were not very detailed (up to about 100 words). Hence, we used the second part of the study to aim for a better understanding of those experiences. Also, the students were not asked whether or not they plan to engage in CS in the future. However, this is an important information. Maybe these students do not plan to engage in CS in the future. One observation that supports the relevance of this question is that the students seldom relate their course experiences to their broader interests that they were asked to describe in the first part of the questionnaire.

IV. PART 2: AIMING FOR DEEPER INSIGHTS

In view of the results of the first part of the study, a follow-up study was conducted to get a better understanding of the students’ course experiences that led to a positive transformation of attitudes. This is interesting, because existing research mainly aims at understanding negative experiences, attitudes, or drop-out. Furthermore, we get the opportunity to explore how these students, that have had very positive learning experiences, reason about future engagement in CS.

A. Research questions

Based on the results of the first study, the aim stated above, and the overall goal of the study described in section I, we pose the following research questions:

RQ 2.1: What have the students experienced that has led to a change of perception: From learning CS is boring or uninteresting or irrelevant to learning CS is useful or interesting or relevant?

RQ 2.2 a: Do the students plan to engage in CS in the future, and during their study by choosing more CS courses?

RQ 2.2 b: How do the students reason about future engagement?

B. Data collection and analysis

The students’ descriptions of experiences in the questionnaire brought up questions such as: How exactly is CS useful to the student? What exactly was interesting, fun etc. about it? Those questions can be best elaborated on in a dialogue with the student. Hence, we decided to use semi-structured interviews that allow follow-up questions [25]. Four lead-questions were prepared. We started the interview by asking the students to explain their experiences and attitudes prior to the course, referring to their choice of either option in the

questionnaire, i.e. CS is rather boring vs. exciting or useful vs. irrelevant. Then, we asked the students to describe their course experiences that affected these prior attitudes (RQ 2.1). The second part of the interview dealt with future engagement (RQ 2.2 a, b): First, we asked the students for their career plans. From there, we moved on to the question whether or not the students are planning to take more IT courses and why.

The categories that were developed in the first part of the study were used to select five students, that described a positive transformation of attitude, but with different foci in their descriptions of experiences. The interviews were transcribed. Then, we did a thematic analysis to explore the research questions. In-depth analysis of the data, as well as further investigations are currently being worked on.

C. Results

First, experiences that led to a positive transformation of attitudes (RQ 2.1) are summarized. Then, reasoning about future engagement in CS will be reported (RQ 2.2 a, b).

Building up students’ self-efficacy is one important aspect that was considered in the course design [10]. Indeed, in the interviews, the students often describe their attitudes before the course similar to Sofia:

I thought, it was gonna be hard and I thought, I shouldn’t be able to understand anything.

The feeling of being capable has strengthened positive emotions, e.g. programming is fun or challenging. Working in pairs that change every week, hence having a partner to find and discuss solutions with, was reported to be very supportive. Furthermore, reflections of last weeks’ lab assignments in the lecture and the increasing difficulty of the lab assignments every week, “starting from zero”, were reported to be helpful.

The experience to be able to create a program that others can use has also led to positive attitudes towards learning CS. Lina for instance states that she thought she would have to study a lot about the computer before being able to write a program, that she would study something that she is not able to use. She says:

I’ve changed now. [...] we actually produced a couple of games, clocks and stuff.

Furthermore, Andreas describes that he has become aware that programming is a creative activity:

First you have to think about how do I solve this problem, then you have to put input parameters, then you have to create the interface. I think that it’s creative work actually – do something and get something real out of it. [...] You can see results that actually I have created and that works. I like that.”

Providing opportunities for creativity was another aspect, that was explicitly considered in the course design [10].

A central and important experience that was reflected on by all interviewees in different ways is that problem solving is an important aspect in programming. Sofia, a student who had not “really anything to do with programming before” and who was thinking that programming is “kind of a nerd thing”, reflects that she has learnt a new way of thinking. After having

made many mistakes by just typing code without planning in the first two labs, she realized:

You had to work in another way, you had to sit down and talk to each other and you had to maybe write down on a paper before, like I wanna do, I have five steps that I have to do: I first have to make this matrix [...]

The importance to communicate was fostered by programming assignments in pairs and groups. Working out problem solutions on a piece of paper before typing was also an important experience for Anneli, a student with a prior attitude of CS being rather uninteresting and boring. Before the course she had the impression that “programming is something that you can only do if you are spending a lot of time in front of the computer”. The importance of a systematical approach was emphasized by the teacher. According to Sofia, he said:

Programming is not just about coding, it's about thinking how to structure the code before you write it on the computer and that's maybe 90% percent of the programming. That's one of maybe the greatest lesson I have learnt from this course.

Usefulness was elaborated on several times, both usefulness of learning CS and usefulness of CS in different contexts.

In the beginning, I just thought we can learn code [...], but after being through the course [...] we actually learned how to create interfaces that people can use – you can feed in your numbers, then get answers.

Here, Andreas refers to programs that are used in research. Further applications mentioned were programs for a bank or ticket system in a bus. When reasoning about socially relevant applications of CS, the students often referred to the internet, which allows people to speak freely. However, only Sofia seems to be able to relate her course experiences to a broader, relevant meaning of CS: “All solutions in the future will have something to do with computers and connecting things”. Sofia finds the fact that she can learn a special way of thinking to solve problems, such as structuring programs, appealing, and argues that all future computer systems will be constructed through such a process of problem solving.

Four of five students express doubts about engagement in the future (all except Sofia). Anneli relates to capabilities: “It's kind of hard for me, or I don't think, that I'm really good at it, yet”. Lina, a student that has worked at a company before, has doubts about the people that she will work with in CS:

I don't think that open mindedness and computer science go very much hand in hand.

To Lina, it seems as if computer scientists often accept only one solution and are sometimes very rude to each other.

Andreas and Kalle are relatively certain that they will not take more courses in CS. Andreas described that, before the course, he expected to just learn how to code. In the course, he experienced that he could learn “how to actually create stuff that others would use”. However, he argues:

I would pick energy because it's interesting and I see the relevance and I would pick the other [CS] mainly because I think it's fun.

How would he reason if he had experienced the relevance of CS for our society on the same level as he can think of the relevance of energy systems?

Kalle argues that he does not want a job where he “sits with a computer and programs”. Asking what computer scientists do, he states:

Solving problems all day long [laughs]. And [...] it's like - [...] if you are an engineer, you work with problem solving. When you are a programmer, I think, you work with problem solving but in, I don't know, like easier way. It's not that complex. You write this code and it's not like you have to think of eh I don't know society [laughs] and eh economy and eh things like that.

How would he reason, if he had experienced the complexity and potential of CS to address current societal problems?

Furthermore, Kalle argues:

Personally, I would like to learn more about it [CS]. Programming is fun, [...] but for the relevance of our course, the STS course, I don't see why we have to learn every little detail in programming. There are a lot of programmers out there. There are guys that are really good at programming so for me, for our course, I don't see the relevance of learning any more.

Kalle seems to understand CS as programming and doesn't see himself as a programmer. Hence, he does not see the relevance in taking more courses in CS. Sofia, the only student that is certain about taking further CS courses, who has experienced CS as meaningful to solve future societal problems, also takes a distant position to the “real guys”. However, she is able to see herself working with CS in a certain way:

Since computer science is the future, I want to work with it [...], maybe I don't wanna be like this hacker, coding, [...] but I wanna be maybe the person deciding what to code or making it work in society and if someone, maybe a computer student, is doing code, you have to figure out where to use it and how and that's what I wanna work with. Maybe be a consultant?

D. Summary and Conclusion

According to the interviewees, the experience of CS being a fun, social, creative activity, that they are capable of, through which problems are solved, turned out to be an important experience. This was supported through assignments to develop different programs, that were worked on in pairs, that changed every week, as well as group work during a project, and through emphasizing the importance of systematically approaching programming problems.

However, one critical aspect is a limited understanding of CS, reduced to programming. Other areas, such as networks and databases, as well as aspects of complexity and relevance of CS to solve societal problems have not been experienced in most cases. This however seems to be of importance for the interviewees. Accordingly, they argue that, since they do not want to become programmers, they do not need to learn more CS than the basics in programming that they learned in the course, and hence they will not take more courses in CS.

This points out the importance of two aspects in students' reasoning about engagement: identification and understanding of CS and its meaning. These aspects seem to relate and appear to be specific for this student group. However, these findings emerge from five interviews with students that belong all to the same study program and that have stated skepticism before

the course. Further research is needed, as existing research has not dealt with identification in relation to understanding of CS.

V. CONCLUSION AND FUTURE WORK

The aim of this study was a better understanding of students' learning experiences that affect students' attitudes towards CS. Therefore, we investigated diverse students of a broad study program at the end of an introductory course in CS (CS1).

The study was carried out in two steps. Data, collected through a questionnaire, convey a favorable image: All students describe overall positive learning experiences. Almost half of the students state that they were skeptical before the course (CS being rather boring, irrelevant, or uninteresting) and point to experiences that supported them to revise their attitudes. Aiming for a better understanding of those experiences, the descriptions of experiences were categorized by the students' foci. This served as a basis to select five students with possibly different experiences for subsequent interviews. The interviews revealed a better understanding of course experiences, that have fostered positive transformations of students' attitudes, and critical aspects in students' reasoning about future engagement.

Two aspects appeared to be significant in these students' reasoning about future engagement: Students understanding of the discipline CS and its meaning and their ability to identify with engaging in the area of CS. Overall, we found a relatively narrow and meaningless understanding of CS being programming. Since the students do not see themselves as future programmers, learning more CS appears useless in many cases.

In conclusion, we believe that more research is needed on how students identify with CS and IT. The ability to relate to the discipline appears to be an important factor for student retention and continued engagement. In particular, we recommend investigation of what students believe a "real computer student" is. Research on these issues will help us to develop meaningful education in CS and IT, and enhance student engagement in these, and related, educational programs.

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Identifying the Impact of the SPIRIT Program in Student Knowledge, Attitudes, and Perceptions toward Computing Careers

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Abstract – Declining interest in computing programs nationwide presents a threat to America’s security and limits potential for innovation across all domains. One way to address this problem is to remove misconceptions held by the nation’s youth about computing, including information about how it positively impacts many subjects and showing them that applying computing can be fun and rewarding. One program at a Midwestern university accomplished this goal through a week-long, residential, summer camp for high school students to educate them about career opportunities and possibilities for people with Information Technology skills. Participants completed a variety of hands-on activities daily, along with listening to work experiences of computing professionals. Feedback collected from the student participants showed that in addition to raising awareness about computing opportunities, the program increased youth interest in IT, prompted many to enroll in computing/engineering courses, and improved their performance in school. This paper shares details about the program and participant feedback to make a case for offering similar programs to correct the knowledge people have about computing.

Index Terms - computing attitudes, outreach programs, STEM, youth interest.

INTRODUCTION

The occupational outlook for computer-related careers through 2018 is considerable when evaluating careers with either the fastest growth and/or the largest numerical growth increase [1]. Unfortunately, student interest in computer science and information technology at the college level has been declining for the past decade to match the levels of 1999-2000 [2]. Given the increasing support that computing provides to all domains, these continuing, insufficient levels of information technology expertise threaten America’s security and opportunity for critical innovation across all disciplines.

A program called Surprising Possibilities Imagined and Realized through Information Technology (SPIRIT) was created in 2008 to address this problem. The premise of the SPIRIT project takes advantage of the coupling of IT with

disciplines that can make a positive difference to society through its support of STEM disciplines. By conveying this same knowledge to high school students, especially women, more will be open to studying IT in college.

SPIRIT includes a two-week professional development summer program for up to 30 high school teachers and guidance counselors, and a one-week summer camp for up to 75 high school students. During the first week, teachers and counselors learn how to use Alice, a 3D storyboarding tool, to present visual information about their subject areas or career planning to their students. Each one creates a minimum of three Alice-based classroom lessons that they will use during the subsequent school year. This indirect exposure to IT through a variety of mostly non-computing subjects is intended to get more students to begin thinking about computing in more positive ways.

During the second week of SPIRIT for the teachers and counselors, students also arrive. Everyone listens to a variety of IT professionals and completes numerous hands-on activities designed to broaden the participants’ awareness of the utility and positive impact of computing across many facets of society. Students are also taught about Alice and complete a project using Alice by the end of the week. Unlike the teachers and counselors who receive one week of focused instruction on Alice, students only need a brief introduction and short hands-on sessions throughout the week mixed in with the other hands-on sessions that introduce different tools and technologies. This part of the SPIRIT program is designed to help participants recognize that computing is an essential tool that can be employed in many fun, interesting, and beneficial ways. Additional details about the SPIRIT approach are available in [3]. The remainder of this paper will focus on the student participants who participate in the summer camp.

High school students apply to SPIRIT through an online application system that includes responses to several short answer questions. A team of 3 reviewers evaluate all applicants separately using an online evaluation tool that allows them to view the students’ responses to these short answer questions. Numerous criteria, including year in school, GPA, ACT/SAT scores, and the scores given by the reviewers are used in scoring the applicants. The goal of the program is to convince students who may not be considering a major in computing to change their minds. Therefore, it

should be noted that applicants who showed definite interest in IT were rated lower than applicants with no definite interest. After all reviews are done, a rank-order list of all applicants is produced and the top 75 applicants are invited to attend the summer program. If any of these students are unable to accept the invitation, the next applicant on the list is invited.

There is no cost for students to attend the program, other than travel to and from the university. Additionally, they receive a daily stipend as long as they complete required assessments. Approximately ten months after the summer program, a follow-up survey is sent to all students. Three cohorts (in 2008, 2009, and 2010) have completed the summer programs to date.

The response rate for the follow-up survey from the first two cohorts was too low to draw any conclusions. Too much time had passed since they completed the program and there were no incentives to encourage their response because the first two cohorts received all monies by completion of the summer program. For the third cohort, a small portion of a deposit was withheld until all SPIRIT obligations were fulfilled, and the completion was the last of these. Not surprisingly, the third group's response rate was very high and enabled conclusive analysis of the data, which are reported in this paper.

This study investigates the impact of the SPIRIT program by investigating the following research question:

What is the impact of the SPIRIT program in student knowledge, attitudes, and perceptions toward computing careers?

METHODS

For the third SPIRIT cohort group from 2010, the previously paper-based follow-up survey was converted into a web-based version using Qualtrics survey software [4]. The primary reasons for this change were (1) to eliminate data transcription errors when manually entering responses on paper forms, and (2) make it easier for students to respond online, eliminating the need and cost for return via postal mail.

Links to the online, voluntary survey were sent to program participants via the email address they provided during initial registration. Once the allotted survey time had passed, the results were collected. The survey results were exported to .pdf and .csv files using the features available in Qualtrics. Many of the responses were open ended. These were coded and placed in appropriate categories for identifying quantitative values for these responses.

The survey collection method was voluntary, but the response rate was 87% for the 2010 cohort, likely due to withholding payment of their small deposit. Of the 75 SPIRIT attendees a total of 65 responses were received although not all questions were required to be answered.

The program participants were all high school students: 12% grade 9, 24% grade 10, 35% grade 11, and the remaining 29% grade 12. The gender distribution was

largely female with 67% being female and 33% male. There was a fairly even representation of ethnicities largely representative of the US populace and the local community demographics with 64% white/Caucasian, 17% black/African American, 9% Hispanic/Latino, 6% Asian, and 3% other ethnicities.

The questions focused on the participants' opinions of the program, changes that occurred academically as a result of the program, and changes in career goals as a result of the program. Several yes or no questions had related free response prompts if the response was "yes." These are indicated below.

The following are the survey questions, including yes/no and free response: (identification and similar questions have been omitted)

1. Did attending SPIRIT change the courses you selected to complete during the 2010-2011 school year? (if yes, prompt next question)
 - o Please explain how SPIRIT influenced your course selection process.
2. Did attending SPIRIT change your performance in any of the courses you took during the 2010-2011 school year? (if yes, prompt next question)
 - o Please explain how attending SPIRIT influenced your course performance in 2010-2011.
3. BEFORE attending SPIRIT, did you have a career goal? (if yes, prompt next question)
 - o Please explain what your career goal was BEFORE attending SPIRIT.
4. AFTER attending SPIRIT, did your career goal change? (if yes, prompt next question)
 - o Please explain how your career goal changed AFTER attending SPIRIT.

Please respond to the following questions on a scale of very unlikely to likely. (0 to 4, 0=very unlikely to 4=very likely)

5. You had plans to attend college BEFORE attending the 2010 summer camp
6. You had plans to attend college AFTER attending the 2010 summer camp.
7. You had plans to pursue a career in information technology BEFORE attending the 2010 summer camp.
8. You had plans to pursue a career in information technology AFTER attending the 2010 summer camp.
9. What was the most important thing you learned during the SPIRIT 2010 summer camp?
10. Do you have any additional comments or advice in regards to the SPIRIT program?

Once results were collected from the survey site, a qualitative analysis of the open-ended responses was done in order to get insight into the students' perceptions of the program as well as effects it may have had in their lives, especially regarding future career plans.

Constant comparison [5] was utilized to analyze the qualitative data. The first step was grouping similar statements and responses together from the survey results. Once initial categories were formed, individual responses

were compared within the category. For example, if a student responded “I decided to take a programming class so that I would be better able to consider a major in Informatics” or “I decided to take an elective in computers”, these responses were coded into the category “enrolled in computing related course.” Statements that were occasionally longer and contained more content were oftentimes placed in two categories. This approach explains why the percentages of the results may exceed 100%. Two of the authors conducted the qualitative analysis independently and the initial categories were compared. The percentage of agreement for the categories was of 90%. Occurrences of categories were then turned into percentages. The results report all of the survey results, in that no responses have been omitted in the totals.

RESULTS

The survey results explained the participants’ views about the program and, more importantly, what they learned during the time spent at SPIRIT and its impact. This section will elaborate on the strength of the responses to each of the key questions, clarifying the impact based on the students’ explanations for their affirmative responses. For each of the categories we also provide sample of quotes to better describe student responses.

I. Influence of SPIRIT Program in Course Selection

The first survey question addressed the impact SPIRIT had on the participant’s course selection during the 2010-2011 academic school year. 85% of the survey participants responded to the question, and 40% of these respondents selected “yes” and were prompted for the next question.

In general, the responses were positive to the survey prompt statement “Please explain how SPIRIT influenced your course selection process.” 63% of respondents to this question stated they enrolled in a computing related course as a result of the SPIRIT program. For example, one student stated, “SPIRIT got me more interested in computers and programming. I actually chose to take a 3D Art Modeling class because of SPIRIT.” All such responses were categorized into students who made an effort to enroll in computing-related courses.

18% of the respondents stated that the SPIRIT program influenced their career objectives. Similar responses were categorized into students who expressed that the program had an influence on their future plans regarding college education and the fields in which they would like to work or study. To illustrate, one student explained, “I decided to take a programming class so that I would be better able to consider a major in Informatics.”

17% stated the program increased awareness of careers and opportunities. These types of explanations were grouped into the category of those who expressed that they were made more aware of opportunities that exist in computing related fields of study and work. For example, one student stated, “SPIRIT showed me opportunities and

career choices associated with Information Technology that I did not know of before.”

One category included those respondents who stated their interest in the field of computing and information technology was increased. 17% stated that the program increased general interest in technology and computing. For example, one student explained, “I realized I enjoyed computer classes more than I do sitting and listening to a teacher talk.”

The general feel of the responses were positive. The significant majority of responses showed that respondents acted as a result of the program and altered their current courses. At a minimum, the respondents displayed an increased interest in technical and computing related fields of study. The effects of the program are evident even in this first survey prompt.

II. Influence of SPIRIT Program in Course Performance

Students were asked to identify if attending SPIRIT changed their performance in any of the courses they took during the 2010-2011 school year. This question received a 59% response rate meaning that respondents had said selected “yes” in saying their school performance had been affected. These “yes” respondents were then prompted for the next question asking for an explanation. These students then were prompted to explain how attending SPIRIT influenced their course performance in the 2010-2011 academic year. The responses were classified according to different categories.

The first category included responses from those who stated that their performance at school had been influenced or that the program had given them an edge or some level of boost in their coursework. 40% of respondents stated it helped them improve their work performance at school, e.g., “I received a better grade in a project due to the Alice world I created and impressed my teacher with.”

The next category included the students who had become more comfortable in working with the technology or software used during SPIRIT. 25% of responses were placed in this category. One such response is, “I felt more comfortable using a similar program.” Then, 21% of students remarked that they became more interested in technology and computing. These responses often demonstrated change in career objectives. For example, one student stated, “I found that I am very interested in the BCM program in the College of Technology. I have spoken to my school counselor about taking courses in that area.”

Other 13% of responses were categorized as saying the student felt they were more thoughtful and/or put more effort into their work with technology. This category was more specific than the first one, which tended to be more general schoolwork improvement. To illustrate, one student stated, “I was a lot better with being quick to use computer software in place of paper and pencil things for planning projects and such.”

The final category grouped those respondents who gained knowledge of available career paths regarding

technology. 6% of responses fit this category. For example, one student stated, “It showed me that IT isn’t just one specific career path but it can be integrated with many things.” Again, the general feel was positive throughout the responses. A large portion of students mentioned the program had influenced their schoolwork either in general or using the technology worked with during SPIRIT.

III. Career Goals of Participants before SPIRIT

The following question, “BEFORE attending SPIRIT, did you have a career goal?” received an 83% response rate with 61% of these selecting “yes.” The participants were then prompted for the next question: “Please explain what your career goal was BEFORE attending SPIRIT.” The purpose of this survey prompt was simply to establish the possible preexisting career objectives of participating students in order to determine possible changes as a result of the program.

The largest portion of respondents stated they were interested in medicine and biological sciences. 36% of responses were placed into the medicine/biological sciences category. Responses were direct for the most part and typically had little overlap. For example one student responded “to become a Pharmacist.”

The results of the responses are depicted on Table I. The results are followed with the percentage of the category found, the field of interest categories for the responses, and examples from the responses. These results show the largest portion of students were interested in medical and biological sciences fields of study before the program.

TABLE I
CAREER GOALS OF PARTICIPANTS BEFORE SPIRIT

| Percent | Field of Interest | Example |
|---------|------------------------------|------------------------|
| 36% | Medicine/Biological Sciences | “Pharmacist,” “Doctor” |
| 18% | Engineering | “Mechanical Engineer” |
| 18% | Technology/Computing | “CIS - Networking” |
| 15% | Related | “Interior Design” |
| 9% | Liberal Arts | “Stock Broker,” |
| 6% | Business/Economics | “Accountant” |
| 3% | Law | “International Law” |
| | Education | “Elementary Education” |

IV. Career Goals of Participants after SPIRIT

The question “AFTER attending SPIRIT, did your career goal change?” received an 83% response rate, of which 44% selected “yes.” These respondents were then prompted for the next free response “Please explain how your career goal changed AFTER attending SPIRIT.”

A stunning 50% of students said their career goals had changed to a technology related field and their response was placed in the appropriate category. Responses in this category expressed interest in technology related careers or integrating technology in their career goals. Two representative quotes are: “it made me want to pursue a career within the information technology field,” “I now aspire to be a meteorologist because of the intertwined use of computers and mathematics - two things I am very

passionate about,” and “Before, I was interested in sociolinguistics. Though I maintain that interest, I am now looking to research technology’s impact on language.”

Responses as the latter two are certainly welcome as the students’ initial interests are maintained and have simply likened to integrating technology into their interests.

The remaining categories fell below 15% and are shown in the following table containing all the totals of both, before and after for comparison.

TABLE II
PARTICIPANTS PREFERRED DISCIPLINES TO PURSUE AS CAREERS BEFORE AND AFTER SPIRIT

| Percent Before | Percent After | Field of Interest |
|----------------|---------------|-----------------------------|
| 18% | 50% | Technology |
| 15% | 12% | Arts/Design |
| 9% | 8% | Business/Management |
| 18% | 8% | Engineering Related |
| 36% | 8% | Medical/Biological Sciences |
| 6% | 4% | Law |

There is a significant increase in interest in technology related fields after the SPIRIT program. The following table shows percentages from before (taken from the previous survey prompt) and after the program alongside the similar categories from both free response sets. The shift in career goals to technology related fields is more evident here. The SPIRIT program has significantly affected the participating students’ career goals as displayed here by the 32% increase.

V. Plans to Attend College Before and After SPIRIT

The next questions in the survey were “Please respond to the following questions on a scale of very unlikely to likely.-You had plans to attend college BEFORE attending the 2010 summer camp” and “Please respond to the following questions on a scale of very unlikely to likely.-You had plans to attend college AFTER attending the 2010 summer camp.”

Both of these questions had an 81% response rate and similar percentages. The first of the two, “You had plans to attend college BEFORE attending the 2010 summer camp” results were 94% “very likely” and 6% “likely.”

The question “You had plans to attend college AFTER attending the 2010 summer camp.” Results were 96% “very likely” and 4% “likely.” Although small, the camp did have an effect on participants’ plans on enrolling in college. After the program, they were more likely.

VI. Plans to Pursue a Career in Information Technology Before and After SPIRIT

The results of this portion of the survey yielded the most interesting results. Participants were asked for a scaled response from “very unlikely” to “very likely” whether or not they intended on pursuing a career in information technology. They were asked for this response in reference to before and after the SPIRIT program.

The first of the two questions, "Please respond to the following questions on a scale of very unlikely to likely.- You had plans to pursue a career in information technology BEFORE attending the 2010 summer camp." received a 75% response rate of survey participants and of those, the responses were as follows. Simply put, there were not very many respondents who stated they would likely pursue a career in information technology before the SPIRIT program.

The following survey question asked the natural follow up of the participants in having them state the likelihood of pursuing an information technology related career after the SPIRIT program. This question received a 77% response rate of survey takers and the results are depicted on Table 3.

Clearly the program had an effect on the participants' career goals. For better comparison, the results are placed side by side on Table 3.

TABLE III
CAREER GOALS OF PARTICIPANTS BEFORE AND AFTER SPIRIT

| Percent Before | Percent After | Likelihood |
|----------------|---------------|---------------|
| 22% | 6% | Very Unlikely |
| 51% | 16% | Unlikely |
| 33% | 34% | Unsure |
| 6% | 34% | Likely |
| 4% | 10% | Very Likely |

Here the shift is obvious. There was only a 6% increase in "very likely," but a surprisingly large 28% shift in the "likely" category. The "very unlikely" and "unlikely" both suffered large reductions from the "before" column.

These results demonstrate the SPIRIT summer camp's effect on participants' interest in the information technology field.

VII. Important topics learned during the SPIRIT program.

The final survey question was "What was the most important thing you learned during the SPIRIT 2010 summer camp?" This question was more open ended than the others and allowed for the students to share what they thought to be the most valuable part of the time spent in the program. This question had an 83% response rate. Responses were categorized in the same manner as in previous free response questions.

The largest of these categories from the results was "learned more about career options." This category was designated for those responses which expressed that an increased awareness of available careers in technology from the program. 39% of responses fell into this category. For example, one student stated: "The breadth of the positions available in information technologies."

The next largest category was more general in that responses stated they learned more about computing and technology in general. 33% of responses were placed into this category. One student mentioned: "I learned that IT can be applied to many other things other than programming."

Then, 13% of respondents mentioned they learned more about the importance of technology and I.T. in the world as

well as other fields and careers. For example, a student stated "How technology played an important role in the medical field."

The remaining categorized responses fell below 7% and are shown in the table of all categories found from the responses.

TABLE IV
MOST IMPORTANT THING FROM THE SPIRIT PROGRAM

| Percent | Important Topic |
|---------|--|
| 39% | Career options |
| 33% | Learned more about computing/technology as a whole |
| 13% | Importance of technology |
| 7% | Learned a new skill |
| 6% | Making friends and/or socializing |
| 6% | Learned about women's role in IT |
| 4% | Learned more about self |
| 4% | Meeting professionals |
| 2% | Learned about college life |

The largest two categories that respondents fell into were "career options" and "Learned more about computing/technology as a whole." The remaining, were much less, but certainly not less important.

A notable topic would be the category "learned about women's role in IT." This is an important and noteworthy category as the majority of SPIRIT attendants were female.

4% of respondents mentioned meeting professionals was an important aspect of the program. For instance, one student stated: "Meeting people who work in the industry and hearing how their careers use information technology."

Bringing in industry and experienced IT professionals is important to demonstrating to the students the role that IT has to play in the work force. Although few mentioned this as the most important, it is important to note that this is a worthwhile pursuit for the program.

DISCUSSION

The goal of the program is to raise awareness of the societal impact of computing and the variety of career opportunities it offers people with IT skills. Before discussing the relevance of the results, it is important to understand the target group. The program is marketed to high school students who most likely have not yet decided on pursuing a computing major. In fact, those who have decided to pursue IT receive much lower scores during the selection process. Thus, even if one student decides to pursue computing based on what s/he learned from SPIRIT, it represents one more person filling the demand for skilled IT workers. Results from many of the survey questions suggest that several students are now considering a college major in computing and/or engineering.

Positive experiences in high school courses tend to influence selection of majors in college [6,7]. Based on their SPIRIT experience, 14 students (21%) planned or had already enrolled in a computer-related course while in high school. One of these students sent an unsolicited email message relating a poor experience in the high school engineering course she took, but went on to explain that she

still plans to pursue engineering in college based on her positive experience in SPIRIT. Furthermore, she planned to form a robotics club at her school to encourage others who may have been equally dissuaded by the high school course, so they could know how interesting and important computing and engineering study really can be.

In addition to more students taking computer-related courses they would not have taken, 38 students (58%) stated that the SPIRIT experience improved their academic performance in the high school courses they took after the SPIRIT program. Some said they were more confident, while others thought their newly acquired technology skills improved their performance.

When asked if their SPIRIT attendance changed their career goals, 24 students (37%) responded that it had changed to a technology-related career. Although some of the detailed explanations from cited disciplines that are peripherally-related to computing, given that SPIRIT sought to show how far-reaching computing is, it is clear that the students that responded affirmatively to this question recognize that computing skills are essential regardless of the specific career path chosen.

The most important set of responses relative to the intended impact of the program were in response to questions about their intentions to pursue a career in IT. The change in response from before SPIRIT to after SPIRIT showed that the level of interest in pursuing an IT career increased significantly.

CONCLUSION

Misconceptions about computing careers are still prevalent in today's society. Educational programs that are able to erase these misconceptions can begin to positively influence young people to consider computer-related careers. Student feedback from SPIRIT demonstrates that providing students with this information not only increases the potential for them to pursue IT, but also enhances their academic performance in their high school courses. Many more programs are needed, however, to make an adequate impact to sufficiently address the predicted computing workforce needs in the foreseeable future. Many of the teachers' and counselors' Alice-based lessons are freely available from the SPIRIT website (www.ITPossibilities.org). Details about developing a similar program, including a schedule of sample activities

will be made available on the website in summer 2012, including detailed steps for a select group of these activities.

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The Students Are Unstable!

Cluster Analysis of Motivation and Early Implications for Educational Research and Practice

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Abstract— The type of motivation that a student evinces can shape such outcomes as academic engagement, performance, and satisfaction. In this paper we explore student motivation using cluster analysis, a quantitative method that has been proven useful in examining group-based motivational profiles within academic settings. We apply a range of clustering techniques to a data set comprising motivational survey responses of undergraduate engineering students at three different colleges. We confirm the outcomes of previous clustering analyses, revealing the existence of different student motivational profiles in academic settings, and we offer several new perspectives on engineering student motivation. First, different cluster analysis methods describe similar trends in motivational profiles, but divergent judgements in the distribution of students into these profiles. Second, examination of longitudinal data illustrates that students' endorsements of the various motivations fluctuate significantly, and sometimes dramatically, within the duration of a single course. This challenges the "they either have it or they don't" concept of motivation, and highlights the importance of understanding of students' situational motivational responses to classroom activities.

Keywords—motivation, self-determination, cluster analysis

I. INTRODUCTION

Motivation has been used as a window into understanding people's behavior and outcomes since psychology moved from a philosophical to an applied discipline in the mid 1800s. Contemporary needs-based motivation theories found in educational research have their roots in early humanistic psychological work by Maslow [1], whose distinction between physical and psychological stimulation in a hierarchy of needs evolved into the concepts of intrinsic and extrinsic motivation. After Maslow developed these macroscopic, life-long interrelations, others sought a framework for investigating the interplay of intrinsic and extrinsic motivation within more discreet contexts. One model that has proved both flexible and insightful is called self-determination theory (SDT) [2-4], which was developed in the 1970s and has since been applied to educational environments, as well as contexts from behavior intervention to sports [5-7].

In this study, we used surveys based on the constructs of SDT to gain insight into students' perceived motivations in a variety of materials science course environments, and will presently investigate the results in light of applied psychology's overarching goal of improving outcomes through understanding their determinants.

II. SELF-DETERMINATION THEORY (SDT)

A. Essential Constructs

SDT investigates the congruence between a person's intrinsic motivations and their environment. The degree of congruence relies on the extent to which an interaction satisfies three basic needs: autonomy, competence, and relatedness [4]. These needs are the cornerstone of SDT, and are understood to influence a person's observable characteristics such as affect, behavior and cognition. This relationship is particularly important in social contexts, where these outward effects partially define the environment as perceived by others. SDT posits that an interaction is integrated into the sense of self, which in turn widens the scope of relatedness and allows for further development within the environment; if unsupportive, it reduces perceived relatedness and decreases the environment's appeal. This process, called internalization, is how intrinsic motivation is facilitated [4]. Furthermore, SDT research posits that individuals perceive motivation at three hierarchical levels of generality (Figure 1), categorized by the persistence of their influence: from most to least recurring they are the global, contextual, and situational levels [8-11]. Influences have been observed to flow both top-down and bottom-up within these levels.

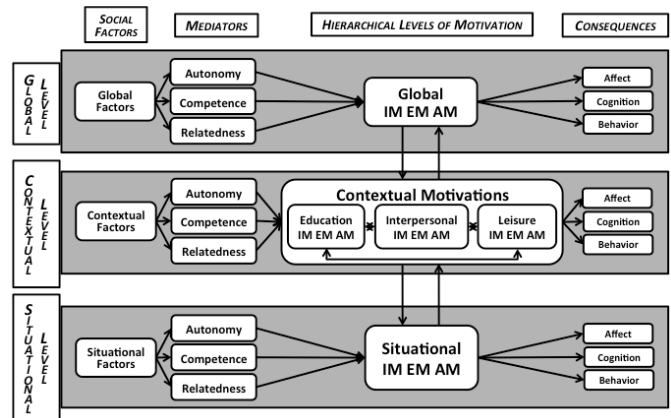


Figure 1. The hierarchical model of motivation, from Vallerand et al. [8].

B. Measuring Motivation

In addition to the theoretical constructs, SDT researchers have also developed survey instruments that can be applied to measure the apparent magnitudes of the hypothesized constructs. The present study made use of the Situational Motivation Scale (SIMS), a 16-item, Likert-scaled (1=corresponds not at all, 7=corresponds exactly) instrument

that uses four subscales that lie along the self-determination continuum: intrinsic motivation (in which one senses an activity's personal relevance), identified regulation (one senses the activity is related to something else personally relevant), external regulation (one does not see the activity's relevance, and so is driven by extrinsic factors), and amotivation (feelings of incompetence and uncontrollability, when one understands neither the activity nor its relevance). SIMS subscale scores for intrinsic motivation, identified regulation, external regulation, and amotivation are calculated as the means of four survey items for each scale. The SIMS has been shown to have internal reliability and construct validity [12].

The four SIMS subscales can be collapsed to a single value called the self-determination index (SDI), defined as: $SDI = 2 \times (\text{intrinsic motivation}) + 1 \times (\text{identified regulation}) - 1 \times (\text{external regulation}) - 2 \times (\text{amotivation})$. SDI values are described as a continuum of controlled to autonomous motivation, with a corresponding range of possible scores from -18 to +18. While some studies have demonstrated SDI's validity in examining learner motivation [10,11,13-15] others have noted its potential to obscure trends in data due to oversimplification [16]. We use it primarily as an easily referable metric to orient an otherwise complex analysis.

Typically, motivation studies have sought to link motivational levels with specific contextual outcomes via correlational factor analysis. Of particular interest to the authors, however, was an analysis method called a *person-oriented approach* [16]. This approach assumes the surveyed factors are related to each other through some combination of origin and/or effect, and thus allows for a more nuanced analysis. Consider two students who both register high intrinsic motivation, but only one of who reports significant external pressure. One can imagine their behaviors and experiences might be different; a person-oriented analysis enables a statistical investigation of this situation. This type of analysis is carried out by employing a data clustering methodology, for which there are various techniques. Specifics are discussed below and in the analysis section.

C. Prior Studies of SDT

Variable-based analyses of motivation have shown that the satisfaction of the three basic needs postulated within SDT does indeed foster increased intrinsic motivation, more persistence, improved academic performance, and healthier learner development [5-7,15-18] – research that lends much credibility to the SDT framework. More recently, a person-oriented study by Ratelle et al. [16] sought to identify distinct “motivational profiles,” that is, trends within the relative values of reported motivations. Using a sophisticated cluster method initially developed for longitudinal social analyses, they studied three datasets: two gathered in a high school setting and one from a college setting. Their analysis revealed four different motivational profiles, however each setting showed only three of the four. Two profiles were shared among all settings: one had moderate levels of both autonomous and controlled (extrinsic) motivations (which they named moderate AU-C), the other had high levels of both (named high AU-C). Unique to the high school setting was a profile dominated by extrinsic and amotivation characteristics; unique within the college

setting was a profile dominated by autonomous characteristics (named truly AU). Ratelle et al. found that performance in high school was best in the high AU-C group; in college they found performance to be similar between the high AU-C and the truly AU groups, but found academic persistence to be greater among the truly AU group. In light of this more nuanced analysis of motivation, we sought to examine the motivations that engineering students adopt in undergraduate classroom settings. We pose several research questions: What motivational profiles do engineering students adopt in undergraduate courses? How are students distributed across these profiles? How do these motivational profiles change over time? What cluster analytical techniques are most useful for examining engineering student motivations?

III. PRESENT STUDY

A. Participants and Methods

Data for this analysis were gathered as part of a larger, mixed-methods investigation of student outcomes in introductory materials science courses. Participants were engineering students enrolled in four different materials courses at three predominantly undergraduate institutions. A total of 404 students participated in the study. The participant group included 93 students in project-based materials science courses at a small engineering college, 137 students in lecture-lab materials science courses at a small liberal arts university, and 174 students in lecture and lecture-lab courses at a large public university. Data were collected via a web-based implementation of the SIMS instrument described above. All students were surveyed at the beginning and end of their term; however one difference was that students in both courses at the small engineering school were surveyed nine additional times throughout the semester, providing longitudinal data for a subset of study participants. In total, our dataset comprised 1278 complete survey responses, 707 of which were collected during the beginning or end of the respective course.

B. Basic Analysis – Dataset Characteristics

Our complete dataset gave mean values for intrinsic motivation, identified regulation, external regulation, and amotivation of 4.5, 4.7, 3.8, and 2.0, with standard deviations of 1.3, 1.1, 1.6, and .96, respectively (Figure 2). This resulted in a mean SDI rating of 5.9, with a standard deviation of 5.4 (Figure 2). The low amotivation mean and relatively high identified regulation and intrinsic motivation values indicate that, on average, the study participants adopt internalized forms of motivation in their materials science course. The mean values do not, however, indicate the extent to which students simultaneously develop more than one type of motivation, e.g., external regulation combined with intrinsic motivation.

A comparison of the data from the beginning against those from the end provided an interesting result for the present context: a Welch two factor t-test revealed statistically significant ($p < .01$) increases in both intrinsic motivation and amotivation within the dataset. At first this seems counter to self-determination theory, which posits these two factors are the least related and should correlate negatively. This result may be explained, however, by considering the classroom context: there could be a statistically significant group of

students who find the courses very interesting, as well as a mutually exclusive but still statistically significant group who find them amotivating. To address individual student needs, it is important for instructors to better understand the origins of these motivational changes. This is an intriguing platform from which to start our person-oriented analysis.

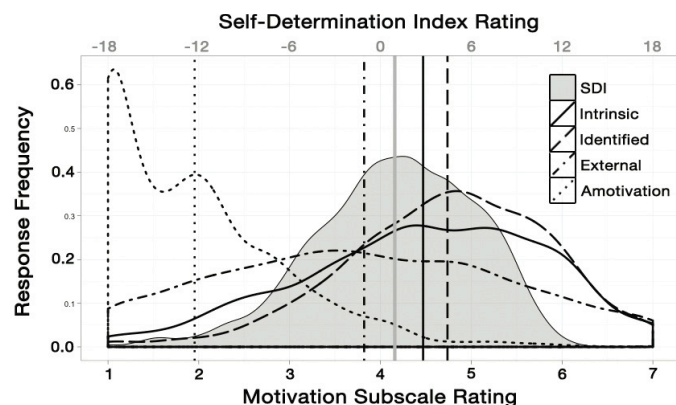


Figure 2. Means and distributions of SIMS subscale (black, line weight relative to scale autonomy) and Self-Determination Index (grey) values.

C. Person-Oriented Analysis – Cluster Methods and Results

Clustering analysis, an approach applied to multivariate social science data to identify similar instances of responses by looking for homogeneities in defining variables, has proven useful in examining student motivations [19-22]. Cluster analysis depends on a family of data grouping techniques which differ in their underlying function but have one common aspect: they will always provide some type of answer. When seeking to apply cluster analysis to a dataset, one must contextualize the results in order to identify whether and why a result is of significance to the researcher. The two main questions to answer when seeking a person-oriented analysis, therefore, are: what method should be used, and how many clusters should be sought? As of yet there is no agreed-upon best approach for the present application, so we take this opportunity to explore these fundamentals before we ascribe too much significance to their practical implications.

One of the most basic cluster methods is called k-means clustering, so named because it asks the user how many clusters to form (k) and does analysis to return the k sets of mean values. This approach treats each instance of supplied data (in this case, the values from one completed survey) as a vector of spatial information, and then inserts k points within the dataspace. All given data are grouped to the nearest inserted point, and a center for each group is calculated. The algorithm then reassigns cluster membership based on the new centers, and continues this process until the change in centers no longer results in a change in the clusters' members.

Basic k-means analysis always has certain characteristics that may in some contexts be drawbacks: first, the cluster results depend on the seed k values and thus can be susceptible to getting "caught" in local minimums or maximums, and second, because cluster discrimination occurs halfway between means, the algorithm is insensitive to cluster-specific density characteristics and tends to make clusters similarly sized. This last drawback is particularly important to us, since we would

ideally like to identify any persistent motivational profile even if it describes a smaller proportion of students than the others.

These drawbacks have led to the development of algorithms that are more sophisticated in their clustering process and that include built-in appropriateness assessment tools. The previously mentioned Ratelle et al. study used such a tool in their analysis, a SAS extension called TRAJ [16]. Ratelle et al. touted its ability to guide the model fitting process, and we were interested in applying this technique. Although the TRAJ module is freely available, it requires the costly SAS base to run. Fortunately, a methodology of similar sophistication, MCLUST, is freely available, and runs on an R base, which is also freely available. MCLUST includes steps to address k-means' shortcomings by attempting to intelligently choose initial centers and allowing for varied, cluster-specific distribution densities. It also employs the same appropriateness assessment tool used by TRAJ, called the Bayesian Information Criterion (BIC). BIC is a widely used metric for selecting which among a finite set of modeling options provides the best relative fit. A single model provides a single BIC value that is always negative, so model selection occurs by iterating model assumptions for a dataset and choosing the assumptions that result in the highest actual (lowest absolute) BIC.

By default, MCLUST will take a dataset and extract BIC values for ten different mixture model assumptions applied to k-values of 1-9. This default analysis investigates a broader range of possible clusters than in Ratelle et al. [16], which compared only k values of 2-4. Their k value limitation, however, is logical given only four psychometric variables rated on a 7-point scale. In our preliminary k-means clustering analysis with k from 2-6, we identified four clusters as a qualitatively useful number for discussing motivational response profiles. The Ratelle et al. study suggested that three clusters provided the optimal solution. We were somewhat surprised to find, then, that the default MCLUST method suggested that a 7-cluster model as best fit for our dataset of motivation subscale ratings. We then ran MCLUST on a dataset of the raw SIMS survey responses, rather than the subscale averages, and found that despite the dataset having 16 factors instead of 4, the algorithm arrived at a simpler, 4 cluster solution (Figure 3). In analyzing BIC values for a range of 2 to 20 clusters, we concluded that it was not particularly helpful in identifying optimal analysis parameters, and that ultimately the best "fit" would still have to be determined by qualitative contextualization of the quantitative analyses. Since both our practical consideration of student motivations and the most data-rich MCLUST analysis suggested 4 clusters, we used that as our k value and compared the outputs of three different cluster procedures forced to a 4 cluster solution: Method 1 was MCLUST on the unmodified motivation averages, Method 2 was MCLUST on the raw question responses, and Method 3 was a basic k-means algorithm.

Tables 1 and 2 provide statistical profiles of our entire dataset and each of the derived clusters, in terms of their means, standard deviations, SDI values, and inter-factor correlations and reliabilities. Within each methodology, clusters are ranked by their calculated mean SDI. Figure 4 shows the Method 1 cluster results with overlaid SIMS subscale mean values. Comparing the various methods' output

clusters reveals several similarities. Each method identified one group with a relatively high SDI, two with mid-range values within two points of each other, and one with low SDI. In terms similar to those used by Ratelle et al. [16], these might be named high AU, high AU-ID, high ID, and high EX. Of the eight inter-factor correlations that were statistically significant among cluster ranks between methodologies, only one correlation was significant in every cluster: IN-ID. This is interesting to consider in light of the fact that, when the entire dataset was analyzed, each inter-factor correlation reported statistical significance.

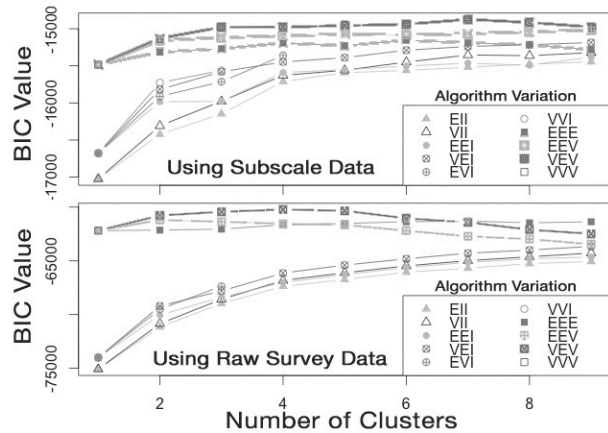


Figure 3. BIC-based model parameter analysis conducted by MCLUST, using survey subscale data (top) and raw survey data (below). Legend indicates model type, and curve maxima indicate optimal cluster number.

Differences among the cluster methods are also readily apparent: principally, the size of clusters varied dramatically. For example, the lowest ranked cluster from Method 1 (MCLUST on averages) was by far the largest within the method with 477 responses. In Method 2 (MCLUST on raw data), however, the largest group (504 resposes) has the second highest SDI, and the lowest ranked cluster is only 55% of the size of that described using Method 1. The clustering methodologies managed to describe similar trends in motivational profiles yet came to different conclusions about

what percentage of the student responses belongs in each. This is especially interesting considering that the subscale averages used in Method 1 are intended to accurately represent the raw responses used in Method 2.

Finally we can see the basic k-means tendency toward equal distribution in action, as its cluster sizes range from 223-393, in contrast to Method 1's range of 217-477 and Method 2's range of 203-504. The cause of this tendency, simple nearness assignment, is born out in that Method 3 has the smallest factor-wise standard deviations. It is again interesting to consider that these tighter looking statistics may in fact portray a characteristic of a less accurate methodology.

D. Implications for Classroom Practice

Although our analyses of student motivation are ongoing, preliminary findings highlight the potential practical value of this approach. Specifically, the cluster-based analyses help identify groups of students who may respond well to motivation-focused interventions, and the longitudinal analyses reveal both group- and individual-based changes in motivational orientation throughout the academic term.

When considering these results within the broad context of SDT, the clusters align on the self-determination continuum. Given this, we found one cluster to be particularly interesting in the context of classroom practice: Method 2 cluster 3. Examining the mean values for this cluster, we find a predominant motivation of identified regulation (4.5) with near-neutral intrinsic motivation (3.7) but low external regulation (2.7) and amotivation (2.0). The correlations for this cluster indicate uncertainty around amotivation's relationship with intrinsic and extrinsic motivation in this student group. We hypothesized this could be the group whose interest could be most readily made or broken by classroom experiences: they may be there of their own volition and sense the material could be relevant, but are not exactly sure why, and are apt to experience bouts of amotivation due to this ambiguity. Examining responses in light of specific classroom activities may help us further explore this hypothesis.

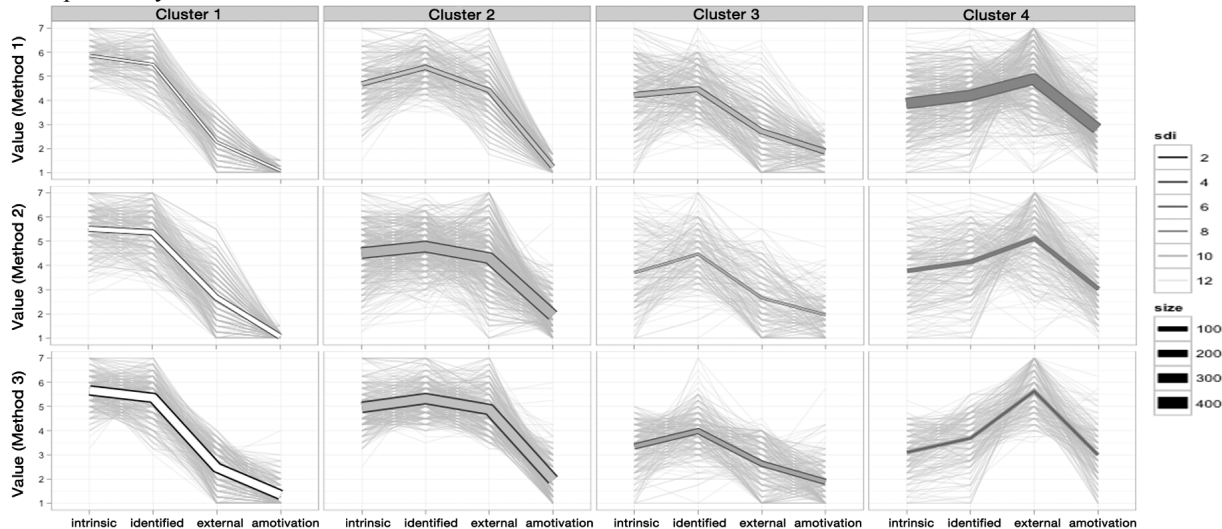


Figure 4. Visualization of Method 1, Method 2 and Method 3 cluster analysis means overlaid on constituent motivation data. Mean curves are sorted and shaded by their implied SDI, and their width varies according to membership size. Note the similarity in each methods's means, but the disparity in member allocation.

TABLE I. STUDENT MOTIVATIONAL RESPONSE CLUSTERS BASED ON THREE ANALYTICAL METHODS

| Method | Cluster Characteristics | | | | | |
|--|-------------------------|---------|------|------|------|-------------|
| | Rank (by SDI) | Members | SDI | Mean | SD | Motivation |
| Entire Dataset | - | 1278 | 5.9 | 4.5 | 1.3 | Intrinsic |
| | | | | 4.7 | 1.1 | Identified |
| | | | | 3.8 | 1.6 | External |
| | | | | 2 | 0.96 | Amotivation |
| Method 1 MCLUST on motivation averages | 1 | 217 | 12.8 | 5.9 | 0.57 | Intrinsic |
| | | | | 5.5 | 0.78 | Identified |
| | | | | 2.3 | 0.75 | External |
| | | | | 1.1 | 0.14 | Amotivation |
| | 2 | 278 | 8 | 4.7 | 1.04 | Intrinsic |
| | | | | 5.4 | 0.77 | Identified |
| | | | | 4.4 | 1.12 | External |
| | | | | 1.2 | 0.27 | Amotivation |
| | 3 | 306 | 6.4 | 4.2 | 1.3 | Intrinsic |
| | | | | 4.5 | 0.96 | Identified |
| | | | | 2.7 | 1.2 | External |
| | | | | 1.9 | 0.46 | Amotivation |
| | 4 | 477 | 1.5 | 3.9 | 1.25 | Intrinsic |
| | | | | 4.2 | 1.15 | Identified |
| | | | | 4.9 | 1.3 | External |
| | | | | 2.8 | 0.93 | Amotivation |
| Method 2 MCLUST on raw responses | 1 | 307 | 11.5 | 5.5 | 0.87 | Intrinsic |
| | | | | 5.4 | 0.92 | Identified |
| | | | | 2.7 | 1.11 | External |
| | | | | 1.1 | 0.13 | Amotivation |
| | 2 | 504 | 5.7 | 4.5 | 1.1 | Intrinsic |
| | | | | 4.8 | 0.93 | Identified |
| | | | | 4.3 | 1.35 | External |
| | | | | 1.9 | 0.68 | Amotivation |
| | 3 | 203 | 5.2 | 3.7 | 1.4 | Intrinsic |
| | | | | 4.5 | 1.1 | Identified |
| | | | | 2.7 | 1.1 | External |
| | | | | 2 | 0.77 | Amotivation |
| | 4 | 264 | 0.6 | 3.8 | 1.3 | Intrinsic |
| | | | | 4.1 | 1.3 | Identified |
| | | | | 5.1 | 1.3 | External |
| | | | | 3 | 1 | Amotivation |
| Method 3 Basic k-means on motivation averages | 1 | 370 | 11.7 | 5.7 | 0.67 | Intrinsic |
| | | | | 5.4 | 0.82 | Identified |
| | | | | 2.5 | 0.81 | External |
| | | | | 1.3 | 0.5 | Amotivation |
| | 2 | 393 | 6.4 | 5 | 0.82 | Intrinsic |
| | | | | 5.3 | 0.73 | Identified |
| | | | | 4.9 | 0.85 | External |
| | | | | 2 | 0.84 | Amotivation |
| | 3 | 282 | 4.2 | 3.3 | 0.93 | Intrinsic |
| | | | | 4 | 0.9 | Identified |
| | | | | 2.6 | 0.95 | External |
| | | | | 1.9 | 0.77 | Amotivation |
| | 4 | 223 | -1.7 | 3.1 | 0.91 | Intrinsic |
| | | | | 3.7 | 0.98 | Identified |
| | | | | 5.6 | 0.92 | External |
| | | | | 3 | 1.03 | Amotivation |

Analysis of our subset of week-to-week data demonstrates that changes in situational motivational orientation and cluster association occur throughout the semester, i.e., *student motivational responses are unstable*. By shading the SIMS motivation output by cluster membership, for instance, we see a shared sensation of externally-dominated orientation during week four of one of the introductory materials courses (Figure 5a).

TABLE II. CORRELATIONS FOR MOTIVATIONAL SUBSCALES WITHIN CLUSTERS

| Method | Pearson Correlations (lower) and P-values (upper) | | | | | |
|----------------|---|-------|--------|--------|-------|-------------|
| | Rank (by SDI) | IN | ID | EX | AM | Motivation |
| Entire Dataset | - | | 0 | 0 | 0 | Intrinsic |
| | | 0.66 | | .0041 | 0 | Identified |
| | | -0.22 | -0.08 | | 0 | External |
| | | -0.36 | -0.37 | 0.41 | | Amotivation |
| Method 1 | 1 | | 0 | .0031 | .9708 | Intrinsic |
| | | 0.51 | | .2556 | .4166 | Identified |
| | | 0.2 | 0.08 | | .5762 | External |
| | | 0 | 0.06 | 0.04 | | Amotivation |
| | 2 | | 0 | 0 | .5071 | Intrinsic |
| | | 0.52 | | .0005 | .8837 | Identified |
| | | 0.28 | 0.21 | | 0 | External |
| | | -0.04 | -0.01 | 0.31 | | Amotivation |
| | 3 | | 0 | 0 | .1478 | Intrinsic |
| | | 0.24 | | .2617 | .0018 | Identified |
| | | 0.22 | 0.37 | | .2843 | External |
| | | -0.04 | 0.42 | 0.55 | | Amotivation |
| | 4 | | 0 | 0 | .1478 | Intrinsic |
| | | 0.82 | | .2617 | .0018 | Identified |
| | | -0.22 | -0.05 | | .2843 | External |
| | | -0.07 | -0.14 | 0.05 | | Amotivation |
| Method 2 | 1 | | 0 | .8207 | .1759 | Intrinsic |
| | | 0.52 | | 0 | .2083 | Identified |
| | | -0.01 | 0.25 | | .9888 | External |
| | | -0.08 | -0.07 | 0 | | Amotivation |
| | 2 | | 0 | 0 | .1017 | Intrinsic |
| | | 0.6 | | .0004 | 0 | Identified |
| | | -0.19 | 0.16 | | .4356 | External |
| | | -0.07 | -0.22 | -0.03 | | Amotivation |
| | 3 | | 0 | .0026 | .9928 | Intrinsic |
| | | 0.4 | | .0004 | .6484 | Identified |
| | | 0.21 | 0.25 | | 0 | External |
| | | 0 | 0.03 | 0.31 | | Amotivation |
| | 4 | | 0 | 0 | 0 | Intrinsic |
| | | 0.78 | | .0031 | 0 | Identified |
| | | -0.28 | -0.18 | | 0 | External |
| | | -0.24 | -0.29 | 0.25 | | Amotivation |
| Method 3 | 1 | | 0 | .1719 | .0497 | Intrinsic |
| | | 0.27 | | .0425 | .055 | Identified |
| | | 0.07 | 0.11 | | 0 | External |
| | | -0.1 | -0.1 | 0.23 | | Amotivation |
| | 2 | | 0 | 0 | .6786 | Intrinsic |
| | | 0.42 | | .0951 | .0007 | Identified |
| | | 0.01 | 0.25 | | .0004 | External |
| | | 0.03 | -0.18 | -0.04 | | Amotivation |
| | 3 | | 0.0234 | .0273 | .097 | Intrinsic |
| | | 0.13 | | 0.3655 | .1813 | Identified |
| | | 0.13 | 0.05 | | .0988 | External |
| | | -0.1 | -0.08 | 0.1 | | Amotivation |
| | 4 | | 0 | 0 | .6786 | Intrinsic |
| | | 0.56 | | .0951 | .0007 | Identified |
| | | -0.32 | -0.11 | | .1265 | External |
| | | 0.03 | -0.22 | -0.1 | | Amotivation |

This external motivation peak corresponds to the time when the first large, individual, written assignment is due in the course. We also witness different types of evolution through the course duration: some students are consistently positive, others steadily develop a positive orientation, some falter and regain their bearings, and others engage in activities seemingly because they have to and only vary in their level of frustration (Figure 5b, top to bottom).

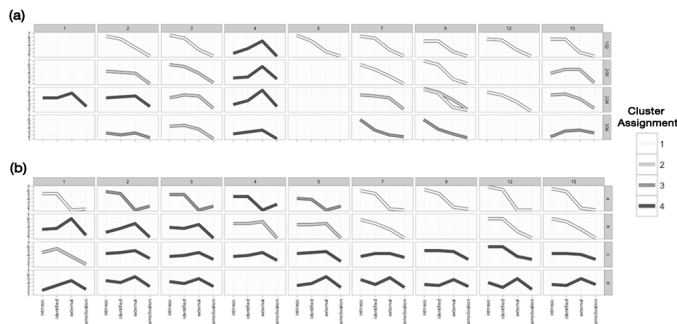


Figure 5. Week-to-week motivational responses of several students in a project-based course. Figure (a) shows a dramatic shift in motivational orientation in week 4. Figure (b) shows different temporal evolutions of individual self-determination. See Figure 4 for reference cluster shapes.

IV. SUMMARY AND FUTURE WORK

Our application of quantitative cluster analyses to student motivation data provided several findings. First, the group-based analysis reveals information that is hidden in variable-based statistical analyses but potentially important to instructors: namely, that engineering students adopt a range of situational motivations that do not fall neatly into the conventional “intrinsic” and “extrinsic” categories. Although the clustering analyses produce groupings that may be arranged by increasing SDI values, a large percentage of students simultaneously adopt both external and internal drive to engage in course activities. Second, although some students adopt fairly stable motivations within a single course, other individual responses change dramatically over time, shifting the distribution of students across clusters. Examining when and how these shifts occur may provide useful information to instructors who wish to revise course activities to maximize internalized motivations. Third, the specific clustering methodology matters. Different analyses provided different cluster means and different distributions of students across clusters, highlighting the need for further investigation of these techniques prior to widespread application. Future analyses will include a more thorough exploration of the temporal changes that occur in student motivations and the effects of these changes on the clusters; and linkage of the cluster analysis results with student interview data for development of qualitative descriptions of motivational responses reflected in the clusters.

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Facilitating the creation of K-12 interactive learning objects using a multi device web tool

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Abstract— This paper presents the experience of designing and implementing an educational content creator adapted to mobile devices in a K-12 environment. Two main issues have been detected when designing this tool. The first one is the screen size, which will limit the contents' size and the quantity of contents presented at the same time in the screen. The second issue is related to the touch screens these devices have, which changes the whole user experience. Four types of resources can be generated with this tool considering these issues. Firstly, a virtual microscope where the user can select a sample and study it in detail through the microscope. Secondly, a quiz where the user has to join words to their corresponding definitions or images. Thirdly, a virtual chemistry experiment where the user has to drag and drop pipettes to complete chemical formulas. And finally, a generic flashcard that presents a background image and several "hot zones" where the user can touch and see additional contents that the teacher has previously tagged. Details about the technologies and details related to its implementation are described in the paper.

Keywords; *interactive learning objects; science in education; multi-device resources; virtual experiments*

I. INTRODUCTION

As technology evolves, new powerful devices with more capabilities are available for the end user, smartphones, tablets, laptops or desktop computers. Even televisions and cars should be considered as they are starting to incorporate a browser, applications and Internet connection. All these devices entail new challenges for teachers to adapt their contents, teaching methods and tools.

With these devices, new opportunities appear to increase student's motivation and engagement while they learn [1] [2]. Nevertheless, learning object repositories usually do not contain suitable resources for this kind of device. Sometimes because they depend on the operating system installed. In other cases because of the differences in the device hardware like screen sizes, touch screens, RAM or CPU capabilities. As a consequence, teachers have to use traditional less interactive resources.

On the other hand, although sometimes they can find suitable resources for these devices, the content does not fit, it can be for example oriented for other ages or in another language, being impossible to customize it. Therefore, in those

cases teachers need to generate their own resources from scratch.

This was the main issue that was pointed out by the teachers participating in the project called GLOBAL excursion (Extended Curriculum for Science Infrastructure Online) [3]. GLOBAL excursion is a supporting action funded by the European Commission under the Research and Innovation Infrastructures programme of FP7.

The project will develop a common understanding, teaching use cases, as well as pedagogical and technical artifacts. The main purpose of the GLOBAL excursion project is to enable students and teachers access to the experimental laboratories and resources of selected e-Infrastructures in order to improve science curricula by enriching school's existing teaching and learning materials.

The scientific partners participating in the project are initially three, the Institute for Biocomputation and Physics of Complex Systems (BIFI) from Spain, the Nanoscience Centre from the Cambridge University (UCAM) from the United Kingdom and the Computer and Automation Research Institute (SZTAKI) from Hungary. Other scientific centers are expected to participate in the near future. The materials currently provided by all partners are based on the following topics:

- Biotechnology and biology from BIFI.
- Grid computing and volunteer computing from STZAKI.
- Nanoscience from UCAM.

These scientific materials are very diverse. However, as they are very technical and specialized they can be difficult to understand for young students. To make these materials attractive and enjoyable for students and to allow the creation of interactive learning multi-device objects, we have designed the Virtual Experiments creator. It is a web tool to integrate the contents that scientific centers provide, like images, videos or texts, or other contents and learning materials that the teachers upload into multi-device applications.

This paper explains with detail the Virtual Experiments creator tool and some examples of how these resulting Virtual Experiments are viewed in mobile and desktop devices. To do

so, we first review related work of ubiquitous learning and other authoring tools. Section 3, 4 and 5 explain the Virtual Experiments, the viewer and the creator. Section 6 follows with the technology we chose and the issues that arose when designing and implementing for multiple devices. We finally end with some conclusions and a short summary of possible research lines related to this tool in the near future.

II. RELATED WORK

Ubiquitous learning or u-learning enables students to learn at any time, anywhere and on any devices. From a real perspective, building a ubiquitous learning environment requires a “ubiquitous” learning device accessible by every learner all times [4]. Ubiquitous learning systems should consider various factors like support for heterogeneous devices with different screen sizes and resolution, storage, processing power, format handling capabilities and network connectivity [5].

Most learning objects have been designed for viewing within learning management systems (LMS) and web browsers. In order to include these learning objects into ubiquitous learning systems, content adaptation is needed. Content adaptation concerns the act of transforming learning content to adapt it to any mobile device capabilities [6]. This adaptation will ensure learning objects can be properly visualized in different access methods and devices, such as mobile phones, laptops, tablets, etc. Numerous initiatives have proposed different content adaptation approaches [7], [8], [9]. [10] even propose a content adaptation tool that provides different templates to reproduce high-quality learning content for specific handhelds.

Although content adaptation is very useful for web pages, it cannot be automatically done with non-web based applications, as they have to be installed, nor with some contents that were specifically created for desktop computers and they are not resizable.

However, a good approach to avoid content adaptation issues is to create the learning objects with ubiquitous or multi device tools. In this case, the contents will have to be properly designed and developed for devices with higher restrictions [11] and then tested with the rest of the devices.

In [12] we can find a comparison among different authoring tools. Only half of them generate adaptable learning resources, and in most cases these resources consist of web pages with text and multimedia resources (videos, audios) integrated.

Other open source, free or commercial tools to create e-learning resources can be found, like Xical [13], eXe [14], and Wink [15] among many others. Most of them allow the user to create web educational resources or flash based objects that won't work on modern handheld devices.

III. THE VIRTUAL EXPERIMENTS

The Virtual Experiments can be considered learning activities or learning design according to the characterization that Allison Littlejohn does of e-learning resources in [16]. They use the digital assets and information objects to compose the structured sequences of information and tasks.

This tool has been designed following the principles explained by Clark and Mayer in [17] related to multimedia learning resources. Together with the principles of interfaces design and mobile interfaces design of [18] and [19]. This way we have created an attractive and useful interface for the generated Virtual Experiments to be used by K-12 students in a pedagogical way. There are no toolbars full of options that can distract the student's attention. The educational content is very visual. It is based on images and videos. The student can interact directly with the learning objects themselves and not only consume the information in a passive way.

Another big concern was about students' motivation. Jere Blophy in his book “Motivating Students to learn” [20] states that students are motivated when they believe they are able to succeed at a given task and when they understand and value the outcome of the task. Here, the simple and usable interfaces will help with fostering students' motivation. Students with a quick look will know how to interact with the Virtual Experiment and will value the outcome of the task. These Virtual Experiments will suppose also a challenge for them. Instant feedback after any action is also provided to engage them.

IV. THE VIRTUAL EXPERIMENTS VIEWER

Four types of learning objects can be created with the Virtual Experiments tool. The only difference among them is the interface design. Images, videos and texts can be integrated in all of them. In the following subsections, we will explain the four interfaces related to the different Virtual Experiments that can be created.

A. Virtual Microscope

This first possibility allows the teacher to create a visualization of a microscope and some petri dishes (Fig. 1). The learner will be able to interact with this microscope either with a mouse (if he/she is on a desktop computer) or with his/her fingers (if using a touch screen on any other device such as smartphone, tablet, etc.).

When the learner clicks/touches a petri dish, the microscope view appears full screen (with or without explanation depending on the teacher's decision) as we can see in Fig. 2. In this view, the student can move around the zoomed in sample in order to see it with more detail.



Figure 1. Virtual microscope main screen

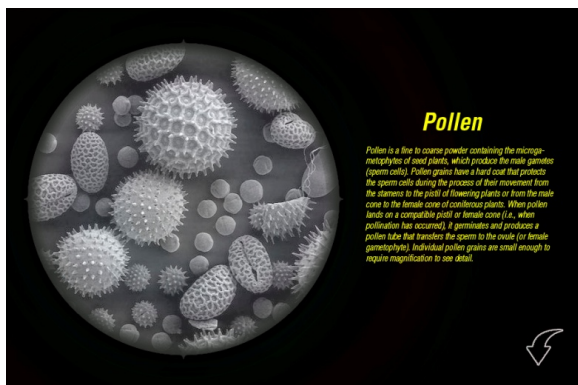


Figure 2. Virtual microscope sample

B. Chemistry Experiment

Fig. 3 illustrates this Virtual Experiment in which the teacher defines some chemistry formulas with some unknown compounds in them. The learner will get the drawings representing these formulas and a test tube holder with the compounds that lack in the formulas (represented in them by a question mark).

The learner has to drag and drop the test tubes to the questions marks in order to get instant feedback if the answer is correct or not (Fig. 4).

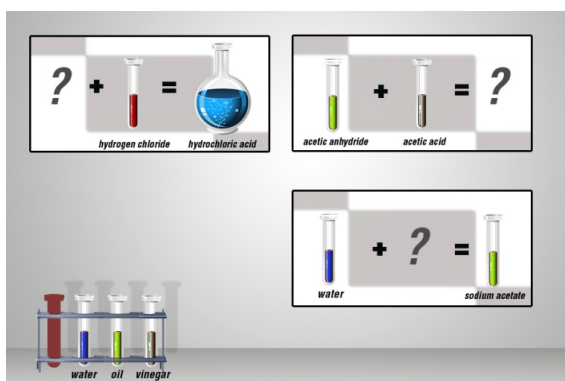


Figure 3. Chemistry experiment main screen

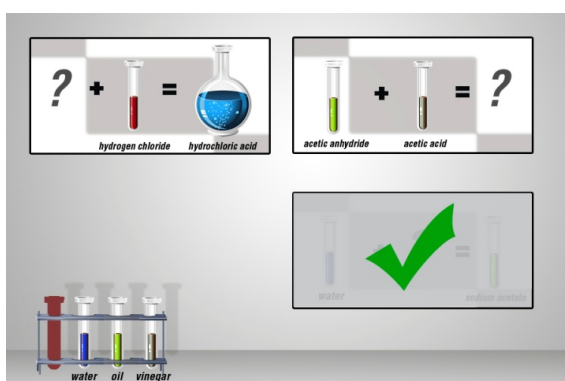


Figure 4. Chemistry experiment result

C. Quiz

In this case a visual graphical quiz can be created. The student will have to click or touch the different options

represented by text (Fig. 5) and images or videos (Fig. 6) to join them. Again, he/she will receive instant feedback about the matching.

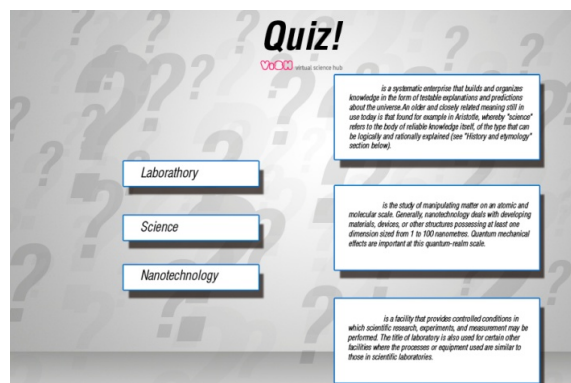


Figure 5. Quiz with texts

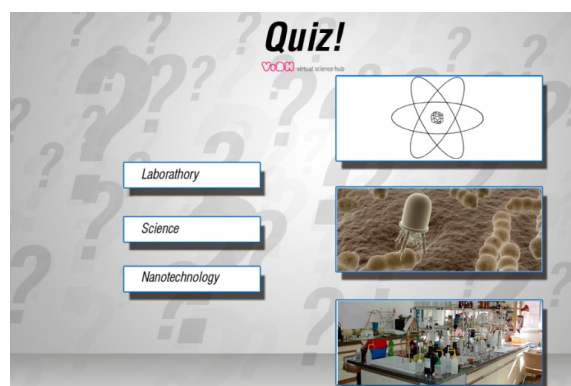


Figure 6. Quiz with images

D. Flashcard

This final Virtual Experiment is the most generic of all, as it does not force a specific interface or scenario. The teacher is the one in charge of uploading or selecting a background image and indicating hot zones on it, linking them with another educational content (text, images, or videos).

The learner will see something similar to Fig. 7 in which there is a background image with several hot zones with moving arrows. If those zones are clicked/touched, the system shows the explanations that the teacher has assigned to each zone.

By using the flashcard learning object, teachers can generate any kind of educational content related to their subject. This way they can re-use their materials.

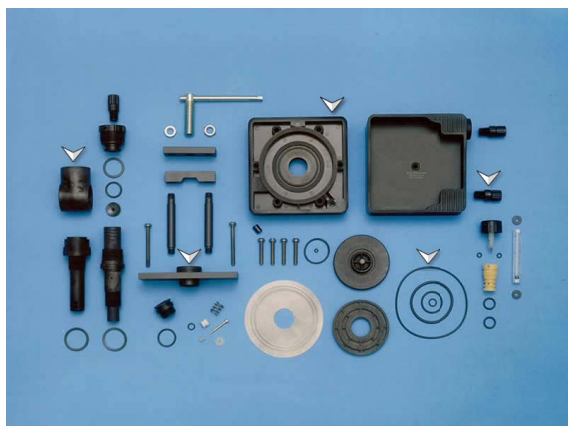


Figure 7. Generic flashcard

V. THE VIRTUAL EXPERIMENTS CREATOR

The Virtual Experiments creator tool (Fig. 8) allows the creation of the multi device learning objects described above. It is also developed in HTML5 and so it is multi device. However, as in this case the teacher has to enter text and explanations, it is more comfortable using it on a desktop computer with a real keyboard instead of a virtual keyboard in a handheld device.

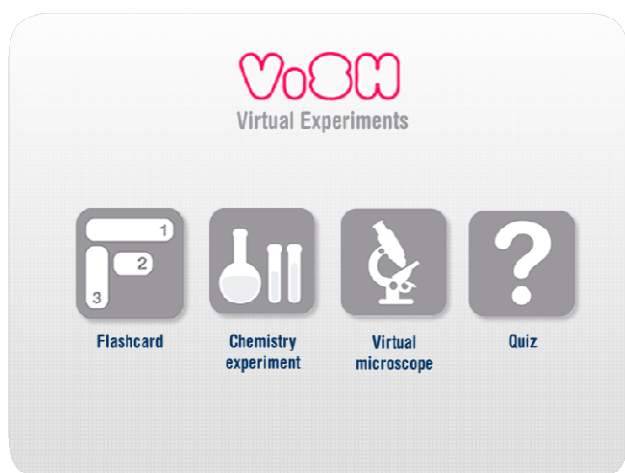


Figure 8. Virtual Experiments creator

The creation process is quite similar in the four types of experiments previously described. We can divide that process into three steps:

1. Select the type of experiment to create: all the possible experiments are shown, and after selecting one of them, the interface for that experiment appears.
2. Click or touch the zone to add content: for example, touch a petri dish to add a new sample in the virtual microscope or to add a new hot zone in the flashcard experiment. The content added can be selected from the pool offered by the platform (previously uploaded by the scientific e-Infrastructures or other teachers), but it can also be uploaded if the teacher does not find anything that fits his purpose and even can be

referenced as an external resource by introducing its URL.

3. Fill in the title and description to show together with the content when the pupil clicks or touch that zone (optionally).

VI. TECHNOLOGY AND IMPLEMENTATION

The Virtual Experiments run on any modern web browser as they have been developed with HTML5 [21], the new standard for the web. For this same reason, once created, they can be integrated with any learning platform or learning management system (LMS). HTML5 offers a lot of possibilities such as geolocation, videoconference and multimedia communications, games, animations, etc.

The Virtual Experiments architecture is quite simple (Fig. 9). Consist of a web server and a database to store the generated Virtual Experiments. The communication between client and server is done via HTTP and AJAX (Asynchronous JavaScript And XML) calls and the Virtual Experiments are defined in JSON (JavaScript Object Notation). The JSON contains all the text and the absolute URLs to the information objects.

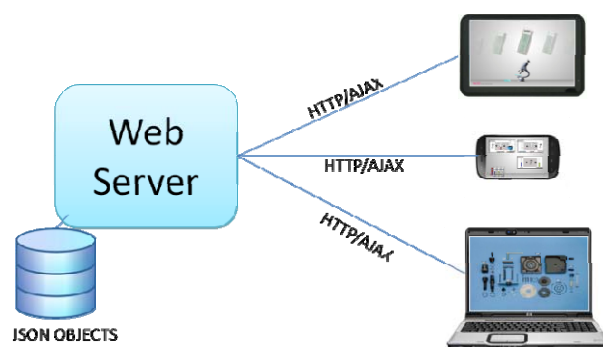


Figure 9. Virtual Experiments architecture

One of the most interesting and difficult issues that we had to address was the multi-device issues. The next section is dedicated to cover it and how we addressed those difficulties.

A. Multi-device issues

Unlike native applications, we can be sure that with HTML5 our application will run in any modern device as this is one of its main features. It only needs to have a browser with HTML5 support.

However, there are multiple device constraints that will make our application to be less usable. As Miller stated in [22], user experience plays a critical, and even primary, role in determining which products stand out. Bearing this in mind, we have to take care of usability to avoid students closing the application and never come back (aborting in this way the learning process).

The main constraints to consider are:

1) *Screen size:*

Screen size is the biggest problem to deal with when designing for mobile devices. It is different from screen resolution since modern mobile devices have big screen resolution (reaching even HD screens). Smartphones for example usually have 3 to 4.5 inches of screen size, and we want to introduce the same information both, in mobile screens and in desktop screens.

Following the principles of [18] and [19] we kept the design of the viewer simple enough to be used in either a big or a small screen. We promote the use of images and videos over texts to avoid as much as possible zoom in/out actions (although they are allowed by touch gestures to see details). As a compromise, we do not let the user to enter lengthy texts as they will not be easy to read in small screens.

2) *Touch screens:*

User interaction is different between devices with keyboard and mouse compared to touch-based screens. In devices with touch screens the keyboard will be virtually drawn and so the resulting screen size to write is even smaller.

Furthermore, HTML5 touch events have to be used together with click events. Otherwise, some special behaviors like zoom in/out gesture (commonly known as pinch action) also had to be implemented as it is very useful and it is becoming a “de facto standard” in touch screens user interaction.

3) *Different browsers:*

There is a high variety of browsers (e.g. Explorer, Chrome, Firefox, Safari, Android, etc.). All of them follow the standards and support HTML5, but there are always small differences that have to be considered. Those differences can be appreciated when entering with a browser in <http://html5test.com/>. Taking this into account, it is necessary to set a minimal set of features generally supported by the majority of the mobile browsers in order to use them in the Virtual Experiments viewer and creator.

4) *Format handling capabilities:*

Although in HTML5 any image or text is recognized by any browser, the same does not happen with video codecs. Three video codecs are supported in HTML5, Ogg Theora, H264 and VP8 (WebM). But not all browsers support all codecs, and this can be a problem nowadays. Fortunately the HTML5 video tag is prepared for this. We can indicate it inside two sources with different codecs and the browser will use the one that can play [23].

The main drawback of this solution is that any video that is uploaded to the platform will have to be encoded in two different formats.

5) *RAM and processing power:*

RAM and processing power does not suppose a problem in modern smartphones that can even have 1GB RAM and 1.2GHz Dual Core. But when the smartphone market started they had 128 MB RAM and 400 to 600Mhz. Right now, the current specifications of the majority of mobile devices is enough to manage images, texts and videos.

6) *Network connectivity:*

Mobile devices usually have 3G/4G and Wi-Fi network connections. In both cases it can be a slow network connection and not enough bandwidth to see a video in streaming or to load several images at a time. This can cause problems in the user experience. We have solved this issue pre-loading all the content before the Virtual Experiment starts, making it transparent to the user.

VII. CONCLUSION AND FUTURE WORK

The work exposed in this paper allows teachers to create customized learning objects that work in any device. Four types of experiments can be created with this tool: a virtual microscope, a chemistry experiment, a quiz and a generic flashcard. Their interfaces are easy to use and reusable as foundations to create more Virtual Experiments that can be implemented with the same technology only changing those interfaces.

Although the technology chosen is multi-device, many issues have appeared. We have described them and have given details about how we dealt with them, so these solutions can be reused by the community.

There is some functionality that we have considered to add to the Virtual Experiments in the future. The first one is based on providing an evaluation and assessment method in the quiz and chemistry experiment, so the teacher can get the pupil's results to be aware about the learning process. This could be done following a standard like IMS QTI.

In the current version, the Virtual Experiments are saved in JSON format. Another important functionality that we want to add is to export the generated resources to standard e-learning formats such as IMS-CP, SCORM or LOM.

On the other hand, to reduce download time and data consumption (in case of 3G/4G connections) we are considering encoding the videos with lower resolution for small screen devices, allowing the system to select the suitable format depending on the context.

Moreover, as we have pointed out before, new types of Virtual Experiments could be developed with little effort by changing the interface design (e.g. a virtual telescope instead of virtual microscope).

Finally, due to the current all-mobile lifestyle and taking into account that everyday mobile devices are getting popular and starting to be used by the general public, we will have to consider them to test the Virtual Experiments on as many devices we can, making small changes in the interface and interactions if needed.

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An INSPIRED Game Programming Academy for High School Students

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Abstract—The demand for computing professionals is growing, but the number of college freshmen selecting computing majors has declined in recent years. Many organizations host academies that attempt to engage students in computing at an early age by exposing them to fun applications. Lamar University's Increasing Student Participation in Computing Program has developed a high school computing academy that uses game programming as an engaging hands-on approach to teach kids computing concepts. The game programming platform is freely downloaded and so is easily accessible to teachers and students. A formal assessment of the 2011 academy found that the high school participants experienced a significant increase in knowledge and interest in computing. This paper describes how the academy is organized, taught and assessed. The paper also has pointers to a website from which the instructional and assessment materials for the academy can be freely downloaded. The intent of the paper is to provide all of the information that is needed for others to host such academies and further promote the effort to increase participation in computing.

Keywords: *game programming, high school, introductory computing, Greenfoot, increasing participation in computing*

I. INTRODUCTION

Lamar University's National Science Foundation supported Increasing Student Participation in Research Development Program ('INSPIRED') was designed to increase the participation of females and underrepresented minorities in computing [1]. The project provided support for small teams of undergraduates from these populations to participate in research and outreach under the direction of faculty mentors. As part of its outreach, the project hosted five-afternoon non-residential high school computing academies from 2008 through 2011. The academies taught computing concepts to high school students through fun hands-on applications with the goal of increasing their interest and knowledge of computing. The first three academies used robotics as the primary teaching platform. The INSPIRED robotics academies are described in a previous paper [2]. Although the robotics academies were effective in engaging the students, buying and maintaining robot software and hardware can be an obstacle to

INSPIRED was supported by Lamar University, a Broadening Participation Grant from the National Science Foundation under Grant No. 0634288, and by grants from ExxonMobil. The development of the instructional materials for the academy was supported by the Collaborative Research Experience for Undergraduates (CREU) program made possible by the Computing Research Association's Committee on the Status of Women in Computing Research (CRA-W) and the Coalition to Diversify Computing (CDC).

establishing and maintaining a robotics-based academy.

In its last year the project moved to a game programming based approach so as to make the academies easier to adopt by others. The 2011 INSPIRED high school academy used a free game development platform as a teaching tool in place of robotics. A team of undergraduate students created the instructional materials, organized, taught and helped assess the effectiveness of the academy. The assessment found that the game programming based academy significantly increased the high school participants' interest and knowledge of computing. This paper will serve as a guide for others who may want to host such academies and further promote the effort to increase participation in computing.

Section II describes the motivation for the academy, related work, and how the INSPIRED academy differs from other academies. Section III describes how the INSPIRED Game Programming Academy is organized, taught, and assessed. It discusses how undergraduates are prepared for their roles in conducting the academy. It includes a brief description of the instructional materials, the concepts taught in each hands-on session, the materials that are used to assess the academy, and the methodology used. Section III discusses the assessment results, including the demographics and comments of the high school and undergraduate participants. Section IV draws conclusions and has pointers to a website from which the instructional and assessment materials for the academy can be freely downloaded.

II. MOTIVATION, RELATED WORK, CONTRIBUTIONS

Although demand for computing professionals is growing [3], the number of computer science bachelor's and master's degrees awarded has sharply decreased sharply from the 2004 levels, and the proportion of bachelor's degrees awarded to women has declined over the last ten years [4].

Many organizations have hosted academies that attempt to engage students in computing at an early age by exposing them to fun applications. Robotics is one such application that has been used extensively. A sample of current robotics camps includes Arizona State University's two-week 9Up RobotCamp [5], University of Houston's Girls Reaching And Demonstrating Excellence ('G.R.A.D.E') week-long day camp [6], and the University of Utah's five-day Graphics and Robotic Exploration with Amazing Technology ('G.R.E.A.T') High School Robotics with Arduino camp [7].

Recently, educators have developed game programming platforms to teach introductory computing concepts. Games are just as attractive to kids as robots, and they offer several advantages. Game programming platforms are easier to install and maintain compared to robotics. In addition, many game programming platforms are free. Therefore, game-oriented academies can be more readily adopted by other schools. Also, the learning curve on game programming platforms is much shorter than that of robotic platforms, which require application-specific knowledge of sensors, actuators, and robot-specific libraries. This shortens the preparation time for instructors and allows the lessons to concentrate more on general programming concepts. Popular game development platforms used for education include Greenfoot, Alice, Scratch, GameMaker, XNA, and Pygame. A summary of the characteristics of these platforms is found in [8].

Greenfoot is a free Java game development environment that was designed for high school and undergraduate education [9]. A textbook has been written for teaching introductory computer science with Greenfoot [10]. Because it is a free download, Greenfoot is easily accessible to both schools and students. Greenfoot also includes a facility to share one's games with others, which helps to broaden the exposure to a wider audience. Greenfoot supports both graphical development and textual coding in Java. Because it uses Java, Greenfoot gives students a taste of a language that is currently used in many introductory computer science courses. Greenfoot won the Premier Award for Excellence in Engineering Education Courseware in 2010. For all of these reasons, Greenfoot was the platform of choice for the INSPIRED academy.

Several institutions are now using game programming in high school academies. The University of Utah hosts a two-week GREAT High School Advanced Programming camp in which 9th – 12th grade students learn to program games in Python [7]. University of North Texas hosts a one-week Xbox Game Programming Camp that uses Microsoft's XNA and Xbox to teach rising 8th through 12th grade students programming concepts [11]. The two-week residential summer camp at the University at Denver [12] teaches rising 9th and 10th grade students introductory programming using a game-oriented curriculum, Pixels, Programming, Play & Pedagogy (P4Games) with Greenfoot.

Several things set INSPIRED academies apart from others. First, they are organized, taught and assessed by undergraduates. This is beneficial in several ways. It helps to reduce costs and removes much of the burden from faculty and staff who often lead these efforts. The undergraduates can serve as role models to the high school students, demonstrating by example that computing can be for kids like them. The undergraduates themselves benefit from the experience as well, in several ways that will be described later. Second, INSPIRED academies are easy to replicate. Because they are non-residential, short duration, and student-conducted, these academies require relatively small investments in time and money, which makes them relatively easy for others to implement.

III. ORGANIZING, TEACHING AND ASSESSING THE ACADEMY

A. Organizing the Academy

The academy is organized by a team of undergraduates under the direction of faculty mentors. Two undergraduates serve as Coordinators for the academy. Typically one has experience coordinating a previous academy, and the second is in training.

To advertise the event, undergraduates prepare a promotional brochure with application form and distribute it to students and teachers at various outreach events. They also prepare an online application form, online packet of consent forms, and online information on the academy. In addition, they help post notices of the event on community bulletin boards, local online event calendars, and other sites.

The Coordinators are responsible for monitoring applications, selecting high school participants, and communicating with the participants' parents. They are also responsible for lining up undergraduate team members to handle the other tasks involved in preparing for, organizing, teaching and assessing the academy.

Other pre-academy preparations include:

1. scheduling a computer lab where the hands-on activities will take place;
2. making sure the software and data files are properly installed and working on the computers;
3. preparing a folder for each participant that holds the assessment forms to be completed by the kids, the academy schedule, information on the department's computing program, and promotional materials; and
4. putting together a bag for each student that holds the folder, souvenir pens and pencils, etc.

The academy is held on five afternoons during the summer. This schedule fits the needs of kids who often want to sleep late in the summer or work in part time summer jobs. It also fits the schedule of the undergraduates who conduct the academy, many of whom take classes in the morning.

The INSPIRED academies are small so as to allow for a low student to teacher ratio. The size is also limited by the size of the computer lab, which houses 24 computers. In the game programming academy, students work individually on their games, with one undergraduate lending hands-on assistance as needed to a few students.

The schedule for the 2011 academy is show in Table I. Each day's activities include hands-on labs in game programming, a short hands-on lab on creating web pages, and a half-hour break with refreshments and guest speakers. Day three of the academy includes a lab session on Scratch, a drag and drop animation program developed by MIT to teach middle and high school kids programming concepts [13].

In the Cookies 'n' Chat sessions, students talk with guest speakers about careers in computing, preparing for college, and other topics. Our guest speakers typically include alumni who

are working locally in the computing industry, a representative from Admissions, and computing professionals who are members of our Computer Science Advisory Board.

B. Teaching the Academy

Undergraduates create the instructional materials and teach the academies under the direction of faculty mentors. The materials for the Web labs were developed by INSPIRED undergraduates as part of their INSPIRED duties. They were used in previous INSPIRED high school academies and described in [2]. The materials for the Scratch lab were developed by an undergraduate in an independent study course under the direction of the first author. They were used in prior INSPIRED middle school academies and are described in [14].

The game instructional materials for the 2011 academy were developed by a team of three undergraduates as a year-long project supported by a Collaborative Research Experience for Undergraduates (‘CREU’) grant under the direction of the first two authors. The three undergraduates had served as instructors in INSPIRED High School Robotics academies in previous years and used those materials as a guide [15]. The game instructional materials include (1) PowerPoint slides that introduce the computing concepts, (2) instructor folders that contain the source code for the completed games, (3) student folders that contain game source code that must be modified or completed by the students in hands-on exercises, (4) a User’s Guide; and (5) assessment materials. These materials can be downloaded from the following website: <http://javagonegreen.blogspot.com/p/teaching-materials.html>.

One of the CREU students served as instructor for each of the game programming labs. In the labs, the instructor uses a projecting monitor to first introduce and explain the computing concepts and then demonstrate how to apply the concepts in hands-on activities. The students follow along, with other undergraduates lending assistance to the students as needed. A good student to teacher ratio is no more than four to one. The setup is shown in Fig. 1.



Figure 1. Set-up in the Hands-on Labs. Undergraduate leader (left) helps a student (foreground) while undergraduate instructor demonstrates at the front of the class.

In the academy’s first four days, the students work with games created by the CREU students and make modifications/additions to them in directed hands-on activities. On the fifth day, students use the Asteroids game in unstructured exploration with hands-on help.

The games developed by the CREU team are loosely tied into a story line. The story line is that an alien is forced to land on Earth when its ship runs out of fuel. The game for each day is a step towards helping the alien to return home. In the Gathering Biofuel game, the alien stops on Earth to gather biofuel in the form of bananas. When the alien returns with the bananas, it finds that the Spaceship Acquisition CREU (excuse the pun) has stolen the ship. The player must solve the Sudoku game to unlock the door to the SAC fortress. Once inside the fortress, the player must help the alien navigate a Maze to get to the spaceship. Then the player must help the alien sneak past the sleeping SAC agents in the Agent Sweeper game. Once the alien has its ship again the player helps it to travel home safely by dodging and shooting Asteroids.

The topics covered in the game programming labs include an introduction to Java and Greenfoot, arithmetic and Boolean operations, control structures, data structures represented as arrays and matrices, and object oriented programming. The concepts, corresponding hands-on activities, sample quiz questions and scoring rubrics for each day are summarized in Table II.

TABLE I. SCHEDULE FOR 2011 INSPIRED ACADEMY

| | 1:00 – 2:45 | 2:45 – 3:15 | 3:15 – 4:30 | 4:30 – 5:00 |
|----|--|--|---|-----------------|
| M | Opening Session, Introducing Greenfoot | Cookies ‘n’ Chat Computers in Medicine | Programming lab, Your first game: Gathering Biofuel | Web lab |
| Tu | Programming lab, The game of Sudoku | Cookies ‘n’ Chat Computers in Business | Programming lab, Sudoku | Web lab |
| W | Programming lab, Maze | Cookies ‘n’ Chat Computers in Entertainment | Scratch lab | Web lab |
| Th | Programming lab, AgentSweeper | Cookies ‘n’ Chat Computers in Science | Programming lab, AgentSweeper | Web lab |
| F | Programming lab, Asteroids | Cookies ‘n’ Chat Preparing for College | Programming lab, Asteroids | Closing Session |

C. Assessing the Academy

Undergraduates participate actively in the assessment of the academy. The undergraduates develop content-based quizzes for each of the labs, as well as rubrics that are used to score the quizzes. Two undergraduates independently score each of the high school students’ quizzes using the rubrics. The undergraduates’ scores are analyzed to determine inter-rater reliability of the instruments. The instruments are refined as needed to improve reliability.

The high school participants complete the content-based questionnaires before and after participation in each lab module. A t-test is performed on the pre- and post-participation scores to assess whether they have learned the concepts.

The three CREU students developed the content-based quizzes and scoring rubrics for the game programming labs.

These materials were reviewed and refined by other undergraduates on the INSPIRED team prior to their use in the

academy. Table II shows a few samples of concepts, quiz questions and scoring rubrics used to assess learning.

TABLE II. CONCEPTS, HANDS-ON ACTIVITIES, AND SAMPLE QUIZ QUESTIONS AND SCORING RUBRICS FOR EACH DAY

| Day 1 | | |
|---|---|---|
| Concepts: <ul style="list-style-type: none"> Intro to Java and Greenfoot Classes, API, objects | Hands-on activities: <ul style="list-style-type: none"> Create a banana object and set its location Rotate an image by incrementing a variable and calling a method | Sample quiz question and scoring rubric: What are the three main types of classes in a Greenfoot scenario? Score: (cumulative) 1 point each: World, Actor, and Other classes |
| Day 2 | | |
| Concepts: <ul style="list-style-type: none"> Data types Arithmetic, Boolean, relational operators If statement | Hands-on activities: <ul style="list-style-type: none"> Work with integer arithmetic Work with Boolean operators Work with if statements, Boolean and relational operators Write get and set methods Import images | Sample quiz question and scoring rubric: boolean aBoolean; boolean anotherBoolean = false; aBoolean = false; //What is the value of "aBoolean" ? false aBoolean = true; //What is the value of "aBoolean" ? true aBoolean = anotherBoolean; //What is the value of "aBoolean" ? false Score: 1 point awarded for each correct answer, for a total of 3 points |
| Day 3 | | |
| Concepts: <ul style="list-style-type: none"> Sequence Selection Repetition | Hands-on activities: <ul style="list-style-type: none"> Write complex conditional statements, nested ifs Use a switch statement Work with the while loop | Sample quiz question and scoring rubric: Name 3 repetition structures used in Java Score: (cumulative) 1 point each: while, do-while, for |
| Day 4 | | |
| Concepts: <ul style="list-style-type: none"> Arrays, matrices Nested for loops | Hands-on activities: <ul style="list-style-type: none"> Use images in Greenfoot Create an array Create, initialize, manipulate a matrix | Sample quiz question and scoring rubric: What repetition structure can be used to fill an array/matrix? Score: 2 pts - for/nested for 1 pt - while, do-while, or something along the lines of having to set the values in the array/matrix manually 0 pts - anything else |
| Day 5 | | |
| Concepts: <ul style="list-style-type: none"> Objects, classes Inheritance | Hands-on activities: <ul style="list-style-type: none"> Create private variables Create a constructor Practice with nested if statements Manipulate images in Greenfoot Detect collision in Greenfoot | Sample quiz question and scoring rubric: An object is defined by a class A class is the model or blueprint from which an object is created. Score: 1 point awarded for each correct answer., for a total of 2 points |

In addition to the content-based quizzes, the high school students also complete pre- and post- academy questionnaires that measure students' self-reported interest, confidence and knowledge of computing. The post-academy questionnaire also asks students what was their most and least favorite part of the academy, what can be done to improve the academy, and what they plan to do with what they learned. A sample questionnaire is shown in Fig. 2.

D. Preparing Students for their Role in the Academy

Faculty mentors direct students in the design and creation of instructional materials for the academy. The materials for the Scratch lab were developed by an undergraduate in an independent study class in the summer under the direction of the first author. The Web lab materials were developed by INSPIRED students under the direction of the second author. The game programming materials were developed by a team of three CREU undergraduates during one academic year under the direction of the first and second authors. The third author held an initial training session on the design of content-based quizzes and scoring rubrics used for assessment and instructed

the students on the procedure to use in scoring the quizzes independently.

After these initial faculty-led efforts peer instruction is used extensively to prepare students for their roles. The undergraduates who will teach the labs hold training sessions for other undergraduates who will provide hands-on help to the high school participants. These sessions also give the instructors practice and feedback that they use to improve their teaching skills. The typical progression is for an undergraduate to start participating as a student helper and progress to being an instructor. Similarly, undergraduates who have experience creating, grading and refining assessment quizzes train others who have no experience, and the same progression from trainee to trainer holds. Coordinators are typically students who have participated in previous academies in several different roles. Because Coordinators have many responsibilities, two undergraduates serve as Coordinators for each academy: one experienced and one in training to become the lead Coordinator in the next academy. The peer learning approach is not only effective but also helps develop friendships and can engage and help retain the undergraduates [16]. It also relieves the faculty

mentors of much of the burden of preparing students for the academies.

IV. ASSESSMENT RESULTS

Eighteen students from nine area schools participated in the 2011 INSPIRED Game Programming Academy, including eight girls and ten boys. Eleven of the eighteen were underrepresented minorities.

The third author, a Psychology faculty member with extensive experience in program evaluation, analyzed the assessment data. The results are reported here.

Significant gains in knowledge were documented through the content quizzes in all of the sessions for game programming, Scratch, and web page development (Table III). Strong internal consistency was noted among all of the content quizzes as well with correlations ranging from 0.709 to 0.988.

Participants reported a significant increase in knowledge as measured on the pre/post academy questionnaire ($t=6.84$, $p<0.000^*$), and 81% of students reported an increase of interest in computer science as a result of participation in the academy. Another meaningful outcome from the high school academy was that 81% of the participants reported that they would take a computer science course either in high school or college, if offered, as a result of their experience.

Here are some comments from the high school participants:

- *"Today was fascinating!"*
- *"I liked how we learned to edit certain programs in simple games."*
- *"It is very interesting and inspiring."*
- *"I enjoyed working on game programming."*
- *"I liked learning about the for-loops for the matrix squares."*
- *"The camp is interesting and I have been taught more stuff than I've learned in the school year"*

The academy not only benefits the high school students but also has an impact on the undergraduates who led the academy. The experience benefits the undergraduates in several ways:

1. They get valuable experience in teamwork, organization, leadership and taking responsibility. For some it is the first event of any significance for which they have been responsible.

TABLE III. 2011 HSA CONTENT QUIZ RESULTS

| Day | Content Area | t score | p value |
|-------|----------------------------|---------|-------------|
| Day 1 | Game Programming Session 1 | 8.60 | $p<0.000^*$ |
| | Web Session | 6.866 | $p<0.000^*$ |
| Day 2 | Game Programming | 6.43 | $p<0.000^*$ |
| | Web Session | 5.10 | $p<0.000^*$ |
| Day 3 | Scratch | 3.74 | $p<0.002^*$ |
| | Game Programming | 5.08 | $p<0.000^*$ |
| Day 4 | Game Programming Part 1 | 5.70 | $p<0.000^*$ |
| | Game Programming Part 2 | 5.51 | $p<0.000^*$ |
| Day 5 | Game Programming Session | 5.05 | $p<0.000^*$ |

* Indicates significant results

INSPIRED Computer Science Summer Academy for High School Students
Post-Program Assessment Questionnaire

Thank you for your participation in this survey. We will use this information to assess our program and improve it. Your answers will be kept confidential.

| | low | 1 | 2 | 3 | 4 | high |
|---|-----|---|---|---|---|------|
| Please check a box to rate yourself in each of the following areas: | | | | | | |
| 1. interest in Computer Science | | | | | | |
| 2. knowledge of Computer Science | | | | | | |
| 3. interest in programming | | | | | | |
| 4. knowledge of programming | | | | | | |
| 5. interest in game programming | | | | | | |
| 6. knowledge of game programming | | | | | | |
| 7. interest in Web page development | | | | | | |
| 8. knowledge of Web page development | | | | | | |
| 9. interest in of applications of Computer Science | | | | | | |
| 10. knowledge of applications of Computer Science | | | | | | |
| 11. interest in going to college | | | | | | |
| 12. knowledge of how to prepare for college | | | | | | |
| 13. interest in Lamar University | | | | | | |
| 14. knowledge of Lamar University | | | | | | |
| 15. interest in Computer Science careers | | | | | | |
| 16. knowledge of Computer Science careers | | | | | | |
| 17. confidence in your ability to do computing tasks like game programming and web page development | | | | | | |
| 18. interest in taking Computer Science courses in high school (if offered) or college | | | | | | |

What was your favorite part of the camp?

What was your least favorite part of the camp?

The game programming labs were ☐ too hard ☐ too easy ☐ ok

The web labs were ☐ too hard ☐ too easy ☐ ok

What do you plan to do with the knowledge you learned here?

How can we improve the camp?

Was your over all interest in Computer Science increased through your participation in the INSPIRED Academy?

| | | | |
|-------------|--------------------|---------------|--------------------|
| No Increase | Increased a Little | Some Increase | Strongly Increased |
| 1 | 2 | 3 | 4 |

Was your interest in taking Computer Science courses in high school (if offered) or in college increased through your participation in the INSPIRED Academy?

| | | | |
|-------------|--------------------|---------------|--------------------|
| No Increase | Increased a Little | Some Increase | Strongly Increased |
| 1 | 2 | 3 | 4 |

Figure 2. Sample post-academy questionnaire used for assessment

2. The instructors get experience teaching and making technical presentations and demonstrations. The process of explaining concepts to the high school kids helps the instructors and undergraduate helpers solidify their knowledge and hone their communication skills.
3. The undergraduates gain the satisfaction of helping others.

These are educational experiences that are not often encountered in the classroom.

Here are some comments from the undergraduate participants:

- “I had the opportunity to help introduce people to some topics that are a bit difficult to grasp at first.”
- “It was additional practice at teaching computer science...”
- “I learned how to talk to students so they can have a better understanding about programming”.
- “I learned that I still need more practice teaching computing concepts.”

V. CONCLUSIONS AND FUTURE WORK

A five-afternoon academy with hands-on activities in game programming can not only be effective in teaching introductory programming concepts to high school students but can also help increase their interest in computing and interest them in taking computing courses in high school or college. With initial guidance from faculty mentors and extensive use of peer instruction, undergraduates can conduct these academies, from developing instructional materials to advertising, organizing, teaching and helping assess the impact of the academy on participants. This experience in turn can help develop the undergraduates by giving them valuable experience that can increase their teaching, communication, organizing, teamwork, and leadership skills.

Because the game software is free and students conduct the academy, the cost is kept low. This short duration five-afternoon academy also takes a relatively small commitment of time and resources. All of the game instructional and assessment materials can be freely downloaded from: <http://javagonegreen.blogspot.com/p/teaching-materials.html>. It is hoped that this will encourage others to host an academy and continue the effort to increase participation in computing.

Future work will focus on using the game programming materials in other settings and further refining them. The first of these is a two-week residential high school mathematics academy to be hosted by Lamar University in summer of 2012. This academy will target females, underrepresented, or economically disadvantaged students rising to grade 10 or 11 who have a strong interest in exploring mathematics and science. In the 2012 computing academy, the material will be taught by two computer science undergraduates in a series of seven two-hour sessions with a 15-minute break in the middle.

The undergraduate teachers will use feedback from a formal assessment of the 2012 game computing academy to make improvements to the instructional materials as needed.

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Work in Progress: Teaching Computational Thinking in Middle and High School

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Abstract - *Computational thinking (CT) does not require profound knowledge of computer science (CS). Vice versa, it helps students organize and build up new knowledge around the core CS concepts they encounter on the daily basis. Furthermore, CT provides a set of problem-solving skills and enhances analytical abilities that are crucial for the young generation to succeed in modern world pervaded with technology. Teaching the principles of computing to students with non-computing tracks of study provides them with a competitive advantage and breaks down stereotypes around CS. Our approach is to introduce a topic related to world issues and students' interests while concealing its relation to CS until students' interest and attention are captured. The approach takes advantage of pattern-matching abilities that are naturally wired in our brain to improve understanding and make the obtained knowledge persist in memory. The paper discusses some of the modules developed as part of the Inspire-CT project that can be delivered in one or part of a class period at high school or middle school.*

Keywords - computational thinking; Fault Tree Analysis.

I. INTRODUCTION

CT gives students the freedom and flexibility in finding new effective solutions supported by analysis and validation of the results. It helps students decompose the problem into manageable steps, employ abstraction to deal with complexity, recognize patterns and create scalable algorithms to solve real world problems. Another important skill associated with CT is the ability to collect and analyze data using proper tools and techniques to derive meaningful conclusions. CT is interwoven with numerous scientific fields such as mathematics, physics, biology, chemistry, economics, sociology, and, of course, engineering disciplines. One of the goals of the project is to reveal the benefits of CT to non-computing students. Middle and high school students often neglect computer science, as it seems overly intricate and tedious, and not relevant to their field of study or interest. However, the ubiquity of technology makes computational thinking a necessity and source of novel solutions.

The developed modules present CS concepts under the cover of the world issues and/or students' interests. However, the relation to CS is concealed until the very end of discussion. Some of the modules start with a recent exciting, intriguing, or even disturbing events supported with abundant visual materials, such as a nuclear disaster, or a skydiver that will free fall from 120,000 feet and break the sound barrier. Modules focus on the core CS concepts that even non-computing students have a prior knowledge of without being consciously

aware of it. Students encounter these concepts on a regular basis, e.g. when playing video games, using Facebook, searching for a movie on Netflix, etc. Such relevant emotionally charged information better captures and holds students' interest and attention and makes it more memorable. Creating associations between real life events, students' experience, and underlying CS concepts helps students' learn foundations of technology with minimum knowledge of science and math.

II. FAULT TREE ANALYSIS AND CHEMISTRY

Working with our collaborating high school teacher, we decided to deliver the first CT module as part of 10th grade chemistry class. Given this requirement, and the recent nuclear accident in Japan we decided to use Fault Tree Analysis (FTA) [1] for our first module. FTA is a technique widely used in safety-critical systems engineering for root cause analysis, risk assessment and design safety assessment. Fault tree is a graphical representation of events and conditions within a system that can lead to a top-level undesired event. We chose FTA for two reasons: 1) FTA is based on fundamental computing and mathematical concepts including Boolean algebra and logic, logical gates, set theory, probability, reliability, redundancy, etc. 2) FTA can model a wide range of systems, it is intuitive and easy to apply, and it finds practical application in the real world.

The module starts with a brief review of nuclear chemistry. It uses real life examples to demonstrate that nuclear energy can be extremely dangerous if not handled properly. To underline the significance of proper management of safety-critical issues the module presents two examples of the nuclear plant accidents. The first example is a recent accident that occurred in Fukushima in Japan. The second example presents Chernobyl disaster that occurred in the Ukraine in 1986. The module discusses weaknesses of the structure, operational failures, and concatenation of circumstances that led to the tragic events.

The module proceeds to basic scenarios of the potential system failure [2]. The examples focus on a water pumping system as one of the critical systems that supplies coolant to the reactor. At a high level of abstraction the system consists of an inexhaustible water source, two pumps, and a valve to supply water to the reactor. The first scenario discusses a condition when a pair of pumps fails. Because of the pump redundancy, a possible way the system could fail is if both pumps fail to run. Using simple blocks, Fig.1 illustrates the AND relation between these two events.

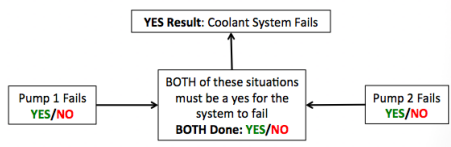


Figure 1. Failure scenario 1.

The next scenario represents OR relation between events. The water pumping system could fail if the valve fails to open or if the coolant supply is lost (Fig. 2).

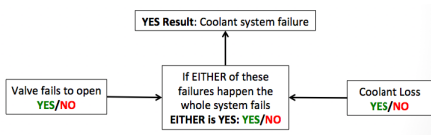


Figure 2. Failure scenario 2.

Next, students are introduced to Boolean numbers by substituting initial “yes” and “no” evaluations for computer science terminology such as “high”, or “1”, or “true” and “low”, or “0”, or “false” respectively. Additionally, natural language descriptions of potential failures are replaced with logical AND and OR gates. Two scenarios illustrate the difference between two types of gates from reliability standpoint. Based on previously discussed definitions of logical gates, the students were asked to fill out the truth tables and discuss their results with class.

Next step is to compile the failure scenarios into a single fault tree, and ask the students to come up with sets of events that can lead to system failure. Without knowledge of probability and reliability theory, the students intuitively came to the conclusion that probability of occurrence of multiple events simultaneously is less than that of an individual event. Therefore, AND gate- are intuitively more reliable than OR gate connections.

To consolidate FTA knowledge in practice, we asked the students to create a fault tree for a game console. We divided the class into groups of 3-5 students. Each group focused on causes of some common error conditions and relations among them, e.g. a console does not produce the sound, controllers fail, game does not load and so on. Upon completion of work in groups, representatives from each group compiled their resulting fault tree analysis on the board, and share their logic with the classmates. A tree representation helped the students diagnose faults that can cause the entire system to fail, estimate their likelihood and severity, and analyze overall reliability of the system based on the types of gates.

The preliminary results of the exercises are as follows: 1) over 50% of students volunteered to share their work with class; 2) the level of creativity and details of some of the solutions greatly exceeded our expectations; 3) almost all students actively participated in the class and team discussions, 4) over 3/4 of the students achieved 100% grade on their Boolean logic/FTA quiz, and 5) upon the completion of the module students expressed their willingness to participate in such

activities more often. According to the teacher, the degree of participation and level of participation greatly surprised him.

III. CURRENT AND FUTURE WORK

We are currently working on adaptation and introduction of other modules, and collection and analysis of results in order to obtain more accurate evaluation of both short- and long-term educational value of the developed modules. One of the modules explains the concepts of a set, Boolean, stack, queue, graph, database, etc. in relation to Facebook functions and structure. In another module, the concepts of an algorithm, searching, sorting and flowcharts are revealed during the discussion of how YouTube, Netflix, and Google search for artifacts. Another module covers physics concepts of speed, velocity, acceleration and rate and presents the story of a skydiver that attempts to break the world record and jump from 120,000 feet. Students collect and analyze data about the jump in Microsoft Excel. Next, the module shows the relation between speed in physics and rate in music, which leads to an exercise where students are asked to compute the size of a music album knowing the duration and rate of each song, thereby highlighting the concepts of algorithm, data storage, and compression techniques.

IV. CONCLUSION

CT does not necessarily involve the use of a computer, and it is not merely about “computer literacy”. School students come across CT concepts on a daily basis and, hence, have some prior knowledge of them. Despite this fact, they will most likely spurn CT principles if they are presented in a straightforward manner. Our approach uses the elements of constructivist learning theory combined with emotionally competent stimuli to introduce concealed CT concepts. The modules are presented in the form of a guided exploration supported with numerous hand-on problem-solving activities. Such approach ensures better students’ engagement, makes the material more memorable, eliminates the fear of complexity of CS, and even stimulates curiosity and interest in this field in non-computing students.

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Work in Progress: The NAE Grand Challenges, High School Curricula and Graduate Student Research

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Abstract—This work highlights a program that pairs Drexel University graduate PhD students with School District of Philadelphia high school teachers through academic fellowship to enhance the math and science education of high school students through the context of the National Academy of Engineering (NAE) Grand Challenges while concurrently illustrating the global nature of these societal issues. An analysis of survey results generated from the first and second years of the program is made public with the goal of demonstrating the program's efficacy in increasing: (1) High school teacher perceptions of their engineering knowledge; (2) Graduate student perceptions of their teaching and communication skills as well as their interest in teaching as a profession; (3) High school students' perceptions of what an engineer is and does; and (4) High school student perception of him/her becoming an engineer.

I. INTRODUCTION

The United States is seeing a decline in the number of science and engineering undergraduate and doctoral students, which puts the US at a disadvantage in globalization. Graduate students are at the front-end of cutting-edge research and provide the best opportunity to innovate transformative technologies and to encourage young people to pursue an education in the STEM fields and become productive engineers and scientists. This premise is being explored in a National Science Foundation (NSF) STEM K-12 program in a 5-year fellowship project at Drexel University. The Drexel NSF STEM K-12 program pairs 10 College of Engineering graduate students (Fellows) with 10 School District of Philadelphia high school Teachers to help introduce engineering concepts to high school students through the context of the National Academy of Engineering (NAE) Grand Challenges. The 10 Teachers reside from 5 unique schools that explore multiple student learner types, including: (1) an all girls school (Philadelphia School for Girls); (2) a public Science and Leadership Academy (Science Leadership Academy); (3) a performing arts public school (Girard Academic and Music Program); (4) Central High magnet school; (5) and an urban neighborhood high school (University

City High School). This paper explores the efficacy of the Drexel STEM K-12 program by examining the methods and results of the first and second year assessments of the program.

II. METHODOLOGY

In partnership with Drexel University staff, Combined Resource Solutions, Inc. (CRS, Inc.) designed K-12 program assessments. Assessments include summer session (pre-school year), mid-year and end-of-year surveys for Teachers and Fellows and beginning-of-year, mid-year and end-of-year surveys for high school students. Qualitative and quantitative assessment tools are utilized. CRS, Inc. analyzes all results.

This manuscript will report on the following questions surveyed in year one and year two:

- 1) Teacher perceptions of their engineering knowledge;
- 2) Fellow perceptions of their teaching and communication skills as well as their interest in teaching as a profession;
- 3) High school students' perceptions of what an engineer is and does;
- 4) High school student perception of him/her becoming an engineer.

III. PRELIMINARY FINDINGS

A. Teacher Perceptions of their Engineering Knowledge

Preliminary findings represented in Figure 1 show an increase in teacher confidence in their knowledge of engineering from the pre-summer session survey in Year 1 to the pre-survey in Year 2. Of the 8 Teachers who completed the pre-survey in Year 2, 87.5 have participated in the Drexel K-12 program previously, compared to 0% in Year 1. On average, the teachers in Year 2 have 8.29 years of teaching experience compare to 6.44 years in Year 1. Teachers mostly teach Physical Science, Biology and Chemistry. At the beginning of Year 2, Teachers rated their current engineering knowledge 2.71 on the 4-point Likert scale, which is an increase from 2.33

in Year 1. Figure 1 shows no one selected Poor in Year 2 as compared to 22.2% selecting Poor in Year 1.

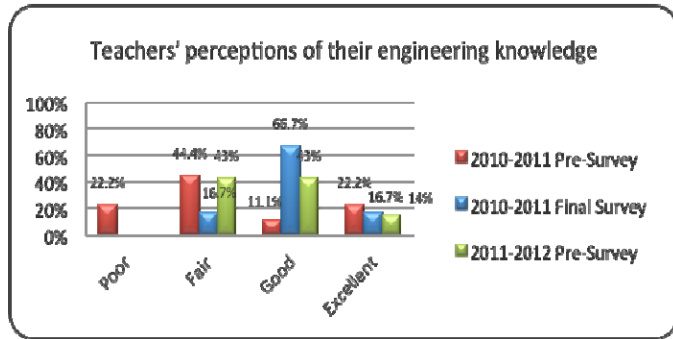


Figure 1: Year 1 and Year 2 analysis of Pre-Program Survey results of teacher evaluations of their current engineering knowledge and Year 1 Pre-survey and Final Survey comparisons.

B. Fellow Perceptions of their Teaching skills as well as their Interest in Teaching as a Profession

All 10 Fellows completed the pre-summer session survey both years. As of Year 2, 70% of the Fellows have participated in the program previously, compared to only 10% in Year 1. All of the Fellows in both Year 1 and Year 2 indicated previous teaching experience, and 90% selected either Interested or Very Interested in teaching as a profession. This results in a 3.10 on the 4-point Likert scale. In Year 2 90% categorized their teaching skills as Good, with the remaining 10% selecting Fair, resulting in a 2.90 on the 4-point scale, which is higher than the 2.30 rating from Year 1.

C. High School Students' perceptions of What an Engineer Does

A total of 248 high school students took both Survey 1 and Survey 2 in Year 1, and 255 took both in Year 2. All students were asked to select all types of problems engineers try to solve. The list was populated with each of the NAE Grand Challenges as well as the additional non-engineering problems. In year 2, the top selection was *Engineer the tools of scientific discovery*, selected by 81.7% of the students. This was also the top pick in Year 1 with 71.7% selection. Both of the top picks in both Year 1 and Year 2 are NAE Grand Challenges. In Year 2, the least selected problem was *Correct grammar in*

newspaper articles selected by 10% of the students, which was down from 10.6% in Year 1.

D. High School Student Perception of him/her becoming an Engineer

From Survey 1 to Survey 2 in Year 1 and 2 there was an increase in the percentage of high school students who selected Yes when asked if they could envision themselves becoming engineers one day. Similarly, there was a decrease in the percentage of students that selected No. Figure 2 represents these results.

IV. CONCLUSION

Overall, data analysis of complete Year 1 surveys and the initial surveys of Year 2 point to the K-12 program having a positive impact on a Teacher's perceived ability to design engineering based materials and to integrate them into the classroom. Similarly, Fellows gain significantly in their perceived ability to engage the classroom and develop a greater interest in professorial or teaching professions. High school students are presented with a context for their STEM education via the NAE Grand Challenges and develop an understanding of and increased desire to pursue careers in engineering.

V. FUTURE WORK

Prior to the end of Year 2, high school demographic data will be collected from the Teachers so that results can be analyzed by gender, race/ethnicity, standardized test scores, attendance records and GPA. This will enable the program to report on the efficacy of the NAE Grand Challenges as a high school learning tool for multiple student learner types.

ACKNOWLEDGMENT

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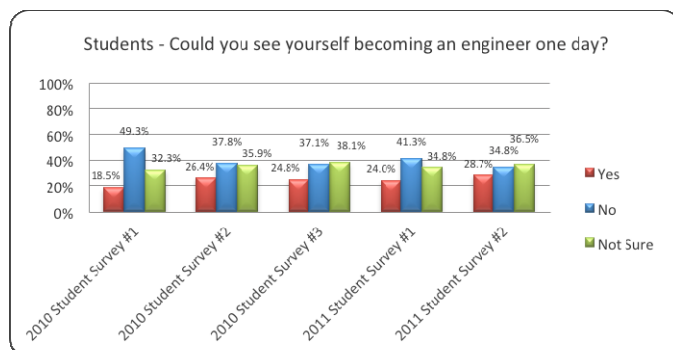


Figure 2: Year 1 and Year 2 comparisons for Survey 1 and Survey 2 data of high school students' responses to if they can see becoming an engineer one day and Year 1 comparisons for Surveys 1, 2 and 3.

“Inform, Experience, Implement” – Teaching an Intensive High School Summer Course

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Abstract—During the summer of 2011, twenty-four high school students participated in an intense, three-week computer science course at the University of Virginia. The course met for twenty-one three-hour sessions, thus encompassing more contact time than a standard college-level course. The course was structured in an “Inform, Experience, Implement” active-learning format: students were exposed to the history of a particular problem in context and participated in an active learning lesson regarding the topic before learning how to address the examined problem through programming. This structure helped integrate into the course best practices from experiential learning, kinesthetic outreach activities, and active learning pedagogy. Utilizing this three-part rotation curriculum achieved some important goals, including holding the interest of students during the summer for six hours a day and successfully motivating students who had no programming background.

I. INTRODUCTION

Diversity continues to be a challenge in many Computer Science departments [1]–[5]. While work is ongoing in fostering diversity inside existing CS programs, many have noted that early exposure to computing, such as in middle school and high school, is essential in eliminating many of the stereotypes and misconceptions about computer science and thus helping to improve the numbers of incoming students into the discipline [6], [7]. However, many middle schools and high schools lack the resources and personnel needed to run such programs during the school year. To help fill this gap, numerous computing summer camps have cropped up at universities around the United States sponsored by various companies and organizations.

One of the main difficulties faced by computing summer camps is in creating a curriculum that can hold students attention for several hours a day, particularly during a time that they are accustomed to spending in more leisurely pursuits. Some summer camps minimize this difficulty by recruiting students that already have some familiarity and fascination with computing. While teaching such students in a concentrated learning environment is both exciting and rewarding, not every summer program has students that come in with that level of familiarity or drive. Indeed, these pre-motivated students are the ones who least need the early outreach of a summer camp in order to choose a computing field.

We embarked on creating a curriculum for students without prior interest in computing during the summer of 2011 at the

University of Virginia. Our camp consisted of 24 fifteen-year old students from traditionally underrepresented demographic groups in computer science. All but two of these students had no programming experience whatsoever and mainly came to the program out of curiosity. Further, we were to have these students for six hours a day, separated into two three-hour blocks, over the course of three weeks. This equated to more contact hours than a standard three-credit college course.

We faced two main challenges with our summer experience: 1) how to hold a young student’s attention during a traditional break time; and 2) how to cover enough material to make an impact without overwhelming the students.

In this paper, we describe the curriculum that we developed for an intensive summer computer science experience for high school students with no programming background. Our goals in this camp were twofold. First, we wanted to treat the camp as an outreach program, with the goal of building interest and excitement in the students. Second, we wanted to provide the students with practical programming skills and experience they could use in the years that would likely elapse before their next exposure to computing instruction. Thus, we decided to include the kinesthetic activities that have been shown effective in outreach, the student-focused educational techniques that have been shown effective in internalizing knowledge, and some degree of direct instruction as the students would not have the time to investigate course topics on their own before experiential instruction. We combined these elements in a curriculum that was based around the mnemonic of “Inform, Experience, Implement”, where our instructional style progressed from contextual history lessons, through active learning experiences, and ending with programming implementation of various solutions. This methodology allowed us to integrate our various objectives in a direct and accessible way, both building interest and developing skills in the students. We found that keeping this mnemonic in mind through our teaching was an effective method for this age group and experience level combination.

II. RELATED WORK

In this section, we describe related work in computer science summer camps and teaching computer science material in the context of the real world.

A. CS Summer Camps

There have been many studies that indicate computing summer camp programs can increase the interest of females and under-represented minorities in computer science (see, e.g., [8]–[21]) and that have discussed other aspects of summer camp design (see, e.g., [22]–[29]).

We note that there is a breadth of discussion on summer camps in educational venues in part because of the many different potential combinations of student age, experience level, demographics, and affluence, along with the wide varieties in contact hours with the students. For example, Miller et al. describe their one-week camp in Colorado as being targeted specifically for middle school students from low-income families [9]. Meanwhile, Carmichael created a day camp specifically for girls in the realm of video game development [15]. Camps range from one to several weeks, with students living on campus and off, and with contact hours ranging from one to seven per day. Ages range from ten to eighteen, with some camps specifically for girls, other for boys, and others still for students that are from underrepresented demographics in computer science.

Our goal is to add to the growing body of knowledge on how computer science educators can successfully run a summer experience for younger students. We feel that our experience is unique from the others in two distinct ways. First, our number of contact hours was greater than the other camps that we examined, totaling more total contact hours than a standard three-credit college course. We believe that our experiences with a camp of this scale can help other instructors tailor their own efforts effectively. Second, our students came from many different cultures and locations. We had students from across the country, not just local to Virginia, and all were from traditionally underrepresented demographics in computer science. Only two of our students had any programming experience prior to coming to the camp.

B. Teaching CS in Context

Teaching computer science in the context of computing problems is something that has been debated in CS education. The argument for contextualized CS education focuses on the idea of grabbing the interest of the student and using that hook to then introduce various computing topics. If the context is “good enough,” then students are more likely to stick through a CS course and go on to a second one [30], [31]. The counter-argument states that students learn computing topics regarding that one context and that introductory students have a difficulty abstracting the concepts that they have learned to be able to apply them to other problems. Further, teaching the context takes up valuable lesson time, which might be spent on covering possibly more advanced programming topics that could have the same luring effect as the problem context [31].

Guzdial argues that if students don’t learn the material in the first place, then they won’t have the opportunity to transfer what they learned from one context to another [31]. Thus, if teaching in context helps students decide to stick with CS where without such context that would leave the course, then

there is a net gain. The main idea behind this and other contextualized instruction arguments is that students want to know why what they are learning is relevant and useful [31], [32].

The desire to teach computing in context is almost axiomatic in summer camp and enrichment programs, with camps focussing on such topics as robotics [11], games [15], [23], [24], [26], publishing [16], web development [20], [21], fashion [14], and creativity through computing [10], [29], [33] to name just a few. We likewise found this desire to understand relevance manifest with our group of high school students. With this age group and experience level, we quickly determined that if we did not provide them with context early on, attention and interest waned.

We had six hours a day with the students which allowed time to cover both the context and the programming in reasonable depth. Our “Inform, Experience, Implement” concept came specifically from the mentality that we had to sell the students on the problem first, have them experience the problem personally, and then learn how to solve the problem through programming.

Multiple studies have argued that mixing various media and motivated examples improve student involvement and learning [33]–[37]. These fit into broader trends in science education to engage students in the learning process through various problem-oriented and student-directed learning structures [38]–[42]. Recent studies have also observed that some activities that have been shown to engage students are not well suited to teaching computing at a deeper level [43], [44], suggesting there may be additional value in mixing instructional approaches.

The main challenge we faced was in devising a structure that would allow us to easily integrate teaching the context of problems, instructing students in core elements of programming, and utilizing kinesthetic, inquiry-based, and student-directed learning. We developed the mnemonic “Inform, Experience, Implement” as a tool to help guide our lesson development, providing a framework that aided our lesson planning to give students opportunities to engage through classroom instruction, learning activities, and programming experience.

III. THE COURSE

In this section, we describe our curriculum and provide an example lesson that we used during the course.

A. Overview

The goals of the 2011 summer program at the University of Virginia were to instill excitement in students about computer science and to provide students with a solid foundation in a production-level programming language, Python. We selected the Python programming language because we believed it balanced accessibility and power. The interactive command shell allowed students to dive directly into programming without the added complexities of editors, interpreters, and environment setup. The students easily moved from typing

short commands in the shell to writing programs in text files as the commands became too long for comfortable shell use.

Our 2011 class had 24 rising high school sophomores and juniors from seven states. A large majority of the students identified themselves as having no or very little programming experience, a small portion had experience with HTML, and two students had a working knowledge of at least one programming language. For three weeks, our students lived in on-campus dorms, attended classes, went on field trips, and completed nightly homework assignments. Their typical day consisted of two three-hour classes and a two-hour study hall session. In total, students attended 21 three-hour-long classes, totaling more contact hours to a standard college course. In addition to class-based instruction and assignments, students worked in small groups on a final project that they presented to a representative from our corporate sponsor on the last day of the program.

B. Staff Composition

The course was taught primarily by one CS faculty member and two graduate students with significant teaching experience. Other CS faculty members and grad students were brought in for either a full three-hour session or a half session to cover a lesson in their particular research area. By splitting up the teaching and having several guests speak on their expertise area, we were able to avoid over-utilizing any particular instructor and kept the instruction fresh for the students. Guest instructors framed their lectures however they liked, with the main instructors of the program arranging the schedule such that the “Inform, Experience, Implement” rhythm was continued.

C. Course Content

One of the messages we wanted to convey to the students is that computing is a broad and enabling field that impacts every aspect of the modern world. To this end, we touched on many topics, including cryptography, GPS and mapping, the Internet, artificial intelligence, game programming, and scientific computing. Additionally, we had pairs of students team up to create projects to show off at the end of the course, and provided time for problem-based learning to accomplish that goal. A full outline of course topics can be found at <http://stardock.cs.virginia.edu/lead>.

We included the “Inform, Experience, Implement” approach within each topic, but not always in a straightforward sequence. For example, in game programming we used extreme programming to repeatedly iterate from experiencing a functional but incomplete game to discussing how it could be improved and implementing those improvements. Another example of adjusting the design is path planning, where we did some of the implementation in advance and used it to increase the learning during the subsequent experience activity.

IV. EXAMPLE LESSONS

To better illustrate how our mnemonic of “Inform, Experience, Implement” informed our course creation, we provide

several example lessons from our camp. A full course schedule and outlines of other lessons may be also be found at <http://stardock.cs.virginia.edu/lead>.

A. Cryptography

After a couple basic introductory lessons, we began the “Inform, Experience, Implement” methodology by teaching cryptography.

The “Inform” lesson was organized around the history of cryptography. The first hour introduced the concepts of encryption and decryption, starting with classic ciphers such as Caesar, pigpen, and Vigenère. Students worked in teams to encode and decode simple messages provided by the instructor. In the second hour, the instructor described how modern computing has cracked classic ciphers through brute force, frequency analysis, and other similar techniques. Students then learned how cryptography has evolved, looking at modern schemes such as RSA. The third hour the students developed their own encryption schemes. Each pair of students was given a standard deck of playing cards. The pairs had to come up with their own encryption methodology, write down a detailed algorithm of how their scheme worked, and then encode their deck of cards to send a message to another pair. Thus, the “Inform” activity in this case actually ended with teaching a lesson about how to write basic algorithms for others to follow.

The “Experience” lesson began during the next morning’s three-hour block. As the students had not yet seen most of the campus, a scavenger hunt was arranged for them to find various clues around the grounds. However, each clue was encrypted with a different scheme, some from the day before and some that they had not yet seen. This lesson both gave the students a well-needed active exercise to get their mind focused for the afternoon and emphasized examining and applying new algorithms in a repeated fashion.

During the afternoon’s “Implement” block, students were asked about the encryption schemes they used. Several students noted that doing Caesar cipher shifts by hand was tedious and that they wished there was a way to automate the process. Similar sentiments were expressed with the other ciphers as well. This desire motivated our introduction of the concepts of strings and loops as we showed the students how to write programs that could encrypt and decrypt these cyphers more rapidly and more reliably than the students could do by hand.

B. GPS and Maps

Another good example of our curriculum pattern is a lesson set on GPS. The “Inform” lesson began with a history of celestial navigation using a sextant and worked up through modern GPS technology. Particular attention was paid to the impact software has had on navigation, including algorithms to deal with errors such as skew and jitter. Students also learned about the great circle distance formula used to find the shortest distance between two points on the surface of a sphere, and calculated several distances by hand.

For the “Experience” lesson, students used Android-powered smart phones to map buildings on grounds. Each

smart phone ran a simple custom application that continuously displayed the current GPS coordinates, had a button to add the current coordinates to a list, and another button to email the coordinate list to the user once the activity was completed. Students were divided into teams, and each team was given a list of buildings to map. While the list of buildings each group of students mapped were unique, each building was mapped by at least two groups. This organization allowed the full set of points to be combined into a larger map, and the duplicate points demonstrated issues with GPS coordinate gathering.

In the “Implement” lesson students learned to read data from a file, graph points, and implement custom functions. Prior to this point in the class, each values had been either hard-coded or read from the keyboard. The long list of coordinates, where each coordinate consisted of many characters, motivated the need for file input. Once the coordinates were read from the files, students learned to graph points on the screen and connect points to form shapes. The class combined coordinates from all groups to form a rough map of grounds. Finally the class wrote a function that implemented the great circle distance formula. Later on in the camp, students also used these coordinates when learning about optimal paths as we had them act out the traveling salesman problem by delivering “packages” to buildings on campus.

V. DISCUSSION

As an instructional staff, we took several lessons from this experience.

A. Classroom Management

We found managing class time was challenging. A typical day in our course consisted of two three-hour sessions with an hour lunch break between sessions. In our experience, few students enjoy sitting through courses lasting more than an hour, and college instructors typically lack experience managing three-hour class periods. A partial solution was to split each three-hour session into two sessions separated by a short break. However, we found it difficult to make breaks long enough for the students to relax and take care of personal business while still short enough that the students didn’t lose focus and initiate lengthy social activities. The most effective counter to this problem was having lessons that were more active and open (“Experience” lessons), which helped the students to feel that they were not trapped in the lab.

PowerPoint slides were not an effective teaching tool for this type of course. We first tried having slides that contained both definitions of various Python concepts and annotated examples of Python code for the students to type in and experience. While the students fully participated in typing in the code, there was a clear disconnect between the slides and the programs. Many students focused on entering the list of commands, not on understanding the commands and the relationship between commands and results.

Because of this disconnect, we switched to executing the commands along with the students. This switch gave us more flexibility to demonstrate the dynamics of each command and

made it easier to field questions from the students. After the switch from slides to the command environment, we polled the class about the two styles, and the students overwhelmingly preferred the command environment.

One drawback of using the command environment instead of slides is the inability to annotate commands. Without annotations, all our explanations were verbal and students who were learning at a slightly different pace sometimes missed our explanations. While it may be possible to use both environments, we found that switching between slides and the command environment was cumbersome and disruptive.

B. Student Participation

The rotation between “Inform” lessons, “Experience” lessons, and “Implement” lessons had several positive effects. First, the students stayed engaged during the three-hours lessons. Putting problems in context and making the assignments meaningful did have a significant effect on the group. Knowing that an active learning session was coming up seemed to keep them more attentive during the lecture and lab sessions. By the time we got to an “Implement” session, students were eager to try out their own ideas on how to solve certain problems.

The students reported that game programming was their favorite topic. For their final projects, all but two of the teams created some form of game. Students indicated that the interactive nature of their projects played a large role in why it was interesting to them. Other interesting projects included a networked, chat-enabled version of Tic-Tac-Toe, a quiz application, and an interactive music creation system. The final project teams each gave a formal presentation of their projects to the camp’s corporate sponsor on the last day of the program.

C. Results

The results of our camp experience can be evaluated from at least two perspectives. As instructors, we found that “Inform, Experience, Implement” greatly streamlined the process of creating lesson plans that incorporated kinesthetic activities, problem-based inquiry learning, topical instruction, and practical hands-on experience in many topics within computer science. Recalling the mnemonic allowed us to easily check if a particular lesson plan was likely to include each of these research-backed pedagogical and outreach elements.

The students also seemed to benefit from the course. Three months after the program completed, we sent informal surveys to the students asking about their experience. Results indicate we achieved our goals of motivating students to explore computer science and providing a foundation for further study. Selected results from the survey are below.

- 1) We asked students how comfortable there were with computer programming. On a scale from one (not comfortable at all) to seven (very comfortable), half of the respondents rated themselves as a three or less before the program; 75% of students rated themselves as a six or higher after the camp.

- 2) We asked students to rate how enthusiastic they felt about computing. On a scale from one (not enthusiastic at all) to seven (extremely enthusiastic), half of the respondents rated themselves as a four or less before the program, all picked at least a five and 63% of students chose seven after the camp.
- 3) We asked students if they are more likely to pursue computing in college or a career after the camp. On a scale from one (No!) to seven (Yes!), 88% of the students rate five or higher.

In addition to these statistics, each individual student rated themselves as more comfortable with and more enthusiastic about programming after the camp than they were before.

VI. USE IN COLLEGE COURSES

After the success of the first instance of our course, we looked to find ways to incorporate our methodology into standard college classes. As one of the authors is the primary instructor for Introduction to Programming at the University of Virginia, we felt it best to pilot some of our lessons in this course. Introduction to Programming is a required course for all engineering students at the University of Virginia and is also taken by a large number of students from the College of Arts and Sciences. In a given year, over 1000 students take some version of our introductory course, with around 750 taking this particular version. We felt that this class would be a good fit for the technique due to its diverse population of student backgrounds and interests and the natural fit the methodology would have with a close lab format.

“Inform, Experience, Implement” lessons were conducted on encryption, GPS, and Python programming. For the most part, the lessons were well received. Many students anecdotally reported that they enjoyed doing things outside of the traditional classroom lecture format, particularly when the classroom has nearly 300 students in it. However, there was a vocal minority that disliked being asked to do something that required them to leave the classroom. Student performance on test questions on this material was, on average, similar to other question score distributions. However, as these topics had not been introduced into this class in any other fashion, we cannot draw any conclusions as to whether the technique itself improved learning. We plan to revamp existing course material to reflect the “Inform, Experience, Implement” methodology to make a better comparison in our future work.

VII. FUTURE WORK

As discussed in the previous section, we are branching out to utilize the “Inform, Experience, Implement” methodology in other courses and formats. Besides using the methodology in introductory college courses, we will use the methodology again in the summer of 2012 with the next iteration of our LEAD summer camp. This summer, however, we will be running two one-week courses, thus substantially changing the amount of time we have with the students. Further, our age group is dropping by a grade level, to rising ninth grade students. Our goal this summer is to evaluate the efficacy of

the methodology when compressed into a tighter schedule. We plan to continue to do lessons on encryption, GPS, and Python, while introducing a new topic on robotics using Lego Mindstorm NXT kits.

Early results from the 2012 summer course are generally positive, with student-reported comfort with computing increasing from 2.7 to 5.0 on a scale of 1 to 7, with 7 being most comfortable. We plan to present more complete results from the 2012 camps in the future.

VIII. CONCLUSION

During the summer of 2011, twenty-four high school students participated in an intense, three-week computer science course at the University of Virginia. The course itself encompassed more contact hours than the standard college-level course. Due to the amount of time that students spent in class (six hours a day split into two three-hour sessions), we looked for novel ways to keep students’ interest and enthusiasm high. We found that teaching CS in context for this specific demographic and experience level was highly effective. The course was structured in an “Inform, Experience, Implement” active-learning format: students were *informed* about the history and importance of a particular problem in context, *experienced* the problem in an active learning lesson, and then *implemented* a program that could help to solve the problem. We feel that this three-part rotation curriculum achieved many of our goals, including instilling in students an excitement about computing and also teaching them the basics of a general-purpose programming language.

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Computer Science Learning Made Interactive – A One-Week Alice Summer Computing Workshop for K-12 Teachers

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Abstract— In this paper, we present our experience, findings, and lessons learned from conducting a one-week Alice summer computing workshop for K-12 teachers. Our workshop focuses on using Alice, a 3D programming environment, to introduce computing concepts to K-12 teachers in all subjects so that these teachers can pass on their knowledge and inspiration to their students. During the workshop, the teachers developed curriculum materials for the subjects they will teach in the following semesters with the help of our workshop tutors. Workshop assessment results show a 52% increase in confidence level in teaching computer science and a 44% computing knowledge level increase.

Computer and Information Science Education – computer science education, information systems education, curriculum

I. INTRODUCTION

The Bureau of Labor Statistics predicts that the demand for computer and mathematical occupations will grow more than twice as fast as the average for all occupations in the U. S. over the next decade [1]. However, in recent years the number of degrees earned in computer science (CS) has been decreasing. According to the Higher Education Research Institute (HERI) at the University of California, Los Angeles (UCLA), between 2000 and 2005 there was a 50% decline in the number of newly declared CS majors and a 70% decline in the number of incoming freshmen who expressed an interest in CS major [2]. A similar steep decline had been reported in the Computing Research Association (CRA) Taulbee Survey during the 2000's. As a result, we might face a shortfall in the computing workforce in the next decade. Even though the 2008-2009 CRA Taulbee Survey reported a two-year increase of 14% in the total number of undergraduate majors with a broader number of degree programs included in the statistics, the College Board discontinued the Advanced Placement (AP) Computer Science “AB” course following the May 2009 exam administration due to the low participation in that course [3][4]. Therefore, the education crisis in computer science still draws critical attention and compels us to produce more computer scientists.

Computer science educators have tried different ways to attract more students to computing fields: computing camps for K-12 students, outreach programs for K-12 teachers, new teaching tools, changes of policy, professional networks, etc.

In this paper, we present our experience, findings, and lessons learned from conducting a one-week Alice summer computing workshop for K-12 teachers. The organization of the rest of this paper is as follows. We review related work and outline our contributions in Sec. II. Next, in Sec. III, we describe workshop organization including learning objectives, schedules, and lesson plans. Then, in Sec. IV, we discuss our experience and lessons learned throughout the workshop. In Sec. V, we present assessment results. Finally, we conclude in Sec. VI.

II. RELATED WORK AND OUR CONTRIBUTIONS

K-12 teacher outreach programs have been shown to be an effective means of making computer science accessible to those teachers. In this section, we first present successful work that has been done on K-12 teacher outreach to improve computer science education. Then, we discuss our contributions.

A. Related Work

Carnegie Mellon University offered the CS4HS and CSbots programs which targeted high school computer science teachers [5][6]. Many workshop materials are shared on the CS4HS website, and the CS4HS model has now spread to many other universities. In 2010, Marquette University led the “Computational Thinking for the Sciences” workshop, a three-day summer workshop for high school science and mathematics teachers. Lamar University (LU) offered a summer workshop for K-12 teachers in 2010 [7]. The goal of the workshop was to introduce fundamental computer science concepts to teachers. LU also conducted a survey on computer science K-12 teacher training programs in 2011 [8].

Duke University has conducted several Alice training workshops for middle school teachers since 2008 [9][10]. Saint Joseph's University became the site at which the Teacher Enrichment in Computer Science course was based [11]. The course spanned two weeks; the first focused on teaching Alice itself while the second allowed teachers in attendance to develop Alice-based curricula that would engage their students.

The Georgia Institute of Technology put in an effort to improve the aging computer science education pipeline currently employed in the state of Georgia by offering a series of teacher workshops, starting in 2006, to influence CS teaching styles in a positive manner [12]. Half of the

participants reported they had been able to effectively use the knowledge and materials gained from the workshop. Through the medium of bioinformatics, Winona State University conducted a computer science based workshop geared for K-12 science teachers between 2006 and 2008 [13]. UCLA offered a yearly program called the Summer Institute for Advanced Placement Computer Science (APCS) teachers in 2004 [14]. The course consisted of a series of lectures and curriculum development opportunities. As a result of this program, the number of students in APCS courses in Los Angeles Unified School District (LAUSD) tripled.

B. Our Contributions

Our work builds upon some of the successful strategies for teacher workshops mentioned in the related work section, and our main contributions are the following:

1. This workshop, unlike most of the workshops mentioned in the related work, is designed for K-12 teachers of all subjects at all levels. Our goal is to equip teachers in not only computer technology, math, and science, but also English, art, and music so that students of all types would have the chance to experience at least a brief interaction with computing in a form they would be able to understand and use. Most students with an interest in computer technology or other computing-related subjects may have already been aware of computer science as a college major and career choice, but the same cannot be said for students in seemingly unrelated fields of interest. We think that expanding our target group can only increase the number of students who eventually decide to become part of the computer science field and fill those positions the future will desperately need.

2. Our workshop focuses on introducing fundamental computing concepts to ensure the learning objectives of the workshop are applicable to the teaching environment of K-12 teacher participants. Our immediate learning objectives target program structure, flow of program execution, objects, methods/functions, conditional branches, variables, loops, user input, and Boolean logic. With the fundamental computing concepts, workshop participants were able to design and implement their own curriculum materials in Alice within only five days.

3. The afternoon sessions offered curriculum development opportunities to the workshop participants. At the end of the workshop, the participants presented their curriculum project to the other participants and submitted their project materials to the workshop staff; those materials include: Guideline to K-12 Teachers, Project Presentation, Project Introduction, Readme, and Alice project file. The curriculum project presentations were the highlight of the workshop. This allowed the participants to share their curriculum they planned to use in their classrooms, exchange ideas in order to better their own curriculum, and help each other locate issues or bugs that could impair students' learning.

Since the goal of this workshop is to better prepare K-12 students for college, the time devoted to curriculum development is crucial, as it ensures the teachers will be able to use their knowledge of Alice to enrich their students' learning experience. The participants could directly take back the

curriculum projects and use them in their classrooms. The materials are also available on our program website for other K-12 teachers.

4. We designed and developed all five-day Alice instructional materials based on the workshop learning objectives. The instructional materials include PowerPoint presentations, hands-on exercise templates, and projects. In addition, all lecture sections were recorded in video. All instructional materials and videos of workshop sections are available to other outreach programs for download on our website. The instructors of other outreach programs can watch videos to learn the details of each section. The materials could be used all together for a week-long workshop or separately for day-by-day workshops.

5. We worked with a program evaluator and designed assessment materials for the workshop. The assessment materials include a pre-workshop survey, post-workshop survey, and pre- and post-tests for each day of the workshop. All assessment materials are available to other outreach programs if any other programs would like to adopt them for their own use.

III. WORKSHOP ORGANIZATION

A. Learning Objectives and Schedule

In order to help the teachers understand fundamental computing concepts, we compiled the following workshop learning objectives.

- Program Structure and Flow of Execution: be able to identify the start of the program and trace its path.
- Objects: know what makes up an object and how it can be used to simplify program design.
- Methods/Functions: know how and when to create a separate method to accomplish a small, recurring task.
- Conditional Branches: how they affect the normal flow of execution based on the value of a Boolean expression.
- Variables: know how to create, change, and use three basic types of variables—numbers, strings, and Booleans.
- Loops: how they can be used to repeat a sequence of steps until a certain condition is met.
- User Input: how to accept and use data and keystrokes supplied by the user to trigger events, call methods, and store information about the user for later use in the program.
- Boolean Logic: understand core Boolean operands such as NOT, OR, and AND and how they can be used in while loops or conditional branches.

Computing concepts for each session and workshop schedule are given in Table I. Participants worked on the curriculum materials that they would use in the subjects they will teach in the following semesters. On the fourth day, each

TABLE I. WORKSHOP SCHEDULE

| Schedule | Day | | | | |
|-----------------|-----------------------------------|----------------------------|----------------------------|--------------|------------------------|
| | Monday | Tuesday | Wednesday | Thursday | Friday |
| 9:00am-9:30am | Opening Session | AS-2 Conditional Branching | AS-4 Variables | AS-6 Arrays | Curriculum Development |
| 9:30am-10:30am | AS ^a -0 Alice Overview | | | | |
| 10:30am-12:00pm | AS-1 Single/Multi-Character Input | AS-3 Loops | AS-5 Functions and Methods | AS-7 Lists | Curriculum Development |
| 1:00pm-3:00pm | Curriculum Development | Curriculum Development | Curriculum Development | Presentation | |

a. Alice Session.

participant presented and shared his/her work with the other participants in order to get feedback and finish the project on the fifth day.

B. Alice Lesson Plans

The first session, or session zero, was a perfect way to start the Alice workshop. Alice is a 3D programming environment and a teaching tool for introducing computing concepts [15]. All of the participants were attentive and able to follow the simple overview of Alice's interface. There are three main components of an object in Alice and in this session, they were only briefly explained. The instructions were given one-by-one with small explanations in places that were necessary. The program consisted of creating a vehicle object, programming it to move, and programming a wheel to spin at the same time the car was moving. All participants knew exactly what to do and were able to complete this task with little help.

In session one, participants were shown how to gather input from the user and how that input can be used to affect a running program. They were also introduced to the problems that could arise when invalid input is accepted by a program. This type of error is seldom encountered due to Alice's strict types but still can be duplicated in some manner. These concepts, while basic to experienced programmers, were eye-opening to the participants in the workshop, who garnered new-found respect for the programs they use on a daily basis and the programmers who created them. At the same time, the almost magical aura felt by non-programmers when dealing with the inner-workings of computers began to vanish, and they realized that they too would be able to tell the computer what to do in a way they had not dreamed of before.

Session two focused on conditional branching as a way of altering the normal flow of execution in a program based on a Boolean expression. The instructor explained this concept with small snippets of Alice programs. The programs were basic and could easily be understood by simply reading. This was done so the participants could understand how these structures can be used in the simplest of tasks. After the participants were fairly familiar with this concept, the instructor moved on to concept of nested if/else structures. With this knowledge, the participants were able to start work on their question and answer games, using if/else blocks to handle right and wrong answers.

In session three, we introduced the concept of loops in Alice. This had been the missing piece in some of the participant's projects and was quickly adopted to minimize the number of blocks needed and provided functionality not possible without loops. The instructor explained each type of

basic loop found in Alice by constructing a very small example using them. The end of the session project required participants to use nested loops. All participants were able to complete it successfully; however, it did require more time for the participants to fully understand nesting of loops. At this point, the participants began to express interest in seeing how other participants, as well as the instructors, had implemented their designs and they started to appreciate elegant, well-formed programs.

Variables were the primary topic of session four. Participants were introduced to various types of variables. They were also shown how to create, use, increment/decrement, and set variables through the use of multiple examples. By storing input in variables, the participants realized that data could be used more than once in whatever order desired. This session should have been taught before session 1 and contained 2 projects. Most participants did not have time to finish the second project, so they finished it during the curriculum development time. The first project showcased behavior not possible without the use of variables, taking the average of a set of values entered by the user. The second project was slightly more difficult and required the participants to switch the values of two variables.

Session five was considered one of the more difficult sessions. In session zero, the instructor briefly explained methods and functions. In session five, instructors not only explained these concepts in much more detail, but they also taught participants how to design and create their own methods and functions. This new concept was perfect for some participants, but sadly, only a small portion understood methods and functions to their full extent. The participants that did not understand how to create their own method or function became more familiar with doing this during the curriculum development time.

Session six contained the most complex ideas covered in the workshop. Participants were introduced to advanced Boolean expressions and arrays. The AND Boolean expression and the OR Boolean expression were received very well and teachers could instantly see how these expressions could help simplify things in their own projects. However, the NOT Boolean expression seemed quite difficult to explain. Even after several very simple examples, many participants simply said "no" to using it in their own programs, even if they had to create more code to accomplish this. The arrays section of this session was extremely difficult for both the instructors and participants. The data structure as a whole was very simple to understand for them, but the methods of stepping through the array using a loop and an index to access each element

individually were overwhelming. The instructor used a small array to store correct answers to a spelling test and this seemed to work really well. They understood that the loop needed to step through the array and check each value to see if the user answered the question correctly, but they had trouble constructing such a loop on their own.

Lists were discussed in session seven. Everyone was very happy to learn about lists and found them much easier to work with. This was because of the way lists are implemented in Alice. Alice has a loop that steps through a list, exactly the way participants stepped through an array in the previous session. This solved the issue the participants had of not being able to create a loop that would access each element one at a time. Since lists are so similar to arrays, an example wasn't necessary. The instructors only explained the methods and functions that belong to a list, and this was sufficient for participants to understand.

IV. WHAT WORKS AND WHAT DOES NOT

A. What Works

1) *Positive Elements Adopted from Previous Workshop:*

The organization of the sessions was much appreciated by the participants. Based on a concept-by-concept progression, the sessions were fairly easy for everyone to understand and keep up with. The content in each session built on the content taught in the previous sessions, forming a strong framework on which to link related concepts together in order to memorize and utilize them to create the desired program behavior. The projects at the end of the sessions proved to be extremely useful for the participants. This hands-on experience was necessary to solidify the concepts in their minds while at the same time, causing them to feel good about themselves when a project was completed successfully. Curriculum development time was sometimes used as an extension of the session project development time to complete difficult projects or modify existing projects in creative ways that often could then be incorporated into curriculum ideas.

Participants were strongly encouraged to apply concepts they had learned during the morning sessions to projects they felt would be useful in their respective classrooms. Since the goal of this workshop is to better prepare K-12 students for college, the time devoted to curriculum development is crucial, as it ensures the teachers will be able to use their knowledge of Alice to enrich their students' learning experience. This opportunity turned out to be the high point of the day for most participants and gave them a chance to really put their new knowledge to work. Project ideas were very creative and often incorporated characters, stories, animations, and sounds. Some of the final projects are summarized in Table II.

2) *Successful Changes from Previous Workshop:*

We adopted the successful strategies in our previous workshop and did our best to correct or avoid the elements it claimed did not work so well. In this section we detail three elements that were not successful in the previous workshop but were more successful in the current workshop.

Of the three, the biggest improvement has to be focusing on teaching just one program. In the previous workshop, we

introduced both Alice and Scratch in the same week which proved to be overwhelming for most participants. This year, we alleviated the problem by focusing on just Alice for the entire workshop. With this much simpler schedule, the participants were able to make more progress on their curriculum projects and forgo the added stress of learning two separate programs in one week.

In order to evaluate the effectiveness of our previous workshop, we developed a series of pre- and post-tests for each of the 13 sessions which consisted of 5-7 questions and determined how much the participant had learned during that session. Towards the end of the week, many participants were experiencing a bit of test fatigue after completing 26 tests, not counting the pre- and post-workshop evaluation and other evaluation materials we had prepared. This year, instead of tests for every session, we decided to group them by day, so participants only had a total of 8 tests (pre- and post-tests for the first 4 days) with each test consisting of 6-8 questions. The participants did not seem to mind this new arrangement nearly as much as they did the previous one and had no trouble completing it in a timely manner. This reduction in test time also had the added benefit of allowing more time for the session projects. This enabled the participants to experience a more complete understanding of Alice and the computing concepts in general.

TABLE II. CURRICULUM DEVELOPED DURING WORKSHOP

| Curriculum Material | Subject | Grade |
|---|--|-----------------------------------|
| Alice in the Classroom | Computer Science | 10 – 12 th |
| A Visit with Mortimer | Science, Geography, Citizenship | 5 – 8 th |
| Super Simple Alice | Technology Apps | 6 th & 7 th |
| A Very Gentle Introduction to Programming Using Alice | Computer Science I, Computer Programming | 7 – 12 th |
| Science Writing Prompts | Science | 8 th |
| Desert Biome | Science, Geography | 3 – 6 th |
| Alice & Mathematics | Mathematics | 6 – 8 th |
| Sig Fig | Science – Significant figures | 6 – 12 th |
| Introduction to Alice | Information Technology, Multimedia, Web | 9 – 12 th |

B. What Does Not Work

While the workshop as a whole was a success, there are always things that could be done to improve the experience and learning potential of the five day period allowed. In this section we will explore elements of the workshop that were not considered positive by either the participants or workshop staff.

The single most common complaint from both workshop staff and the participants was Alice itself. Alice, although a great introduction to programming concepts, has quirks and bugs. There were times a participant would create a program that appeared to be correct upon examination of the blocks themselves, but when ran would not produce the expected result, throw a vague error, or crash the program completely. These problems could sometimes be corrected by discarding

the blocks and curriculum developed during the workshop and recreating the program, but in some cases a solution was unable to be found. It is accepted that no programming environment, however simple or complex, is without fault, but the amount and severity of bugs in Alice appears to be much higher than other applications of similar type (e.g. Scratch). Feature organization in Alice, while trivial for experienced Aliceans, can be counter-intuitive for newcomers.

For example, many commonly used blocks like Boolean comparisons and user input are found in the functions tab of the world object when, as object-oriented programming principals suggest, we would expect them to be considered general utilities not associated with an object. Working with arrays in Alice is also needlessly complex even for the instructors and tutors who have experience with Java and C++. Due to the nature of Alice, (a purely graphical, drag-and-drop programming environment) a degree of uncertain feature organization is to be expected, but when compared to the highly organized and intuitive layout of Scratch, it is clear that Alice leaves a lot to be desired.

Another recurring complaint concerned the availability of the presentation slides during the workshop. In the previous workshop, participants were given all presentation materials at the beginning of the workshop and were able to peruse them at their leisure; however, in order to keep everyone on the same page, we did not include any presentation slides on the flash drives this year. Instead, we decided to post the presentations for all the sessions for that day on our website immediately following the morning sessions of that day. This was also done to prevent the participants from using the answers found in the slides on their pre- and post-session tests. Unfortunately, this caused more problems than it corrected. Participants were no longer able to follow along with the presentation on their own computers, and consequently were not able to grasp the concepts as quickly as they could have. A few participants had trouble keeping up with the pace of the more advanced sessions and expressed a desire to have their own copy of the slides during the session so they could go back and re-read the sections they did not understand. This is a valid problem, and we are in the process of developing a method that will allow the participants to have access to the slides whenever they need them, yet, at the same time, prevent that access from skewing workshop assessment results.

The wording of the pre- and post-tests was again the subject of criticism from the participants. After receiving similar feedback from our previous workshop, we examined the questions contained in those tests for any ambiguity or poor wording. Even though corrections were made, the participants again voiced their dissatisfaction with the quality of the test questions. These questions are extremely important to us as they tell us how well the workshop is meeting its goals. While we feel the current questions were precise enough for a valid workshop evaluation, it is clear we must continue to refine their wording and structure.

V. ASSESSMENT RESULTS

An outside program evaluator worked with us and developed all workshop assessment materials. Our assessment approach includes two types of assessment: workshop

participant self-assessment and assessment by the workshop instructors to avoid self-interest issues in the workshop effectiveness outcomes.

- Workshop participant self-assessment includes a pre-workshop survey with 57 questions and a post-workshop survey with 62 questions.
- Assessment by the workshop instructors includes pre- and post-tests with a total of 28 questions with 7 pre- and post-questions each day.

Both pre- and post-assessment results show significant improvement in participants' knowledge of computing subjects taught at the workshop.

Twelve participants arrived the first day, but only ten participants were able to complete the workshop. Results from the pre-workshop survey showed that three participants have a bachelor's degree and seven participants hold a master's degree. The workshop had a good mix of middle school teachers and high school teachers. Six participants teach middle school and four teach high school. Their areas of teaching range from Science, Chemistry, Math, Web Mastering, English, Tech/teacher training, and other computer related subjects.

Pre- and post-surveys were given at the beginning and end of the workshop allowing participants to rank themselves in their conceptual knowledge of the items taught. All self-assessment questions are ranked on a scale from 1 to 5; 1 indicating they felt very uncertain and 5 indicating they felt very comfortable with the concept. The post-workshop self-assessment per-person average was 4.1, which was an appreciable improvement from the pre-workshop average score of 2.7.

From our in-depth face-to-face interviews, participants mentioned several suggestions. Some found the pace of the presentations not conducive to their learning style and would like to have had some step-by-step directions to be better able to follow along. Another suggestion was to offer workshops for different programs that target teachers of certain age ranges. Some suggest that Alice may be too difficult for most middle school students and that it may be impossible for elementary teachers to take advantage of Alice in their classrooms. These suggestions indicate that Alice is most effective in high school and tertiary education.

We also developed a number of questions to measure the amount of material the participants would take away from the workshop. We did this by creating pre- and post-questions to test their knowledge of the subject discussed during each session. Table III shows average percentage increases ranging from 31.2% to 63.1%. The rubric used for grading these tests is given in Table III.

VI. CONCLUSIONS

Our workshop focuses on using Alice, a 3D programming environment, to introduce computing concepts to K-12 teachers at all K-12 levels to expose students to computing at an early age and to reach more students. During the workshop, the teachers develop curriculum materials for the subjects they will

teach in the following semesters. Based on the pre- and post-workshop assessment results, the participants were able to indicate their confidence in the concepts presented in the workshop. In the pre-workshop assessment, the results indicate a confidence level average of 2.7 out of 5. However, the average post-workshop assessment score was 4.1 out of 5, indicating a 52% increase in confidence level. A similar change was observed upon analysis of the pre- and post-tests (graded by workshop instructors) for each session. Participants scored an average 2.5 out of 5 on the pre-session tests, but that score rose to 3.6 on the post-session tests, which resulted in a 44% knowledge level increase.

TABLE III. PRE-TEST AND POST-TEST ASSESSMENT RESULTS

| Session | Pre-Test Average score/ per participant in each session | Post-Test Average Score/per participant in each section | Score changed (percentage increased) |
|--|--|---|--|
| Day-1 | 2.44 | 3.98 | +1.54(63.1%) |
| Day-2 | 2.81 | 3.74 | +0.93(33.1%) |
| Day-3 | 1.99 | 3.01 | +1.02(51.3%) |
| Day-4 | 2.79 | 3.66 | +0.87(31.2%) |
| Rubrics: 1. Posses no understanding of the concept 2. Posses very little understanding of the concept 3. Posses little understanding of the concept 4. Posses moderate understanding of the concept 5. Posses complete understanding of the concept | | | |

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Teaching Software Inspection Effectiveness: An Active Learning Exercise

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Abstract—This paper discusses a novel active learning exercise which teaches students how to perform and assess the effectiveness of formal software inspections. In this exercise, students are responsible for selecting an artifact from their senior capstone design projects. The students then use fault injection to strategically place faults within the artifact that should be caught by the inspection exercise. Based on the needs of the team, students prepare an inspection packet consisting of a set of inspection instructions, applicable checklists, and the inspection artifact. Students then “hire” a set of inspectors based on classmates’ backgrounds and experiences. The team leader then holds two inspection meetings and reports the results. The results are then used to assess the effectiveness of the inspection. Overall, in analyzing 5 years worth of data from this exercise, it is found that students are capable of selecting appropriate materials for inspection and performing appropriate software inspections. The yield of students is lower than an experienced professional might have and the inspection rates tend to be slightly higher than desired for their experience. However, the yield is related to individual preparation time. Students overall find this to be a highly educational experience and highly recommend it be continued for future classes.

I. INTRODUCTION

Software inspection has long been viewed as one of the most effective mechanisms for ensuring the quality of developed software. Ever since Fagan [5] published his proverbial paper on the subject in 1970, inspections have been used by industrial practitioners to aid in improving the quality of software products. While there have been improvements in the inspection processes used in software development, the basic inspection process has remained virtually unchanged.

Typically software engineering courses may lecture on the benefits of software inspections as a quality assurance component, but active learning exercises are not included. Research has shown that students’ acceptance of inspections increases with watching a video showing an inspection in progress [2]. However, the acceptance of the practice increases even further after students actively participate in an inspection session [2]. Active participation in software inspections has also been shown to increase a student’s critical thinking and analysis skills [11].

The classical approach for teaching inspections using active learning is a case study based approach. With a case study based approach, students are provided with a predefined artifact and are then broken into teams to inspect the artifact

[3], [10], [13]. While this method can be effective, it also suffers from problems. Students may lack domain knowledge of the material being inspected, and because they see the exercise as purely an educational exercise and lacking a long term stake, they may not be as interested in the outcome. A second approach to teaching inspections involves a project based approach. In this approach, students work on a project, and as part of that project, the team members hold one or more inspections with the team members working on that project [1], [6].

II. THE LAB EXERCISE

The objectives for this active learning exercise are multifaceted. First and foremost, at the completion of this exercise, students are to have an appreciation for the process of conducting a formal inspection. Students should be able to describe the roles for each participant and explain the interactions between inspection participants. Students should be able to define inspection objectives and determine the appropriate scope for an artifact inspection given a fixed time constraint. Students should recognize the importance of inspection preparation, and should be capable of quantifying the effectiveness of the inspection. Students should also obtain an understanding their own personal capabilities and limitations when inspecting others’ work.

A. Exercise Specifics

The exercise is based upon the Team Software Process (TSP) [7] inspection procedure, though it does not follow the steps verbatim. The exercise is designed for a course which does not have an associated project, but has the majority of students enrolled in a co-requisite capstone design course.

The exercise sequence begins with teams selecting their artifact for inspection. The artifact is selected from those which are substantially complete as well as significantly important to the senior design project. Students are provided with guidance as to the desired size of the artifact based on the time allocated for the in lab review, as well as instructions indicating that, if necessary, it is acceptable to only review a subset of an artifact. Students are informed that the inspection meeting is planned for 50 minutes, and they should plan on approximately 60 minutes preparation time from their inspectors. Previously in

lecture students were provided with generally accepted rates for effective inspections [7], [8], [12].

At this point, teams are tasked with determining a team leader. The team leader is responsible for handling the coordination of the inspections with other classmates. Tasks given to the team leader include distributing the artifact to inspectors as well as moderating the inspection meeting. The team also selects one member to be an inspection scribe. The scribe is responsible for recording the defects encountered during the inspection meeting. Those who are not tasked with being either the team leader or the scribe are tasked with being inspectors for other teams.

After selecting the moderator and scribe, the team is responsible for “hiring” a set of inspectors. Depending on the class size and composition, each artifact will be inspected twice by two independent sets of inspectors. While at first selecting inspectors may appear to be a simple exercise, effective inspector selection involves significant analysis. Team members must think about which classmates have relevant technical experience or knowledge of the given product or technology. Team members also must deal with the fact that their desired inspectors may have already been “hired” by two other teams and thus are unavailable for the given inspection. To help in this step, students prepare a resume (properly sanitized to avoid FERPA issues) which is posted on the “hiring board” in the lab. Teams can use these resumes to screen potential inspectors during the “hiring process”.

B. Fault Injection

Once the inspectors have been hired, the teams are responsible for using fault injection to place faults in the inspection artifact. Since the assumption is that the initial artifact is a quality artifact, the goal is to ensure that there is something for the inspectors to find during their inspection. However, these injected defects also can be used to estimate the effectiveness of the overall inspection process. In some cases, teams will revert to a previous version of an artifact which had been corrected, while in other cases the team injects faults which are of a similar classification to those found during their own informal review process. The exact details of the type of faults to be injected as well as the number is left up to the teams aside from the suggestion that the faults be of varying difficulty to detect as well as somewhat evenly distributed throughout the artifact. Once the team has completed injecting faults into the inspection artifact, it is appropriately labeled as an inspection artifact and placed into their configuration management system.

The team leader then distributes the artifact to the inspectors. In nearly all cases, this has been accomplished electronically, though students are given the option of distributing a hard copy of their artifact. The team leader also distributes a set of instructions to the inspectors. The instructions indicate the scope of the inspection, any known defects which the inspectors should ignore, and a checklist that they should use for their individual preparation.

C. Individual Preparation

Once the inspectors receive the artifact from the team leader, they are tasked with preparing for the inspection meeting. In specific, inspectors are tasked with individually going through the artifact and recording the location, the type, the severity, and a short description of each discovered defect on a log form. The inspectors are also tasked with recording their preparation time. While inspectors are not specifically told how much time they should spend preparing for the inspection meeting, they have previously been lectured on the impact of inspection rate on inspection effectiveness.

As the inspectors complete their individual logs, they are responsible for submitting them to the instructor to verify their own preparedness for the meetings. Students are not graded based on the number of defects found or the correctness of the defects, as the instructor does not have appropriate knowledge to assess the correctness of the inspection results. Rather, the submission of the log is used simply to ensure that the student performed some preparation.

D. Inspection Meetings

During the following lab session, the inspectors will meet back with the team leader for the inspection meeting. During this meeting, the team leader will go through the artifact with the inspectors. Using their inspection logs as a guide, the inspectors will highlight the defects they uncovered. Discussion may occur as to the validity of the defect, the severity, or the categorization of the defect. Once the inspectors are in agreement, the scribe will log the defect on the inspection log. Additionally, the scribe will record which of the inspectors actually found the defect.

Once the inspection meeting is completed, the scribe will record metrics associated with the the inspection meeting. If time permits, the team leader and scribe will review the injected defects which were not found by the inspectors. This provides the inspectors with valuable feedback on the types of defects missed during individual preparation.

The instructor for the class attempts to visit each inspection meeting to act as an external auditor. This act is not intended to directly assess the students on their work, but rather, to ensure that they are following the guidelines for an effective inspection. The instructor specifically avoids answering technical questions related to the artifact. The instructor does, however, attempt to ensure that there are no hostilities toward the team leader or the inspectors.¹

The inspection meeting occurs twice with two independent sets of inspectors. By holding the inspection meeting twice, it provides the inspection leader with two chances to lead an inspection meeting, as well as the opportunity for each inspector to inspect two different artifacts. It also provides two data points which can be used for statistical measurement of the effectiveness of the inspection process.

¹It should be noted that the instructor for this course is actually not a stakeholder for the artifacts which are being inspected. The instructor for this course does not teach the capstone project course, and is entirely independent of any project assessment.

E. Post Inspection Analysis

Once the inspection meetings have been completed, the original team meets again in order to assess their artifact and the effectiveness of the inspection.

The teams are asked to assess how many of the injected defects were found during the inspection process. A high yield in this aspect can be considered to indicate that an effective inspection has occurred. A low yield in this aspect may indicate that there are problems with the inspection process. Using the injected defects and a capture-recapture approach [4], [7], students are asked to calculate approximately how many additional defects remain within the artifact.

Teams are then asked to compare the effectiveness of the two inspection meetings. In this analysis, students again use capture-recapture to estimate the number of remaining defects in the artifact by comparing the defects found in inspection meeting A and inspection meeting B. This calculation is completed twice, once with all defects being included and once with the injected defects being excluded from the calculations.

Teams are then asked to analyze the overall effectiveness of the inspection if only a single inspection meeting had occurred but certain inspectors had not participated. In doing this, the results of both inspection meetings are combined together into a single data set. Calculations are then performed on the data set with the defects found by the most effective inspector and / or the least effective inspector removed from the assessment.

As a last assessment, teams are asked to compare the inspectors' yield versus the individual preparation time reported by the inspectors. The goal is to attempt to detect trends in the preparation time and the resultant inspection yield amongst inspectors.

F. Lecture Review

Following the completion of the lab and after all students have completed their individual analysis and assessments, the instructor prepares summary lecture slides showing the pertinent trends from within the student data. While this summary information has varied from offering to offering, in general, it includes a cursory assessment of the overall effectiveness inspections as well as a demonstration of the relationship between preparation time and inspector yield. Both inspectors and leaders are encouraged during this lecture review to discuss with the class any observations that they had about the process and their findings.

III. STUDENT PERFORMANCE

A lab exercise such as this involves many aspects to be successful. Students have not previously used formal inspections, and they are inspecting an artifact with which they may not have extensive technical knowledge. This potentially makes in-depth student analysis difficult. However, with 5 years of data, certain trends can be analyzed.

A. Artifact Selection

The first question to ask is did the teams select an appropriate artifact to review in terms of size, complexity, and

TABLE I
ARTIFACT SELECTION BY TYPE

| Artifact Type | SRS | Software Design | Source Code |
|-------------------|-------|-----------------|-------------|
| Percent Selecting | 52.9% | 17.6% | 29.4% |

TABLE II
ARTIFACT SIZE AND INJECTION DETAILS

| | Artifact Size (Pages) | Injected Fault Count | Injected Density | Overall Density |
|---------|-----------------------|----------------------|------------------|-----------------|
| Average | 10.78 | 11.95 | 1.39 | 4.22 |
| Median | 10 | 10 | 1.3 | 3.58 |
| St. Dev | 5.73 | 6.29 | 0.76 | 2.21 |
| Max | 22 | 35 | 3 | 10 |
| Min | 3 | 7 | 0.32 | 1.74 |

scope. Table 1 provide a summary of the artifacts selected for review. In essence, the majority of students desired to inspect their Software Requirements Specification (SRS) artifact. This is most likely a product of where students are within their project. The timing of this course within the Capstone design sequence is such that the SRS artifact is usually complete and some design work has started. However, a significant percent of students choose source code as well, as they may be using a shorter cycle time on their project and may have portions of their code nearly completed. Software designs which have been selected typically involve UML class, state chart, and sequence diagrams with supporting narratives. It is usually found that the teams have not used any systematic review mechanisms in their own process.

Table 2 provides a summary of information relevant to the artifact selected. In essence, most teams select an artifact that is around 10 pages in length. To convert source code into page counts, the lines of code was divided by 40. Most teams also selected around 10 defects to inject into their artifact. 10 defects is large enough to provide a fair number of defects for analysis but is small enough to avoid skewing the results. The injected density shows how many defects were injected per page, and the overall density shows how many defects were detected during the inspection meeting. It should be noted that, in general, for each injected defect, there were three other unknown defects uncovered during the inspection, indicating that the artifacts may not have been as high of quality as the teams thought during artifact selection.

B. Individual preparation

The next risk to an exercise such as this one is the preparation of the students. In order for this exercise to be effective,

TABLE III
INSPECTOR INDIVIDUAL PREPARATION RATE

| | Preparation Time (Minutes) | Preparation Rate (Pages per hour) |
|---------|----------------------------|-----------------------------------|
| Average | 64.8 | 13.02 |
| Median | 60 | 10.43 |
| St. Dev | 40.95 | 11.60 |
| Max | 300 | 79.8 |
| Min | 5 | 1.86 |

the students must perform their own individual preparation in advance of the lab session. Being unprepared will result in an ineffective inspection.

Unfortunately, the analysis of student preparation time and review rates yields significantly more variability than would be desired. While the average and median results for preparation time and review rate are very close to that which would be desired based on accepted inspection rates, the variance in time spent is quite large. Some of this may be brought on by the fact that each inspector is assigned to inspect two different artifacts from two different teams, resulting in the first artifact being inspected “properly” and the second artifact being “rushed”. Some of this also may have come from the inexperience of the inspectors. Since they are not necessarily familiar with the domain or knowledgeable about the product, they may have felt that further time being spent may not have been productive. On the other extreme, some of the reviewers spent significantly more time than would be expected for an inspection of the given size. This also may be attributable to inexperience with the product and the domain.

Another explanation for the variability in this data is that it is student self reported data. It is very possible that the students did not keep accurate track of how much time they spent or how many interruptions in their work occurred. This may have resulted in the actual preparation time being significantly different than that which was reported.

C. Review Effectiveness

The most important metric for any formal inspection is the inspection yield. In essence, this metric indicates how many of the existing defects were found by a given inspector, and, as an overall metric, how many of the defects were found. Overall, the yield from a formal inspection varies from a low of approximately 20% yield to a high of approximately 75% yield based on training and experience level [9].

Table 4 provides an overall summary of the inspections yield for the conducted inspections. For each inspector and artifact, three calculations of yield have been made. The first calculation shows their yield versus the injected defects. In essence, a high yield for this value indicates that they were effective at finding the injected defects. The second calculation shows the individual inspectors yield versus all of the defects found in the artifact during the two inspection meetings. A high value here would indicate that an inspector was effective at finding most of the defects within the artifact. The last column calculates the inspector’s yield versus the estimated total number of defects within the artifact.

In general, the yields found within the exercise were lower than would be desired. However, because this represented the students first formal inspection, it is not unexpected that their individual performance would be lower than that of an experienced professional.

An interesting analysis that can be conducted from this data is to determine if the inspection yields were consistent between the injected defects and the overall review. A high correlation here would indicate that the inspectors were

TABLE IV
INSPECTION YIELD ASSESSMENT

| | Individual Injected Defect Yield | Overall Individual Yield | Overall Yield versus Total Estimate |
|---------|--|--------------------------------|---|
| Average | 0.404 | 0.348 | 0.297 |
| Median | 0.364 | 0.323 | 0.279 |
| St. Dev | 0.194 | 0.160 | 0.158 |
| Max | 0.857 | 0.758 | 0.710 |
| Min | 0.000 | 0.000 | 0.000 |

equally effective at finding injected defects as they were at finding general defects within the artifact. To determine if such a correlation existed, the total yield and injected yield for each inspector were plotted, yielding the plot shown in Figure 1. This plot indicated a general correlation between the two measures. This correlation was confirmed by calculating the Spearman Rank order correlation coefficient for the data set, $\rho_s = 0.6335$, $P = 0.000001$. From this analysis, it can be concluded that an inspector who did well at finding the injected defects also did well at finding the other defects within the artifact.

D. Individual Preparation Versus Yield

The next relationship that would be desirable to show is the relationship between preparation time and yield. Establishing this relationship would indicate that those who spent an adequate amount of time in their individual preparation were more effective at finding defects. It is also desirable to see if there is a correlation between the total yield and individual preparation given that the relationship between the injected yield and the overall yield. Based on industrial data [7] it is expected that those with a lower preparation rate would have a higher yield.

To prove this hypothesis, a Spearman Rank Correlation was calculated between the overall inspection yield and the preparation rate. This resulted in $\rho_s = -0.1956$, $P = 0.08591$, which indicates a weak negative relationship between the two items. These relationships match what would be expected in an industrial setting. While this relationship is somewhat weaker than would be ideally desired, this weakness can be accounted for by the students lack of experience with inspections and generally low yields due to inexperience. It is expected that this relationship would become stronger as overall yields increased with more experience.

IV. STUDENT ASSESSMENT

With any active learning exercise, an important question to ask is have the students gained an understanding of the activity, and do they feel that they have learned from the activity. As part of the course assessment, an exit survey is conducted which asks the students to assess the effectiveness of each lab activity conducted in the class. The majority of the survey uses a 5 point Likert Scale. The responses from three of the questions specifically relevant to this activity are given in Table 5. Note that while the exercise has been performed for five

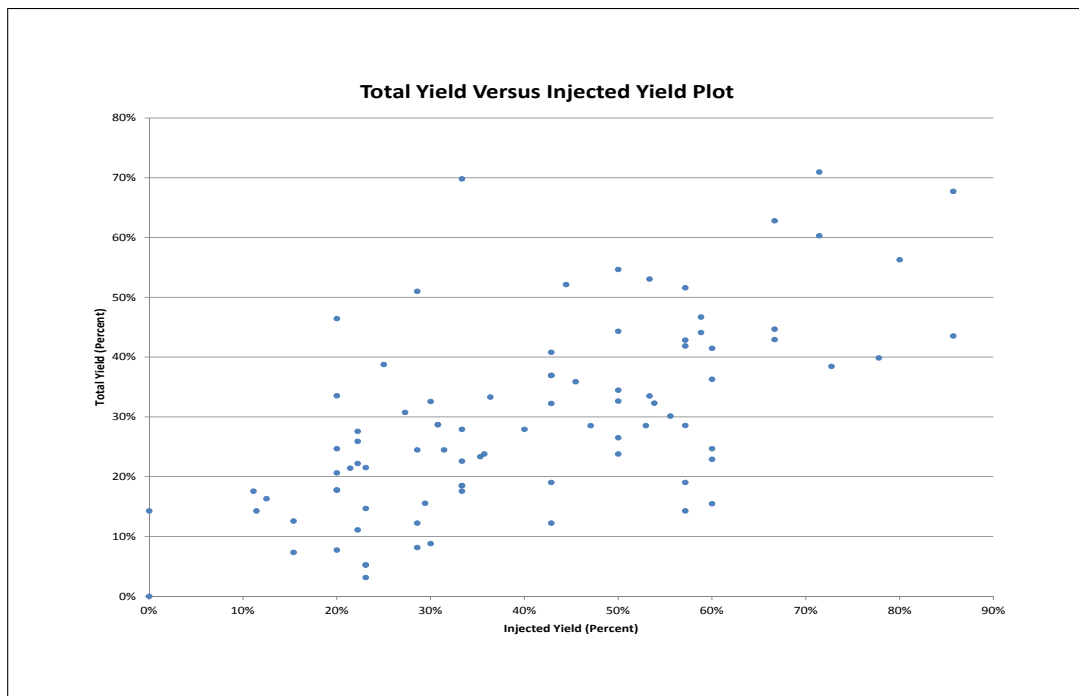


Fig. 1. Rank plot of total versus injected yield.

TABLE V
SUMMARY RESPONSES FROM LIKERT SURVEY

| Question | Offering 1 | | | Offering 2 | | |
|---|------------|-----------|------|------------|-----------|------|
| | \bar{x} | \hat{x} | s | \bar{x} | \hat{x} | s |
| I learned a lot from this lab. | 4.29 | 4 | 0.78 | 4.00 | 4 | 0.78 |
| This lab helped me in my senior design project. | 3.95 | 4 | 1.02 | 3.75 | 4 | 1.03 |
| This lab should be continued for future students. | 4.52 | 5 | 0.60 | 4.25 | 4 | 0.60 |

years, these particular questions have only been specifically asked in the past two years.

In essence, 84.8% of students either “Agreed” or “Strongly Agreed” with the notion that they learned a lot from this lab. Of all survey responses, only two people “Disagreed” with this statement, and no one “Strongly Disagreed”. Similar results were also found for the statement “This Lab should be continued for future students”, where in fact, 93.4% of students either “Agreed” or “Strongly Agreed” with the statement. In essence, this set of responses indicates that the students felt this active learning exercise was beneficial to them and would continue to offer a benefit to future students.

Student response was less supportive to the statement “This lab helped me in my senior design project.” While a secondary intent of the assignment was to provide a mutualistic relationship with the co-requisite senior design sequence, this relationship was not as strong as it could have been for all teams. Part of this may stem from a problem selecting inspectors. Due to the diverse nature of the capstone design

projects, finding inspectors with adequate knowledge proved difficult for some teams. On rare cases, inspectors were not very effective, and this may have influenced teams to feel that the activity was not beneficial to their project. That being said, 64.7% of participants felt that this activity did help with their senior design project.

While the quantitative assessment provides an indication that this activity was successful, further understating of the students thoughts about the assignment can be derived from the student comments written within the lab reports and course assessment forms. For course assessment forms, 75% of students provided meaningful written commentary related to this project. Table 6 provides selected comments related to this lab from the end of the course evaluation forms. It should be noted that the comments have not been edited to remove negative comments; there simply have not been any significantly negative comments within the course assessment surveys.

Another area of assessment for the effectiveness of the lab was in the student lab reports. As part of the activity, all teams submitted written lab reports including a “things gone right” and “things gone wrong” write-up where students were tasked with critiquing the lab and suggesting future improvements. In reviewing these write-ups, the majority of the students identified that their current review processes had failed to catch problems within their artifacts. They also supported the idea of independent inspectors looking at their artifact. Another common thread was a realization of the fallibility of their own inspection skills. While many students seemed to feel that the defects they injected were obvious, the significant number of inspectors that missed the defects demonstrated that this may

TABLE VI
SAMPLE COURSE EVALUATION COMMENTS

| |
|---|
| Most of the issues found in our review were irrelevant. There was not enough shared knowledge between students to have useful results. |
| We made process improvements in our project as a result of this lab. |
| The formal inspection (& the statistics calculations) helped formalize our peer review process. |
| Useful statistics |
| Using actual projects for the lab was the best part of the class. |
| The Formal Inspection was the best part of the class. |
| Helped to identify issues, but didn't use process afterwards to review future artifacts. Distributions of documents was not streamlined well. |
| It found a lot of useful bugs and suggestions for my senior design project. |
| My reviewers weren't very good. |
| Very useful lab and study. |
| I learned a lot from this lab. |
| (The best part of this class was) incorporating real documents from senior design and SDL into lab activities. |
| We got real experience with real projects, and the errors found improved the documentation of our project. |

TABLE VII
SAMPLE LAB REPORT COMMENTS

| |
|---|
| We have discovered that our current review process is inadequate to discover all of the defects within our artifacts. |
| This lab really showed the importance of reviews and what they can accomplish. While we only injected 7 defects (and 4 of our 5 reviewers found all 7) there were plenty more defects that we didn't find and they did find. |
| We learned quite a bit from this lab activity. We found that our own reviews didn't go as expected, since there were a lot of spelling errors in the document. |
| This experience, of doing a code review the correct way and parsing statistics out of it, was very good. |
| Overall, we found the process of doing reviewing and discussing to be an effective use of time. |
| The injected defects showed us a lot. Only three of the nine injected defects were found. This made us not very confident in the reviews that were performed on our documents. |
| Quality was improved, and we gained experience with the software review process. |
| We have concluded that the capture-recapture method of inspection along with injected defects is an effective way to analyze quality. Our results suggest that we should not use a single reviewer, no matter how effective he/she may be, but use teams of reviewers instead. ... We have determined that this method of reviewing is much more effective and helpful than a regular code/document review. |
| The formal inspection (and the statistical calculations) helped to formalize our peer review process. |
| This lab has provided us with not only general knowledge about increasing software quality through effective reviews, but we have also come out with a helpful product for our senior design project. The input gathered from our peers has already been put to good use in our project. |
| We also learned a bit about each of our effectiveness's during the lab activity. |
| In addition to lessons learned about review activities, we also benefited from a review of a document that we may not have realized contained as many defects as it did. |
| In regards to the inspection of our team's artifact, we were able to find a major bug that was overlooked. |
| The performance of our peers was somewhat surprising; it was lower than expected. This was their first time participating in a formal inspection, however; it can be postulated that with practice their effectiveness will improve. |
| In conclusion we learned that Fagan inspections can be very effective in estimating the total number of defects in a document. We also learned that having outside inspectors review our artifacts helps to find defects that our senior design team was unable to find in our own inspections. |

not be true. Other reports commented on how important it was to review the injected defects that they missed in order to improve their own inspection skills.

V. CONCLUSION

This article has discussed an active learning exercise developed to teach students the advantages and disadvantages of formal inspection of software artifacts. From this exercise, students gain the skills necessary to critique the effectiveness of formal inspections, as well as insight into their own capabilities and limitations. Students view the exercise favorably and demonstrate comprehension of the exercise objectives.

While the lab activity offers many benefits to students, there are potential improvements. One idea involves making this the second part of a two exercise sequence. The first exercise would involve all students inspecting the same artifact. This would give students practice with a standard artifact that can be tailored to their skill level before inspecting a random artifact, improving the yield. A second idea involves the addition of auditing roles. An auditing role would provide students with the opportunity to critique teams adherence to the inspection process.

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Work in Progress: Sustainable Projects for Software Engineering Courses

Collaborating with Technology Courses

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Abstract—Teaching Software Engineering (SE) based on “real-world” projects engages students with practical application of software engineering concepts—students develop a deeper interest in the project deliverables while they acquire the skills of critically analyzing the problem and determining the best course of action. It can be challenging to find and maintain a reliable stream of suitable software projects that match learning outcomes, technical scope, and academic calendar of an SE class. On the other hand, a typical university campus has many non-Computer Science (CS) technology classes that require their students to study, understand, and evaluate existing software applications in specific areas. With purposeful coordination, these non-CS technology classes can serve as effective source of real projects for SE classes. This paper describes our experience of collaborating with the Education Program in their Technology in Education course. While we encountered some challenges, our experience has demonstrated that it is indeed mutually beneficial and rewarding for students in both courses. We offer recommendations on choosing non-CS technology classes and logistical guidelines to ensure the success of such collaborations.

Keywords—software engineering education; education

I. INTRODUCTION

Integrating “realistic” projects in Computer Science (CS) classes increases student engagement while strengthening student learning outcomes [1, 2, 3]. However, as pointed out by many (e.g., [3, 4, 5]), coordination and logistic arrangements for external “real-world” projects can be demanding. Establishing and maintaining relationships to ensure a healthy supply of such projects can be difficult and in the absence of systematic institutional support (e.g., office of Service Learning), faculty often must be “courageous” [1]. On the other hand, the key characteristics of “realistic project” that motivate students are not the demanding “relationships”; rather, the key characteristics are the actual clients and “real-world” problems [6, 7, 8]. With these observations, instead of looking externally outside the university, many educators search internally for opportunities for collaboration, and design classes with less

logistically demanding projects. In the case of Software Engineering (SE) classes, video games [9], or even other CS classes [10], have been used as “real-world contexts” for teaching the involved concepts. A natural continuation of this “internal approach for real-world project” is to explore the possibilities of integrating projects from non-CS classes into an SE class. Such integration will be advantageous for CS students: working with real clients who may not have CS expertise or knowledge, yet having real demands for CS skills.

At the University of Washington, Bothell, interdisciplinary collaboration is encouraged, as evidenced by the establishment of the Collaboratory, an on-campus facility where faculty and students from various disciplines can collaborate on research or course projects. In one of the Collaboratory planning meetings, we discussed the possibility of having the Master’s Prep SE students work with the Master’s Education students. The SE students were tasked with developing software that can help the Education students with the technical aspects of their pedagogical assignments (i.e., collecting data on the web and visualizing the data). The Education students in turn would act as a customer for the SE students. As the students interact with each other, we intended that the SE students could also answer any technical questions that the Education students may have, thus making the interaction mutually beneficial to students in both courses (see Figure 1).

The Technology in Education course featured in this work is a course for pre-service and in-service teachers currently working on a Master of Education degree. The course is designed for teachers of any subject at the K-16 level to explore ways to use emerging technologies to enhance classroom instruction. Students in this class may have a traditional teacher education background or may be career-changers from multiple disciplines who are seeking a teaching certificate. The students taking the Technology in Education class have a wide range of abilities both in personal use of technology as well as application of technology in Education.

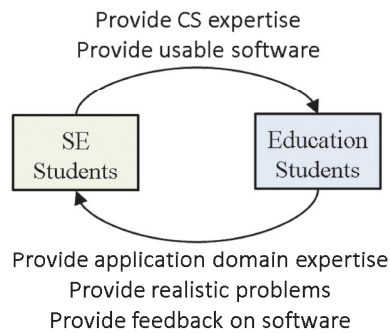


Figure 1. Mutually beneficial interaction between SE and Education students

Our SE class is a typical Junior/Senior-level class that covers traditional topics such as software development life cycle (SDLC) models, requirements analysis, design, implementation, quality assurance, and process improvement [11]. The class is organized based on projects to maximize student engagement [12]. In the previous offerings students worked individually on projects they proposed while they worked in groups on other class activities.

One of the main goals of the SE course in collaborating with the Education course was to give the students the opportunity to apply the concepts they learned to a project with real customers. Thus, the students were tasked to perform software lifecycle activities in the context of their projects. The collaboration was designed to help students acquire skills in interacting with their customers and teammates, managing and prioritizing requirements, and incorporating existing software into the system they are tasked to develop.

This paper describes our experience of collaborating with the Education Program in their Technology in Education course. The paper begins with a survey of existing efforts in bringing real-world projects into SE classes. Section 3 covers the backgrounds of the involved classes, discussing the logistic arrangements, project and team coordination. Section 4 presents student project deliverables. Section 5 provides an evaluation of the course collaboration and Section 6 elaborates on guidelines and recommendations.

II. BACKGROUND

Using real-world software projects as contexts is effective in engaging students with learning abstract CS concepts [1, 2, 3]. This is especially the case for SE, where the discipline itself is the study of software development process. A real-world software development project can naturally serve as practical context for topics covered in an SE class.

Many educators in SE seek real-world projects for teaching their classes either via direct collaboration with industry partners (e.g., [13, 14, 8]), or working with community partners through Academic Service Learning format (e.g., [3, 15]). These kinds of collaboration generate excellent projects for SE classes because the customers are knowledgeable in the problem domain, are genuinely concerned with the outcome of the project, and the projects themselves are usually based on

real problems that require custom solution design and hands-on implementations. An additional benefit of these real-world projects is that the scope usually dictates team work which helps students develop interpersonal and communication skills [7].

Before projects from external to the institution can proceed, it is important to communicate and align class learning outcome requirements with customers' priorities. The students should be coached about industry culture and professionalism while the customers must appreciate students' course workload, understand the needs for assessments and support academic-oriented evaluations, and most importantly the customer must develop a realistic expectation [3, 14]. On the faculty side, it is essential to work with external partners to develop projects with proper scope of work that align well with academic calendar. For all the above reasons, it is a significant challenge to identify potential partners, and the partnership requires careful nurturing and maintenance [3, 4, 5].

The key engaging factors of "real-world" projects are the real customers and the real problems [8]. It has been noted that there are many potential benefits for such projects coming from within the institution [10, 7]. There has been approaches that integrate SE with other CS classes. For example, Fenwick and Kurtz interfaced a lower level data structure class, a human-computer interface class, and a database class with their SE class [10]. The students from the different classes worked together to simulate a real-world project, with the SE students acting as project managers and dictating the specifics of lifecycle activities such as requirements, design, testing, and management. Tvedt et. al. further integrated SE into CS curriculum where students are required to take eight semester sequence of Software Factory courses to assume the different roles (e.g. tester, designer) in software development process [12].

The main advantages of projects from within the institution are the similar cultural background, simpler logistics requirements (e.g., academic calendar, expectations, assessment requirements), and long-term sustainability. The main shortcomings of using CS classes for projects and CS students as customers are that the problem domain is closely related to SE and that the customers are often highly knowledgeable and fluent in CS concepts. These issues can be avoided if the projects and customers are from classes that are completely unrelated to CS. We have observed no reported attempts of collaboration between SE and classes from outside of CS discipline.

III. OUR COURSES

A. The Education Class

In the Technology in Education course, students, who are all teachers, learn how to use emerging dynamic visualization software to create interactive visualizations related to their subject area that can then be used in their classrooms. This particular class focused on Google motion charts and Tableau software as their two primary software sources.

In order to implement their projects, the Education students also had to find appropriate data sets to import into the software in order to create the visualization. This task proved to be their biggest hurdle and the one which required the most assistance from the SE students. Once the students found an appropriate data set, the SE students helped them extract and/or organize the data in the correct format for the software program they were using. To facilitate this task, SE students wrote or configured software to convert the data to the appropriate form.

The characteristics of the Education class were suitable for the SE class. First, the students are well-advanced in their fields (e.g, students are teachers). Second, there is a well-defined task that the Education students needed to perform. Finally, there is a recognized need by the Education students that SE students can fill. These characteristics will be discussed in detail in Section 5.

B. The Experiment Setup

We planned to have our classes meet at the same time in the Collaboratory. This setup allows meetings with the customer, the Education students, to be built-in to the class meeting times. Due to logistical reasons, our classes were not scheduled at the same time. As a result, the students had to meet outside of class times, or the SE students would meet the Education students during their class times. For the SE students, more meetings with the customer were necessary at the beginning of the quarter in order for them to gather customer requirements.

A group of SE students (2-5 students each group) was teamed up with a group of Education students. Having more than one customer for each team was a good setup because some of the customers later became unable to continue meeting with SE students. For the teams that did continue to have more than one customer, it was an added challenge for the SE students to learn how to find a common set of functionalities that caters to all their customers. Since the Education students were free to choose the type of data and the type of visualization they wish to create, they have different requirements for the SE students.

For the SE course, assessment included an exam and deliverables for each milestone such as requirements document, design document, test document, and working software. Deadlines of milestone deliverables were flexible, but final delivery of software was fixed.

For the Education course, assessment included four visualization tools packaged with curriculum questions to use in a K-16 classroom, a final project paper, and a reflection on the collaboration process.

Before the end of the quarter, the SE students delivered the software to the Education students. The Education students then performed trial usage of the software. Overall, the Education students were happy with the software they received, with some of the students even taking the software to use in their classrooms.

The expected gains for the Education students as well as the CSS students included an opportunity to work with a group of people from outside their subject area and experience a true trans-disciplinary collaboration similar to what happens in the

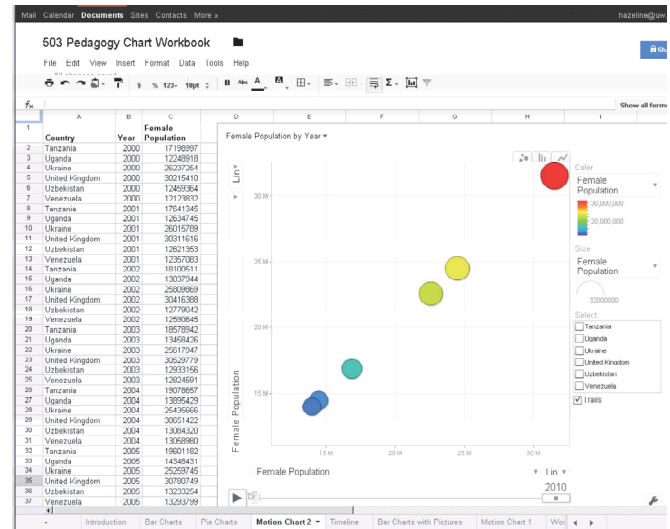


Figure 2. Pedagogy Chart Workbook Template allows users to simply enter data and the charts are automatically updated.

real world. The Education students would gain experience in articulating their projects to people from other disciplines who were unfamiliar with the software they were using and the pedagogical applications of that software. The CSS students would gain experience in responding to clients, having to listen to their needs, and finding appropriate solutions.

IV. RESULTS

The SE students gained the following skills while working on this project: communicating with customers, managing requirements, interacting with their teammates, and creating a software program either from scratch or with existing third-party tools. The SE students also learned a new language or development platform on their own.

The SE students also learned how to cater to the requirements of a customer or multiple customers, for some SE groups. Consequently, students learned to analyze, prioritize, and manage requirements. Having the students work with real customers also helped them realize the challenges of eliciting requirements from non-technical users. Requirements elicitation can be considered one of the most crucial activities in software development. Without a proper understanding of customer requirements, the likelihood of project failure increases [6]. In addition, customers and users often do not know exactly what they want. Thus, it is the task of the developers to help customers determine what they need [16].

The SE students were also given the option of developing the software from scratch, developing the software with third-party tools, or configuring an existing software to be used by the users. An industry project often involves reusing existing software; being able to incorporate existing software into software under development is a necessary skill [17].

The software projects produced by the students include DataGrabber, Pedagogy Chart Workbook Template, and VizTool File Prep. DataGrabber is an Excel add-in that allows users to extract data from a webpage, a text file, or a

spreadsheet and to import the data into an Excel spreadsheet. The Pedagogy Chart Workbook Template provides pre-configured spreadsheets where educators can simply enter data and the charts/graphs are automatically updated. The Template also allows users to enter data that is automatically fed into Google Motion Chart, as shown in Figure 2. The VizTool File Prep allows users to extract data from multiple PDF files, formats them into the Open Doors Data format (specified by customer), and saves the data into a text file (see Figure 3).

Students in the Education course enjoyed working with the CS students. Initially there was frustration due to their inability to communicate. Education students could not articulate their requirements because of the language barrier and because they did not know what was possible from the CS students. They felt that the CS students were not responsive to what they needed at first, but that through an iterative process were able to overcome the communication barrier to appreciate the “value-added” that the CS students gave to the project.

Although our results are based on more mature students with real-life working experience, we expect the results to be transferable to a *typical* undergraduate SE class. Our graduate students, not from CS background, are typically more experienced, but less fluent with existing technology, e.g., slower to learn new technologies or application programming interfaces (API). Though typical undergraduate students may lack life experience and maturity, they are savvier with current software technology, and have the advantage of being better prepared and having more familiarity with recent programming techniques.

V. EVALUATION

A key measure of success is whether the SE students were able to deliver software that was useful to the Education students. At the end of the quarter, all the Education students were happy with the software provided by the SE students because it conformed to their requirements—automating the extraction of data or visualization of data.

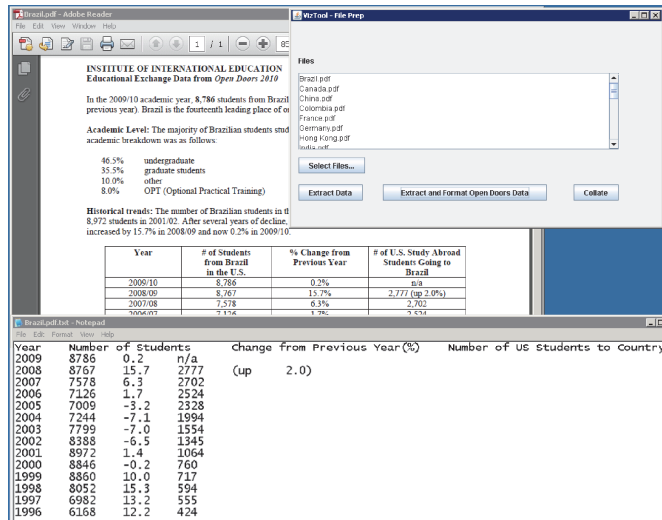


Figure 3. VizTool File Prep extracts data from pdf files (shown in the background) and saves the data into a text file (bottom).

In the course of our collaboration, we encountered three main challenges: scheduling, language barrier, and time constraints. We now discuss these challenges in detail.

The first challenge is scheduling in terms of student meetings and synchronizing the assignments. Since we were not able to have the two courses meet at the same time, the SE students met with their customers outside of class times, which was a problem for some of the students since they were working full time. To work around this issue, only one representative of the group was required to meet with the customer. Outside the class meetings were also identified as a problem in [7], but the difficulties occurred within the teams, not with the customer. The SE students did not have issues with team meetings because the class met twice a week in the evenings and students often stayed after class to conduct team meetings.

It was also important to ensure that the class assignments between the two courses are synchronized. Since it took the SE students a bit of time to understand the requirements for the software, the SE students were not able to support the Education students for their first deliverable. They were, however, able to support them in their final project deliverable, which was due at the end of the quarter.

Language barrier was another key challenge we faced. The SE and Education students had difficulties communicating with each other since both groups lacked the understanding of technical terms used by the other group. It was also difficult for the Education students to express the functionality they needed and it was difficult for the SE students to elicit requirements. This difficulty, however, is not unique in this setting. There are industry software projects where developers lack the understanding of the domain of application—which can sometimes be costly [18]. One of the key skills a software engineer must have is the ability to interact with experts from other domains [19].

For the SE class, there was the additional challenge of time constraint. The course was only ten weeks long and the students were required to perform an entire software lifecycle which includes requirements, design, implementation, and testing. In this context, the requirements phase took longer than expected. Thus, the other phases had to be shortened.

VI. GUIDELINES AND RECOMMENDATIONS

We now offer logistical guidelines for course collaborations and recommendations for selecting a technical course that satisfies SE project requirements.

Guideline 1: Schedule the two courses at the same time. It would be optimal to have the classes co-located in one room. If not, the classrooms should be closely located to each other so that students can easily meet each other.

Guideline 2: Minimize the language barrier by briefing students with background information regarding the other course. We suggest having all students meet in one room with both professors on the first day of class. This will allow instructors to address issues and questions before the students collaborate with each other. It will also enable students to

build community and rapport with each other. This allows collaborators to build a level of understanding of group members in an informal way either before they formally start as a project team or concurrently.

Guideline 3: Explore ways to address the time constraint. Both the SE and Education courses were limited to one quarter (ten weeks). Because of this time constraint, it is important that students understand the requirements quickly so that they have time to analyze the problem and develop the software. This could potentially be achieved by minimizing the language barrier between the two classes. Another possible approach is to allow the SE students to select which software development lifecycle (SDLC) method to use, as long as the delivered software is acceptable to the customers.

For the Education students, even though they understood their course assignments, the major time barrier was in trying to determine what the SE students could actually do for them that they could not do themselves. Teachers tend to work in isolation, in individual classrooms, so when they need something done they are conditioned to reasoning it out and doing it themselves. It was a major hurdle for them to even determine what the CS students could do for them and then articulate that in a way that the CS student could understand. This created a roadblock for the CS students and they were not able to help the Education students with their first deliverable.

The following are our recommendations for choosing non-CS technology classes:

1. The non-CS students are in the advanced courses in their major (i.e., students are at least junior standing in their major). This will ensure that they have a good understanding of their field (i.e. they know the tasks they need to perform, the processes or procedures in their area) so that they can identify their requirements for a software tool.

2. The projects or assignments of non-CS students require custom technology. For example, technologies that are currently available do not exactly meet the requirements of the non-CS students (i.e. students still need to perform time-consuming manual steps). These opportunities will allow SE students to be creative on how they can develop a software tool to meet the customer requirements.

3. Software developed by the SE students will be used by the non-CS students in their project deliverables and the course schedule should allow for this integration. With this structure, both the SE and non-CS students will have an interest ensuring that the software project succeeds. As a backup, the non-CS students may also use an existing technology in the event that SE students are not able to deliver the software.

4. The deliverables of the non-CS students is multi-part (or graduated) to allow SE students the time to understand the requirements at the beginning of the course. For example, the project of non-CS students may be in three parts:

Part 1: Project deliverable uses an existing technology. Prior to this deliverable, SE students will gather requirements by observing how the customer interacts with existing software and by asking the customer's opinion of the software.

Part 2: Project deliverable uses another existing technology and/or uses the first version of software developed by SE students. Prior to this deliverable, SE students will solicit feedback on their software with regards to problems encountered or new features.

Part 3: Project deliverable uses 2nd or final version of software developed by SE students. Prior to this deliverable, SE students have performed various software tests (integration tests, usability tests, acceptance tests).

Non-CS students can then compare how the software developed by SE students, with their guidance in the design, is an improvement over existing software for their task.

VII. CONCLUSION

We took the approach of collaborating with the Education course because it would provide SE students the opportunity to apply software engineering concepts to a realistic project while minimizing the overhead in project coordination. We initially encountered several challenges such as scheduling, language barrier, and time constraints. Students from each class were also unsure of how to collaborate with each other. The Education students felt unsure of the capabilities of the SE students. The SE students also felt unsure of the requirements for the software they will deliver. Over time, the students in both classes overcame the language barrier. At the end of the course, students from both classes were happy with the results. Education students felt more confident in their abilities both in terms of technology and interdisciplinary collaboration. SE students also liked the idea of working with real-life customers. Based on this collaboration, we offered logistical guidelines and recommendations to faculty who may wish to take a similar approach in teaching SE courses.

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Work in Progress: Transitioning From Novice to Expert Software Engineers Through Design Patterns: Is It Really Working?

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Abstract— Since their wide adoption by the software engineering community in the mid-90's, design patterns have become an important educational component in the training of novice software engineers due to the common belief that, as distilled experience of seasoned software designers, they can transform novice software engineers into skilled professionals in a relatively short time frame. This paper questions the validity of this commonly-held belief about the educational value of conventional patterns, arguing that although there is tremendous value in capturing and disseminating software engineering experience in the form of patterns, conventional design patterns cannot deliver on this expectation to significantly shorten the experience growth curve. We report initial results from an ongoing research project that aims to not only identify the difficulties in using conventional patterns as educational means for novices, but also to use such insights to develop new forms of patterns to help educators and experts to more effectively communicate and transfer their software engineering knowledge, experience, and understanding of best practices to novices.

Keywords- *Software Engineering Education; Design Patterns;*

I. INTRODUCTION

Since their wide adoption in the mid-90's, design patterns [1] have become an important component in the education of novice software engineers; they have entered software engineering text books and are discussed and taught as part of various courses such as software architecture and design, software engineering, as well as courses on programming and software development. Design patterns are recurring software design problems along with their solutions, which are captured and documented in a reusable format. Since design patterns capture the design experience of seasoned software engineers, they are believed to help novice software engineers to become professionals in a shorter time frame. In other words, the underlying claim about the educational value of design patterns is that instead of taking the natural and lengthy route to becoming an experienced software designer through trial and error over many years, one can study design patterns that capture the essence of expert design knowledge and as a consequence become experienced in a significantly shorter amount of time. The common belief is that, after all, design patterns are supposed to help inexperienced software engineers to come up with the same design models as experts, without much need to gain experience over a long period of time. This paper questions the validity of this commonly-held belief about the educational value of conventional patterns, arguing that although there is tremendous value in capturing

and disseminating software engineering experience in the form of patterns, conventional design patterns cannot make novice software engineers perform at the level of experienced software professionals in a short period of time. In this paper, we will argue that design patterns do not replace design experience; in fact, paradoxically as it may seem, one must be experienced to correctly identify opportunities for the application of patterns and implement them appropriately. Based on our observations, we provide an explanation as to why this is the case and accordingly propose criteria for alternatives forms of software patterns to make expert software design knowledge more accessible to beginning software engineers. This paper reports on an ongoing project that aims to improve software engineering education by understanding how expert software engineering knowledge can be made more accessible to novice software engineers.

II. OBSERVATIONS AND ANECDOTAL EVIDENCE

Our observations of software engineering students, who learn about design patterns as part of their program courses, are that a great majority of these students, when asked to apply the patterns they have learned to their course projects, misuse design patterns. This misuse of patterns takes various forms, perhaps the most notorious being the application of a pattern to a design problem that does not warrant the use of that particular design pattern. That is, a design pattern is forced, as a solution, to a design problem, for which the pattern was not originally intended as a potential solution. The ill-definedness of design problems in typical software engineering contexts, on the one hand, and the imprecision in the specification of the problem and the context components of a pattern, on the other hand, make the objective and correct recognition of opportunities for the application of a pattern a great cognitive challenge, especially for inexperienced software engineers. This inexactitude in distinguishing when, a chunk of software engineering knowledge, codified experience, or best practice, represented as a pattern, is the right solution to a software engineering problem is not peculiar to novices as we have seen numerous examples of applications of patterns in industrial software projects to problems to which they do not offer a solution, resulting in an unnecessary increase in the complexity of the system and consequently software comprehension and maintenance problems. Unfortunately, in software engineering, in the absence of hard physical laws, it is always possible to produce numerous functionally-correct solutions to a problem, most of which are deficient in several

ways in terms of non-functional aspects of the solution including its understandability and the maintainability.

III. PROJECT STATUS, RESULTS, AND EXPECTED OUTCOMES

An underlying premise of this current research project is that, in order to address the above-mentioned problem with software engineering education, we must shift our research focus in the direction of investigating effective ways to more accurately specify both software engineering problems and the patterns that are intended to provide reusable solutions to these problems. In technical terms, the goal is to find a *match* function or operation that, given a problem and a list of predefined solutions (e.g., a catalog of patterns), accurately determines whether the conditions that warrant the application of a pattern (i.e., the problem description component of a pattern) match those of a given problem. It is precisely the complexity of the cognitive match operation that confronts the beginning software engineer. To make the cognitive match operation for a pattern accurately possible, we need to rethink how we specify software engineering problems and patterns.

Our research project draws on both theoretical and empirical software engineering research to address this problem. On the theoretical side, our goal is to develop a formal foundation for the specification of software problems and their corresponding patterns. Formal specification can be a fruitful avenue of research to address the problem as the observation is that the informal and inaccurate definition of problems and patterns make them subject to individual interpretations, which, in turn, makes it difficult to achieve an objective mental match operation on the part of the software engineer. Our work in formalizing the specifications of software engineering problems and patterns has resulted in two formalisms, namely the Problem Decomposition Scheme (PDS) [2] and Systematic Translation Scheme (STS) [3]. The former formalism provides a way to accurately and objectively classify software problems into requirements categories or problem dimensions, while the latter links each problem category to a set of design regularities [4] that form a predefined solution, resulting in a form of pattern known as traceability patterns [5][6]. Design patterns are, for the most part, meant to address non-functional problems such as extendibility and maintainability. An accurate characterization and definition of such non-functional concerns, due to their abstract and somewhat vague nature, is difficult to achieve. Design patterns, in effect, attempt to link from such non-functional problems to a predefined solution and are consequently subject to difficulties arising from the lack of accurate problem definitions. In contrast, traceability patterns link a category of functional problems, such as business rules category of requirements in enterprise information systems, to a predefined solution. Initial results from a previous study shows that functional problems, when stated as atomic requirements statements, can be objectively recognized [2]. This suggests the hypothesis that, software engineering knowledge, represented as traceability patterns, should be easier for novice software engineers to consume. We plan to test this hypothesis as part of our ongoing research effort.

Traceability patterns aim to solve some of the issues associated with conventional patterns through tracing problem dimensions that can be objectively recognized to their corresponding predefined solutions. This predefined solution contains the wisdom we try to transfer to the software engineer. This capability to objectively and consistently recognize problems that have predefined solutions, without much reliance on experience on the part of the software engineer, makes traceability patterns a more appropriate educational tool for software engineers, at least for novices. To enrich the theoretical foundation underlying traceability patterns, we are currently investigating the use of ontologies [7][8][9][10][11] and domain models as a formal means to capture and communicate software engineering knowledge.

On the empirical side, we have conducted a user study to empirically verify whether indeed software problem defined in PDS-based functional specifications are objectively recognizable by software engineers (i.e., is an accurate mental match operation possible?). Initial results have been reported in [2] and are promising. The technical feasibility of traceability patterns in software projects has been demonstrated in a proof of concept system [5][6]. We plan to further evaluate traceability patterns by putting them into practical use in industrial software projects. We expect that these efforts will positively impact educational outcomes for software engineers. We also expect that results from our project will be of importance to the software engineering education community as they will afford us the knowledge and insight necessary to devise better approaches to bridge the gap between novice and skilled software engineers.

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A Snapshot of Current Languages Used in Industry

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Abstract— We provide results from a nationwide survey of advertisements for jobs in the technology sector. This snapshot of 521 job postings provides an interesting glimpse into the state of the computing industry in the U.S., quantifying the programming languages most frequently requested by employers today. This study reveals industry preference for Java and C++ skills. C++ is requested most frequently in the South Atlantic Region and was also favored on the west coast. Additionally, SQL skills were more requested for positions related to testing, JSP skills were more requested in architect positions, and both C and C++ were more requested in analyst positions. While academic practices should not be based solely on industry practice, industry demand for languages serves as one useful data point when institutions make pedagogical choices.

Keywords—computer science education; languages; curriculum; industry

I. INTRODUCTION

In 2010, the first U.S. national survey of programming languages and practices used in introductory Computer Science courses in colleges and universities was conducted [1]. The survey showed that Java was the most frequently taught language in both CS1 and CS2 courses. One reason often cited by educators for languages choice in a particular course is industry demand [3,4] but few resources exist to quantify the industry demand. Our study provides a current data point about language popularity and also provides more specifics about the correlation of language popularity to other variables such as geographic region and job classification.

Trends in language use nationally as well as regionally are examined. Additionally we report on trends seen for various job categories. While academic practices should not be based solely on industry practice, industry use of languages does provide an important consideration for institutions to consider when making pedagogical choices. Comparing the data based on geographic regions and job categories can potentially allow faculty to consider the data in a more meaningful way for their institution and the students that they serve.

II. BACKGROUND

Several past studies have reported on language prevalence in industry. In 2002, a national survey of languages used by industry in Australia was conducted. Educators sampled employment advertisements in the IT section of The Australian newspaper and recorded the languages mentioned

for programmer positions. It was found that the average advertisement required 1.84 languages, that 48% of jobs required more than one language, and the most popular languages were C++ and Java (30% each)[2]. TIOBE Software conducts ongoing surveys of programming language popularity by tracking the number of hits when querying popular web sites such as Google, Blogger, Wikipedia, YouTube, Yahoo!, Bing, and Baidu. The results as of August 2011 show Java as the most widely used language (19%), followed by C (17%) and C++ (8%)[5]. As reported by TIOBE, these three languages have maintained the same popularity for the last 12 months.

These previous works provide interesting data about language choice, but fail to correlate the languages required to common programming jobs and also do not report on regional differences in language prevalence within the U.S. This study provides a current data point about language popularity and also provides more specifics about the correlation of language popularity to other variables such as geographic region and job title.

III. PROCEDURE AND METHODS

We gathered computer science related job advertisements from online newspapers for major U.S. cities from the various geographic regions of the country, specifically: Silicon Valley, California; Seattle, Washington; District of Columbia; Denver, Colorado; New York City, New York and Detroit, Michigan. We also included other major newspapers and geographically dependent publications to get a balance of geographic regions. The online job search engines associated with the newspapers used are shown in Table 2.

The data was gathered every fourth day from January 29, 2011 until August 8, 2011. We gathered fifteen different job advertisements each day until April 2011, half using the keyword “programmer” and the other half using the keywords “computer science”. Additional data was collected during the summer months. Jobs that had no reference to requested language or experience in language were discarded, otherwise, every third entry was manually parsed into the following; date, keyword used, language, job title, location and URL. If the job was already entered with the alternative keyword (programmer or computer science), the job was discarded and the next job in the list was entered.

After collecting and parsing the data set we categorized the jobs by the regions and divisions listed in each job description. We used the US Census Regions and Divisions as shown in Table 1 [6].

TABLE I. U.S. CENSUS DEFINED GEOGRAPHIC REGIONS

| US Census Regions | | | |
|--|---|---|--------------------------------------|
| Region 1: Northeast | Region 2:Midwest | Region 3:South | Region 4:West |
| 104 jobs | 100 jobs | 162 jobs | 155 jobs |
| Division 1: New England (44 jobs) | Division 3: East North Central (57 jobs) | Division 5: South Atlantic (83 jobs) | Division 8: Mountain (57 jobs) |
| Division 2: Mid- Atlantic (60 jobs) | Division 4: West North Central (43 jobs) | Division 6: East South Central (36 jobs) | Division 9: Pacific (98 jobs) |
| | | Division 7: West South Central (43 jobs) | |

IV. RESULTS

We collected data on a total of 521 job postings over an eight-month period. These postings appeared in a variety of sources, from geographically dependent publications (e.g., Maine Today) to national job boards (e.g., dice.com.) The number of ads represented from each source is depicted in Table 2.

TABLE II. SOURCES FOR JOB ADS

| Source | Number of Postings Used |
|---------------------|-------------------------|
| Washington Post | 67 |
| Dice.com | 58 |
| Nytimes.monster.com | 56 |
| Denver Post | 55 |
| SJ Mercury News | 54 |
| Detroit Free Press | 47 |
| Seattle Times | 45 |

| Source | Number of Postings Used |
|-------------------------|-------------------------|
| Minnesota Star | 24 |
| Boston.com | 23 |
| Job hunt | 23 |
| Tennessean | 17 |
| News OK | 16 |
| Careerbuilder.com | 14 |
| Maine Today | 12 |
| Lexington Herald-Leader | 10 |

For simplicity, we use the most conservative "universal" margin of error in computing the confidence interval for all languages, using 0.5 as the sample proportion \hat{p} . We assume an infinite population, and use 521 for the sample size, which gives us a (conservative) margin of error of

$$1.98 \times \sqrt{\frac{\hat{p} \times (1-\hat{p})}{n}} \pm 4.29\%.$$

(1)

A. Overall Language Prevalence

Table 2 and Figure 1 depict the overall prevalence of the most popular languages and technologies, in terms of the total percentage of all sample job ads containing that language. Java was mentioned most often, but this is (just) within the margin of error, and so we consider Java, C++, SQL, and C# in a virtual tie. C, presumably used mostly in operating systems and embedded applications, still has a very strong showing despite its age. Note that many of the Web-only languages and technologies (PHP, ASP, Ajax, etc.) are much less frequently requested overall than the mainstream application development languages, although the number of different choices here makes the overall Web contribution still quite significant. Python, despite its popularity in academic circles, is still far from mainstream in industry.

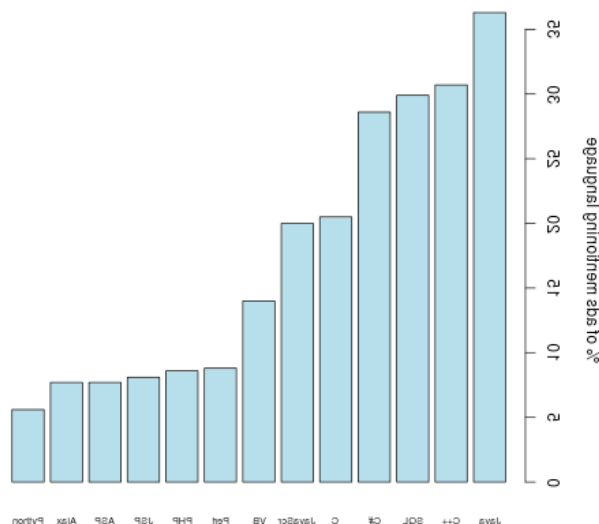


Figure 1. Percentage of all sample job ads that mentioned certain languages. (Only languages that appeared in at least 20 of 521 job ads are shown.) Note that most job ads mention more than one language, so the total is much greater than 100%.

B. Results by Job Title

We attempted to gain insight into how language use varies among workers with particular job functions. A typical software development effort involves not only programmers but also architects, analysts, testing and QA, and support staff. How do the languages advertised correlate with these sets of responsibilities?

It is difficult to get a precise measure because postings are highly variable in the language they use to describe job positions. One company advertises for a "software developer" and another for a "programmer." Are these essentially the same? Does "software engineer" imply programming, or is it a broader term encompassing other aspects of the development process? "Programmer/analyst" is a common catchphrase; so are "programmer" and "analyst" still different descriptions?

Although the data is thus a bit dirty, we still believe there is value in ferreting out some of these subtleties. We defined five broad categories of job positions -- architect, analyst, programmer, tester, and miscellaneous -- and used the following decision procedure to classify each ad:

1. If the word "test" or "tester" appeared in the job title, it was classified as a **tester** position (even if other indicative words appeared; see below.)
2. If "development," "developer," or "programmer" were in the title, it was classified as **programmer**.

Note that this is true even for the numerous "programmer/analyst" descriptors, since we reasoned that such positions would involve writing substantial project code.

3. If "analyst," "engineer," or "researcher" were in the title, it was classified as **analyst** (except as indicated above.)
4. If "architect" or "designer" were in the title, it was classified as **architect**.
5. Finally, if none of the above rules applied, the ad was classified as **miscellaneous**.

The totals for each job classification are presented in Table 3.

TABLE III. NUMBER OF ADS CLASSIFIED IN VARIOUS BROAD JOB CATEGORIES.

| Job Classification | Number | Percentage |
|--------------------|--------|------------|
| Architect | 41 | 7.9% |
| Analyst | 120 | 23.0% |
| Programmer | 288 | 55.3% |
| Tester | 46 | 8.8% |
| Miscellaneous | 26 | 5.0% |

To detect correlations between job classifications and language prevalence, we used a χ^2 test for each popular language with α set conservatively to .01 (instead of .05) to compensate for the total number of tests being so large. Even with α so low, there were still a large number of languages whose null hypothesis was rejected. To cross-check and further refine the results, we examined the job classification's standardized (adjusted) Pearson residuals for each language whose χ^2 test was positive. Only if at least one residual had an absolute value greater than 2.5 (meaning that its observed value was more than 2.5 standard deviations away from its expected value) do we include it in the list of significant results as shown in Table 4.

TABLE IV. SIGNIFICANT CORRELATIONS BETWEEN LANGUAGE PREVALENCE AND JOB CLASSIFICATION. RESULTS ARE SHOWN IN THE TABLE ONLY FOR LANGUAGE/CLASSIFICATION PAIRS WHOSE χ^2 TEST HAD $P < .01$ AND A STANDARDIZED (ADJUSTED) PEARSON RESIDUAL WHOSE ABSOLUTE VALUE WAS GREATER THAN 2.5.

| Language | More prevalent among | Less prevalent among | Overall Percentage |
|----------|--------------------------------------|----------------------|--------------------|
| C | Analysts (29.2%) Misc (42.3%) | Programmers (16.3%) | 20.5% |

| Language | More prevalent among | Less prevalent among | Overall Percentage |
|----------|----------------------|----------------------|--------------------|
| C++ | Analyst (47.5%) | Testers (10.9%) | 30.7% |
| VB | Programmers (19.8%) | | 14.0% |
| JSP | Architects (31.7%) | | 8.1% |
| SQL | Testers (45.7%) | Analysts (19.2%) | 30.0% |
| PL/SQL | Misc (11.5%) | | 2.1% |
| Ruby | Misc (15.4%) | Programmers (0.7%) | 2.5% |

Several tentative observations can be surmised from these results. SQL is prominently demanded for tester positions, perhaps indicating that managing a suite of test cases, and implementing scenarios to test an application's edge cases, frequently involve database skills in today's software processes. JSP appears far more often in ads for architects/designers than anything else, which may be a signal that the majority of "programming" work in a typical J2EE Web application is actually done in Java libraries rather than JSPs or servlets themselves, which are the realm of architects and designers. Ruby and PL/SQL, two languages that appear very rarely in the overall data set, are actually fairly frequent among miscellaneous ads. This may indicate that these languages are rarely used in product implementation, but can be important tools employed by "utility players" on the support staff.

Interestingly, the term "programmer" appears to be used more often to describe (perhaps) developers of high-level end user applications, as evidenced by the prevalence of Visual Basic requested for those job titles. "Analyst," on the other hand, correlates more often with C and C++ development, and less with database interfaces, perhaps indicating lower-level infrastructure.

C. Results by Geographic Region

Our sample job postings obviously contained information about the physical location of the job opportunities, so it is interesting to explore whether there are overall geographic trends. Following the above reasoning, we again used a χ^2 test with $\alpha=0.01$ for each language, and identified standardized Pearson residuals greater than 2.5 for specific region or division.

The results reveal some dramatic differences between different parts of the country. For one, the South Atlantic region (stretching from Delaware down to Florida) is a hotbed of C/C++ development, far more than most other areas of the country. This area features the Research Triangle Park in North Carolina, the Florida High Tech Corridor, and Virginia's strong Department of Defense presence. It is possible that sites like these have influenced projects to adopt proven, reliable, natively compiled, and fast implementation languages. C++ is also very strong on the west coast, which may be surprising to those who associate that region with Web applications and rapid prototyping. By contrast, the C language -- while still retaining an important niche throughout most of the country -- has nearly disappeared from the northeast region, especially New England where it is largely absent.

The most atypical region overall is the midwest, and particularly the East North Central division of Illinois, Indiana, Michigan, Ohio, and Wisconsin. This area has been hit as hard as any other by the recent economic downturn, and hence its economy is distinctive in many ways. Perhaps this has had some influence in driving high-tech project decisions away from the national norm. In any event, this region is currently strongly focused on Microsoft environments like VB and ASP, and only rarely searches for C++ developers. The prevalence of Visual Basic is also very noticeable in the neighboring East South Central region of Alabama, Kentucky, Tennessee, and Mississippi.

Note that Java, the programming language most heavily sought after overall, did not appear in any of the correlations in this section or the previous one. It is strong and well-represented in all sectors, and can almost be considered the lingua franca of the high-tech world.

TABLE V. SIGNIFICANT CORRELATIONS BETWEEN LANGUAGE PREVALENCE AND GEOGRAPHIC REGION. RESULTS ARE SHOWN IN THE TABLE ONLY FOR LANGUAGE/REGION OR LANGUAGE/DIVISION PAIRS WHOSE χ^2 TEST HAD $P<.01$ AND A STANDARDIZED (ADJUSTED) PEARSON RESIDUAL WHOSE ABSOLUTE VALUE WAS GREATER THAN 2.5.

| Language | More prevalent among | Less prevalent among | Overall Percentage |
|----------|--|--|--------------------|
| C | South Atlantic (31.3%) | NE (7.7%), especially New England (4.5%) | 20.5% |
| C++ | West (41.9%) Especially Pacific (46.9%) also South Atlantic (45.8%) | Midwest (16.0%) especially East North Central (12.3%) | 30.7% |

| Language | More prevalent among | Less prevalent among | Overall Percent age |
|----------|---|----------------------|---------------------|
| VB | East North Central (31.6%) and East South Central (38.9%) | | 14.0% |
| ASP | East North Central (17.5%) | | 7.7% |

D. Co-occurrence of languages

Finally, it is of interest to consider which languages often appear together in the same job ad. To do this, we use the Phi coefficient ϕ to measure statistical significance of co-occurrence. $\phi \times \sqrt{N}$ gives a distribution that is approximately standard normal, in which positive values indicate positive correlations. It is a more accurate measure of correlation than a simple count of co-occurrences would be since it adjusts for the overall frequency of appearance of each language by itself. Following our previous benchmark, we consider values whose $\phi \times \sqrt{N} \geq 2.5$ (that is, more than 2.5 standard deviations from its expected value) to be significant. The results are shown in Table 6.

As can be seen, C and C++ are by far the most tightly correlated languages, appearing together in 87 ads, which works out to a phi statistic over 12 standard deviations higher than the expected mean. Many of these co-occurring languages are not surprising (for instance, JavaScript is a necessary component of Ajax, and Java of JSP, while VB and C# are two of the most common CLI languages used in ASP.)

One bit of insight can be gleaned by observing that Perl frequently occurs with a number of different languages, probably indicating that it serves a utility role in many development teams, complementing a main implementation language. It is also perhaps surprising that C++ and Java co-occur so frequently, since they are often seen as implementation alternatives. On the other hand, the pairing may simply represent an industry preference for object-oriented language experience, rather than a specific language. The same could be said for C++ and Python. This could be an indicator of multi-language projects that include both a low-level, performance-driven component in addition to a user interface that benefits from a virtual machine's features. Clearly, there are numerous job opportunities that require developers to have experience with both.

TABLE VI. SIGNIFICANT CO-OCCURRENCES OF LANGUAGES. THE "FREQUENCY" COLUMN GIVES THE TOTAL NUMBER OF TIMES THE TWO LANGUAGES WERE MENTIONED IN THE SAME JOB AD (OUT OF 521 ADS), AND

THE " $\phi \times \sqrt{N} \geq 2.5$ " COLUMN GIVES AN APPROXIMATE STANDARD NORMALLY DISTRIBUTED STATISTIC INDICATING THE STRENGTH OF THE CO-OCCURRENCE. LANGUAGE PAIRS WHOSE PHI STATISTIC IS GREATER THAN 2.5 ARE SHOWN.

| Language 1 | Language 2 | Frequency | $\phi \times \sqrt{N}$ |
|------------|------------|-----------|------------------------|
| C | C++ | 87 | 12.78 |
| JavaScript | Ajax | 29 | 8.67 |
| Python | Perl | 15 | 8.45 |
| Java | JSP | 36 | 6.85 |
| VB | ASP | 20 | 6.85 |
| VB | C# | 44 | 6.39 |
| PHP | JavaScript | 25 | 6.16 |
| ASP | C# | 27 | 5.71 |
| SQL | PHP | 28 | 5.02 |
| PHP | Ajax | 11 | 4.34 |
| Java | Perl | 28 | 3.65 |
| C++ | Java | 74 | 3.20 |
| C++ | Python | 16 | 2.97 |
| C++ | Perl | 23 | 2.97 |
| C | Perl | 16 | 2.51 |

V. CONCLUSION

As many institutions report that popularity of a language in industry is one item taken into consideration when a language is selected for classroom instruction, it is interesting and useful to compare the industry results to those of the previously conducted national survey of languages used in introductory programming courses [1]. Table 7 compares the top 4 languages mentioned in job ads to the same languages' reported use in CS1 ad CS2. In both studies, languages could be selected multiple times, *i.e.* an institution may have indicated that some sections of CS1 used Java and some sections used C++ and similarly a job ad may have mentioned multiple languages. As a result the percentages do not sum to 100% in either study.

TABLE VII. COMPARISON OF LANGUAGE PREVALENCE IN INDUSTRY AND EDUCATION.

| Language | Industry job ads mentioning | CS1 | CS2 |
|----------|-----------------------------|-------|-------|
| Java | 36.3% | 48.2% | 55.8% |
| C++ | 30.7% | 28.8% | 36.1% |

| Language | Industry job ads mentioning | CS1 | CS2 |
|----------|-----------------------------|------|------|
| SQL | 29.9% | N/A | N/A |
| C# | 28.6% | 1.9% | 1.6% |

As can be seen, C# is often requested in industry job ads but seldom taught in CS1 and CS2 courses. Java and C++ are frequently requested by industry and frequently taught in CS1 and CS2. SQL is rarely if ever taught in introductory programming courses. The previous study referenced did not collect data about languages used in upper level or elective courses, so it unclear whether students typically receive experience in SQL as part of their undergraduate education. Given the relative frequency in which job ads mention multiple languages, it is interesting to observe that in the previous study approximately 50% of institutions reported teaching the same language in CS1 and CS2. Additionally we observe that 63% of CS1 and CS2 courses used only object-oriented languages, while in industry, languages supporting a range of paradigms are used. Again, it is possible that institutions are teaching these alternate paradigms in upper level courses, which were not included in the previous survey [1].

As a final note, we remark that it may be beneficial to the computer science education community to develop a practice

of collecting data about language use in industry and education, as this can provide a practical consideration as we develop curriculum for the future.

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Work in Progress: Modeling Employer Assessments

Using Professionalism in Computer Science Courses

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Abstract—This paper outlines a grading system designed to replicate a manager’s perception of an employee’s reputation which starts out high and sinks with the employee’s unprofessional behavior. By modeling this perception, our program has begun to increase the number of seniors who can successfully complete their capstone projects on time. This program stands out from other similar attempts increase consistent effort and conscientiousness because it increases the impact of unprofessional behaviors on a student’s overall grade. Results from the senior capstone course inspired the use of professionalism grades in our freshman lab courses as a way to help students understand how the demands of college are different from the demands of high school and to help them take responsibility for their academic success. **Keywords**—*professionalism; senior capstone; CSI*

I. BACKGROUND

There is consensus that teaching professionalism should be part of all computer science curricula as evidenced by its inclusion as a core topic in the ACM’s 2008 Curriculum Update [1]. That standard defines professionalism to include “care, attention and discipline, fiduciary responsibility, and mentoring.” The 2008 Update is an interim revision of the 2001 standard [2] that specifies that aspects of professionalism should be addressed in introductory and intermediate courses and as part of a senior capstone experience. Fuller et al. [3] acknowledge that assessment of professionalism requires different techniques than assessing computer science content in the curriculum. In fact, their work reveals a “lack of alignment between learning outcomes and assessment practice in the area of professionalism.” They advocate for addressing “students’ lack of commitment to good engineering principles” by specifically evaluating that commitment through the use of self, peer, and instructor assessment of affective characteristics including professional attitudes and values.

There are a number of existing strategies for assessing professionalism in students. Clark [4] runs a team project course in which professionalism is assessed three ways: the instructor evaluates the team’s professionalism, the team’s customer assesses their professionalism three times throughout the project, and, finally, self and peer evaluations are completed four times in the semester. All of these assessments are combined and become 10% of the student’s grade. Sabin [4] runs a similar course with similar levels of assessment (self and peer, instructor, customer, and external evaluator). These assessments were weighted and combined as 12% of the course grade. In general, when characteristics related to professionalism are directly assessed and given as feedback to

students, the grading strategy is to use that assessment as a small portion (5-15%) of the final grade.

II. MOTIVATION

A. Professionalism in the Senior Capstone Course

In recent years, we detected a trend developing in the capstone course: a significant minority of students was unable to successfully complete the course and graduate on time. As an isolated incident, this might have been dismissed; however, this pattern repeated itself for several years running and seemed resistant to incremental changes made to the course.

The core of this problem does not appear to be in the technical skills of our students. Instead, most projects failed because students did not pursue them consistently throughout the term. As one student said, “April seemed so far away in January.” During this trend, only the standard grading strategies for assessing the professionalism of the student were used. Specifically, up to 10% of a student’s grade resulted from status reports and meeting commitments.

B. Professionalism in CSI Labs

In AY 2011, we added a freshmen seminar that was designed to help our students develop the general survival skills needed to transition from high school to college. This course was an ideal place to include a professionalism component to the grade. By grading the professionalism of the freshmen, we helped reinforce the expectations of college classes and prepare them for what was to come in their senior capstone.

III. MODELLING EMPLOYER ASSESSMENT WITH A PROFESSIONALISM GRADE

Based on discussions with members of the department’s Industrial Advisory Council, an employer’s overall perception of an employee’s professionalism has two main characteristics. First, it starts high and generally goes down, requiring a dramatic event or a long period of time to raise it. Second, unprofessional behavior taints the perception of the quality of the employee’s work. We wanted to model how professionalism affects perceptions of quality, so final grades are calculated based on two major grades, the professionalism grade and the quality grade. The quality grade is the traditional portion of the grade; it starts at 0% and builds up over the course of the semester based on the student’s deliverables. The professionalism grade starts at 100% and can only go down; when a student fails to perform in a professional way, her professionalism grade is reduced. The final grade the student

receives is the *product* of the quality and professionalism grades. If the quality grade is on a border, a small reduction in professionalism can lower the letter grade, and, even if the quality is perfect, the maximum grade that the student can achieve is the professionalism grade.

This was a radical shift in grading scheme, and so every effort was made to make this change clear to students. The syllabus spelled out the grading scheme and explained what behaviors were considered unprofessional and what the consequences of such behavior were (*i.e.* -5% professionalism for an unexcused absence). On the first day of class, the slide presentation that covered the syllabus used music and arresting imagery to grab student attention. After the syllabus was discussed, students were asked to sign an agreement stating that they understood the grading policy and the effects of not passing the course. Finally, the grade sheet was posted on the course website that tracked the professionalism grade and the quality grade and showed the estimated final grade. Daily updates to the grade sheet gave students real time feedback on how their professionalism influenced their final grade.

IV. PROFESSIONALISM FOR SENIORS

The Shippensburg University Computer Science program requires an individual senior capstone project that is completed in two semesters. The first semester includes content on research methods and requires the student to complete a literature summary and to plan and propose a project. In the second semester, students implement and complete their projects.

Students who graduate from our program should be ready for the workplace or graduate school. Failing to complete the senior research project delays graduation by a year. We set two goals for the most recent revision of the course. First, we wanted to reduce the number of course failures and incompletes. Second, if failure seemed likely, we wanted to make that clear to the student as early as possible.

V. PROFESSIONALISM FOR FRESHMEN

We used the professionalism grading scheme to help students quickly understand differences between the expectations of high school and college. In AY 2011, the 4-credit CS1 course was restructured to accommodate a first year seminar for computer science majors, packaging conceptual material into a traditional 3-credit lecture and adding a small-sized 1-credit lab focusing on active learning material. The labs met for three continuous hours a week with two hours dedicated to lab exercises and a third hour nicknamed “boot camp”.

The boot camp material addresses the “soft skills” that our freshmen lack and helps students develop a graduation plan. In AY 2011, topics included: professionalism, new skill acquisition, time management, study skills, and awareness of campus resources [6].

In order to accommodate for the fact that this was the first semester for most students, a small change was made to the professionalism grade: there were a few opportunities for students to earn back professionalism points. These opportunities involved pursuing the seminar topics above and

beyond the required assignments, and they were always focused on improving a student’s college skills.

The overarching goal of the boot camp for computer science majors was to help them understand and adjust quickly to the expectations of the program. Professionalism was used to help students develop good self-management habits.

VI. RESULTS

A. Senior Capstone Results

Table 1 shows the grade distribution for the second semester of Sr. Research since AY 2007. Failing and incomplete grades are presented as a single group to control for changes in course policies. The professionalism component of the grade was instituted in AY 2010. Of necessity, this study has a small sample, making it difficult to draw statistically significant conclusions from the results; however, the initial results are promising. The same instructor has taught the course from AY 2009 through AY 2011. The academic content has been the same throughout that period.

Table 1: Grade Distributions for the 2nd Capstone Semester

| | A | B | C | D | F / I | Total Students |
|----------------|-----|-----|-----|----|-------|----------------|
| AY 2007 | 18% | 36% | 5% | 9% | 32% | 22 |
| AY 2008 | 50% | 14% | 7% | 0% | 29% | 14 |
| AY 2009 | 12% | 35% | 12% | 0% | 42% | 26 |
| AY 2010 | 60% | 12% | 0% | 0% | 28% | 25 |
| AY 2011 | 55% | 22% | 4% | 4% | 17% | 23 |

AY 2010 and 2011 show improvement over the previous years. The AY 2008 class was significantly smaller than the other years, and so it is difficult to know how well the AY 2010 numbers really compare with that year. Table 1 also shows that there was a significant increase in the number of As and Bs starting in AY 2010, but it is difficult to identify the source of this change as opportunities to earn extra credit were also included in the grading policy. The extra credit may account for higher passing grades in AY 2010 and AY 2011, but extra credit could not be used to save a student from failing; therefore, the evidence suggests that the lower number of Fs and Incompletes was due to the professionalism grading scheme.

B. CS1 Results

The long-term goals of the changes we made to CS1 include increased retention and early voluntary attrition. While it is not the intention of the department to “weed out” students, it is important that students settle on a major as soon as possible to maximize their chances for long-term success. Both long-term goals will be measured over the next several years to assess the impact of the first year seminar.

The effect of the professionalism grading system on CS1 lab grades was noticeable, but not catastrophic; no student lost more than one letter grade as a result of professionalism. We will continue to monitor the attrition and success rates of students who have passed CS1 as they move towards graduation. Currently, there is no clear impact on CS2 grades.

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// TODO: Help Students Improve Commenting Practices

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Abstract—One implicit purpose of writing software code is to communicate ideas. Commenting source code helps explain these ideas and provides background on the semantics of a program. Yet, enabling students to acquire good commenting practices remains difficult. Instructors can find it hard to meaningfully discuss such practices in both introductory and advanced undergraduate courses. Furthermore, comment *grading* is an imprecise, labor-intensive procedure at best. But just what practices should we be encouraging students to emulate?

To help address these issues (learning about professional code commenting patterns and best practices, objectively grading student comments), we developed the *COMTOR* tool as an open source project and web service. *COMTOR* provides a platform for helping assess source code documentation in an objective, structured fashion. We conducted two experiments using *COMTOR*: one that examines a set of popular open-source Java code projects and one that measures a baseline of student-generated code comments. The latter are based on three semesters worth of data from two different undergraduate courses.

Our aim is to extract knowledge about the state of professional practice in source code comments and how these properties vary over the lifetime of a project. We can then begin to make recommendations and communicate best practices (or a lack thereof) to our students.

I. INTRODUCTION

For students, the process of documenting software is unlike almost any other activity in the traditional Computer Science undergraduate experience. The act of writing high quality source code comments requires developing skills in clear, concise technical writing and applying these skills in concert with a deep understanding of both the practical and theoretical underpinnings of a code modules and subroutines. Although the design of algorithms and the use of a programming language to encode them does require clear, disciplined, and creative thinking, mathematical rigor almost always constrains the expression of a solution. At the very least, this expression is restricted to a language with unambiguous semantics and highly structured syntax.

In contrast, source code comments offer a freedom of expression that students can struggle to make full use of. Source code comments can help describe a wide array of software properties at a variety of abstraction levels. For example, comments might indicate what the code can or should do, what the history of a function or module is, what the properties of certain data structures are, what error or failure modes the code might have, what the implications of a particular implementation trick are, any external interactions,

and assumptions the programmer may have made. Unfortunately, teaching undergraduates to write good documentation — particularly source code comments — presents an imposing challenge for two tightly coupled reasons.

Learning Challenges From a learning perspective, students can find it difficult to create good documentation because they believe that the code is ultimately more important than the prose explaining it, and they can struggle to gain an understanding of how such a construct might be evaluated by their instructors, peers, or employer. Early programming courses reinforce this attitude because assignments tend to focus on basic ideas and first principles, and students (naturally) focus more on learning the syntax of a language.

Evaluation Challenges Since comments possess a more free-form nature than most constructs in traditional programming languages, the process of grading or evaluating this type of documentation requires a significant amount of *manual* effort (despite the existence of schemes like Javadoc [1]–[3]). Due to the freedom that students have in expressing themselves and the reluctance of many students to spend time on writing documentation (a goal that they can easily — and understandably — view as secondary to constructing a working solution), actually assessing comments can present a monumental task for faculty, teaching assistants, tutors, and graders, especially when dealing with large class sizes or extensive assignments.

As a result, many grading efforts rely on only a cursory examination of the presence or absence of certain key commenting practices (even if in-depth assessment is conducted, the inherently manual nature of such activity almost ensures that any such in-depth assessment is unsustainable beyond a few exercises). Furthermore, almost no general tools exist for helping students vet the quality of their own comments as a form of active learning [4] — bringing us full circle back to the learning challenge listed above.

A. Motivation

Comments supply an ongoing conversation between multiple developers (or even a single developer over a period of time) by explaining the logic expressed in the code itself. Comments are often the most immediately intelligible part of a module's source to a non-developer or other non-technical audience. As such, they serve an important role in the design, maintenance, and use of software programs [5]. **But how can**

we teach students to adopt and nurture practices and skills that lead to the production of high quality software documentation? From our experiences as Computer Science educators and the anecdotal evidence of our colleagues, we observe that this major need of students and their future employers is not being met.

B. Contributions

Although many faculty members and software engineers might argue that commenting is important, such skills are rarely mature in undergraduates. One way to support their skill development in this area is to provide them with tools for assessing the quality of the comments they write. We believe that comments and other documentation serve a vital role in helping students engage with the practice of design and continuous evaluation of their software.

We built an automated analysis tool called COMTOR (Com^{ment} Men^{TOR}). COMTOR helps to observe the evolution of commenting practices across versions of a single project and across projects. Applying COMTOR to both student baseline code (i.e., code that students write for assignments and labs in the absence of any specific training for code commenting best practices) and to professional open-source code can help show how wide the “gap” between industry and academia is on this topic. Analysis of code using COMTOR is one way to help students nurture good habits by getting them to buy into evaluating their own code and making them a partner in the process by giving them control over a feedback process.

II. THE COMTOR SYSTEM

The primary mode of operation of COMTOR is aimed at gathering and summarizing properties of source code comments. COMTOR was designed to process source code through a pipeline of analysis and reporting modules. We chose to focus on analyzing comments in Java source code because it serves as a relatively common language for use in undergraduate programming courses, and it provides the Javadoc [1], [3] convention for structuring comments and automatically producing API documentation. We benefit from the flexibility of the Javadoc interface by building some of our analysis modules on Javadoc’s facilities for adding new tags and other comment constructs. We used COMTOR as a command line tool for the experiments this paper describes.

COMTOR currently includes these analysis modules:

- 1) *Check for Tags* (relies on the presence of Javadoc-style comment tags [1]) – Searches the submitted source code to evaluate whether all user-defined methods contain the correct use of three core Javadoc tags (*@return*, *@param*, and *@throws*).
- 2) *Percentage Methods* – Measures the percentage of methods in a class that are documented with a Javadoc header; in essence, this module measures the “density” of commented code.

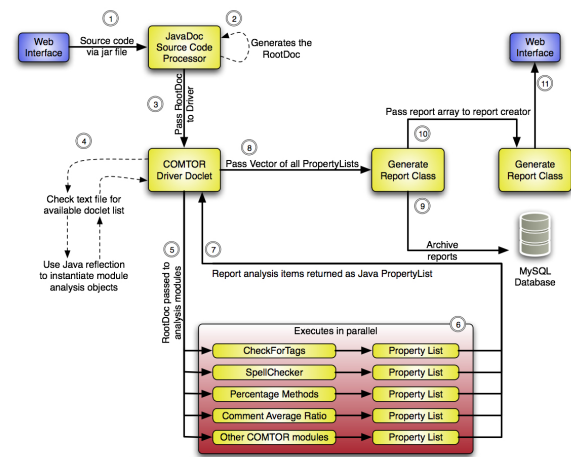


Fig. 1. *The COMTOR Architecture*. COMTOR can be driven by the command line or as part of a web service. Its main mode of operation is to take a collection of packages and source files, run them through a series of specialized doclets, and gather the output of each module.

- 3) *Comment Average Ratio* – Calculates the length of documentation (in number of words) for all the methods in a given class, and computes the average.
- 4) *Spell Checking* – The spelling of the words present in source code comments is checked against a modified version of the Linux words file as well as other dictionaries and word collections. This module automatically incorporates symbols like method, variables, and class-names.
- 5) *Offensive Words* – Checks comment bodies for the presence of potentially offensive words and phrases.
- 6) *Check Author* – Profile the use and presence of the *@author* Javadoc tag.
- 7) *Pre- and Post- Conditions* – COMTOR defines custom *@pre* and *@post* tags.

Although many of these modules report on relatively simple measures of comment properties, we believe that they provide an objective basis for evaluating the quality of comments as a whole. Indeed, we seek to provide a range of reporting on many different features of comments: some dealing with the quality of the actual prose and others dealing with how well the comment describes the source code features associated with it. While some modules are simplistic in nature, they help to automate the process of a basic sanity check for grading purposes – a widely appealing prospect to a number of faculty doing this work currently “*by hand*.”

III. APPROACH

The main line of argument in this paper is that we as educators need to do a better job of teaching students professional code commenting and documentation tactics and strategy — but we need a real-world basis for our recommendations. So what do “real world” code commenting practices look like?

Our best approximation is by looking at large, popular, widely-used open source projects.

This section describes our research methodology and provides an overview of our experiments. The current focus is twofold: (1) evaluating student code to get a sense of the “gap” and (2) observing properties of established open-source code. Although we are currently using COMTOR in the classroom to assess its impact on student commenting practices, those latter experiments are ongoing and not ready to be reported.

A. Student Baseline Code Experiment

We first use COMTOR on three semester’s worth of student code from two different introductory computer science courses. This student data was collected under conditions that were not influenced by the presence of COMTOR; in other words, students and instructors had no knowledge of COMTOR and received no special guidance or encouragement to alter their standard commenting or teaching practices. This data is purely historical data from the past few years.

We gathered this data to serve as a baseline for comparison with similar courses that *did* use COMTOR and to give us an idea of the kinds of commenting practices communicated to students early in the computer science undergraduate course sequence. This paper focuses on this latter purpose. We measured an Introduction to Programming course and a Data Structures course; raw results are shown in Table I.

| # of: | CSC 220 | CSC 230 |
|-------------------|---------|---------|
| Students | 43 | 29 |
| Projects | 561 | 299 |
| Classes | 1395 | 951 |
| Constructors | 1460 | 1074 |
| Methods | 11599 | 4688 |
| Fields | 7168 | 3043 |
| Commented methods | 2170 | 2794 |
| Correct spellings | 15808 | 17233 |
| Mispelled words | 899 | 717 |
| Offensive words | 0 | 0 |

TABLE I

Using COMTOR on Student Baseline Code. AN OVERVIEW OF RUNNING COMTOR ON BASELINE DATA: CODE FROM STUDENT PROJECTS AND ASSIGNMENTS IN WHICH STUDENTS DID NOT USE COMTOR AND WERE NOT EXPOSED TO ANY FORMAL COMMENTING BEST PRACTICES.

CSC 220 (Introduction to Programming) has nearly double the students and projects, slightly more classes, double the number of fields, and three times the number of methods as CSC 230 (Data Structures). Nevertheless, the number of methods commented is relatively the same. CSC 230 students commented methods at a rate of about 50% while CSC 220 students commented less than 20% of the methods they wrote. Most methods were lacking Javadoc-style tags. Overall, these numbers and results are a stark illustration of the gap between what we think students should learn and what they pay attention to: for a skill that is not routinely tested or evaluated, students simply do not put effort into it, and this trend persists across multiple courses and semesters.

B. Jakarta Experiment Overview

We next seek to derive some characteristics of professional source code documentation to inform best practices and recommendations to students. Focusing on such code helps us calibrate our expectations about the types of properties and comment quality we can expect COMTOR to pick up on, in turn helping us to summarize and convey commenting practices in the real world to our students.

We used COMTOR to assess a large amount of existing open source Java code from the Apache Jakarta project (specifically: POI, Oro, Maven, Tomcat, and Ant). These projects represent a variety of software: a format parsing framework (POI), a regular expression library (Oro), a network server and execution container (Tomcat), a build management tool (Maven), and a tool and scripting platform that performs software builds (Ant). This experiment observed how comment properties vary both within (i.e., from early to current versions of a single software application) and across (i.e., between different projects) this software collection.

The goal of this experiment is to provide an independent calibration of COMTOR on non-student code and to help us derive an assessment of existing best practices and pressures on commenting practice in real-world code. *Even though we use relatively simple metrics, automated assessment of even simple features provides value because it helps scale an otherwise a manual task.*

| Version | # classes | # constructors | # methods | # fields |
|---------|-----------|----------------|-----------|----------|
| 4.1.40 | 853 | 966 | 9640 | 5105 |
| 5.5.0 | 797 | 947 | 8979 | 4514 |
| 5.5.33 | 929 | 1092 | 10404 | 5717 |
| 6.0.0 | 1204 | 1392 | 12696 | 6721 |
| 6.0.18 | 1272 | 1470 | 13217 | 6891 |
| 6.0.33 | 1310 | 1512 | 13670 | 7178 |
| 7.0.0 | 1387 | 1595 | 13254 | 6983 |
| 7.0.2 | 1398 | 1607 | 13309 | 7001 |
| 7.0.4 | 1411 | 1618 | 13310 | 7013 |
| 7.0.5 | 1415 | 1620 | 13180 | 7071 |
| 7.0.6 | 1428 | 1627 | 13176 | 7072 |
| 7.0.8 | 1426 | 1626 | 13178 | 7088 |
| 7.0.10 | 1431 | 1630 | 13197 | 7085 |
| 7.0.11 | 1429 | 1628 | 13204 | 7076 |
| 7.0.12 | 1433 | 1621 | 13238 | 7112 |
| 7.0.14 | 1437 | 1626 | 13267 | 7133 |
| 7.0.16 | 1449 | 1637 | 13310 | 7139 |
| 7.0.19 | 1452 | 1642 | 13334 | 7166 |
| 7.0.20 | 1454 | 1644 | 13352 | 7175 |

TABLE III

Size of Tomcat Codebase. WE ALSO TESTED A NUMBER OF EARLIER RELEASES IN THE 3, 4, AND 5 SERIES, BUT COMTOR COULD NOT PROCESS SOME OF THEM WITHOUT REVERTING TO EARLIER VERSIONS OF THE JAVA LANGUAGE; WE EXCLUDE THESE PARTIAL RESULTS.

C. Caveats and Limitations

One criticism of our approach and experiments is that we do not process the semantics of the comments we find; we restrict ourselves to coarse-grained measures of overall commenting practice quality (e.g., density of comments, length/size of comments, and a measure of misspelled words in those comments).

| Version | # classes | # constructors | # methods | # fields | % commented | # misspelled | # offensive words |
|---------|-----------|----------------|-----------|----------|-------------|--------------|-------------------|
| 1.6.0 | 895 | 963 | 7100 | 4102 | 79 | 1741 | 10 |
| 1.6.1 | 900 | 968 | 7191 | 4167 | 79 | 1757 | 10 |
| 1.6.2 | 926 | 1002 | 7380 | 4283 | 80 | 1403 | 10 |
| 1.6.3 | 962 | 1041 | 7652 | 4396 | 81 | 1420 | 10 |
| 1.6.4 | 962 | 1041 | 7653 | 4396 | 81 | 1420 | 10 |
| 1.6.5 | 962 | 1041 | 7656 | 4396 | 81 | 1421 | 10 |
| 1.7.0 | 1068 | 1200 | 8503 | 4893 | 88 | 1486 | 10 |
| 1.7.1 | 1079 | 1215 | 8691 | 5131 | 88 | 1451 | 10 |
| 1.8.0 | 1144 | 1313 | 9207 | 5410 | 86 | 1489 | 12 |
| 1.8.1 | 1145 | 1317 | 9226 | 5423 | 86 | 1488 | 12 |
| 1.8.2 | 1159 | 1337 | 9339 | 5485 | 85 | 1500 | 12 |
| 1.8.3 | 1161 | 1339 | 9376 | 5511 | 85 | 1499 | 12 |

TABLE II

Size of Ant Codebase. AN OVERVIEW OF THE “SIZE” OF THE ANT CODEBASE FROM RELEASE 1.6.0 TO 1.8.3 IN TERMS OF MAJOR CHARACTERISTICS LIKE NUMBER OF CLASSES, CONSTRUCTORS, METHODS, AND FIELDS.

| Version | # classes | # constructors | # methods | # fields | % commented | # misspelled | # offensive words |
|---------|-----------|----------------|-----------|----------|-------------|--------------|-------------------|
| 1.5.0 | 285 | 547 | 2788 | 1399 | 63 | 544 | 3 |
| 1.5.1 | 290 | 552 | 3959 | 1415 | 62 | 555 | 3 |
| 2.0.0 | 370 | 724 | 4683 | 1848 | 61 | 809 | 3 |
| 2.5.1 | 445 | 840 | 4851 | 2669 | 59 | 868 | 3 |
| 3.0.0 | 510 | 826 | 7416 | 2869 | 59 | 937 | 3 |
| 3.5.0 | 920 | 1227 | 8643 | 4555 | 50 | 1494 | 5 |
| 3.7.0 | 994 | 1320 | 7956 | 4907 | 49 | 1605 | 5 |
| 3.8.0 | 1105 | 1457 | 8675 | 5232 | 49 | 1737 | 0 |

TABLE IV
POI Characteristics.

| Version | # classes | # constructors | # methods | # fields | % commented | # misspelled | # offensive words |
|---------|-----------|----------------|-----------|----------|-------------|--------------|-------------------|
| 2.0.0 | 62 | 92 | 314 | 271 | 59 | 140 | 0 |
| 2.0.1 | 62 | 92 | 318 | 273 | 59 | 139 | 0 |
| 2.0.2 | 62 | 92 | 322 | 293 | 59 | 143 | 0 |
| 2.0.3 | 62 | 92 | 324 | 303 | 59 | 144 | 0 |
| 2.0.4 | 62 | 92 | 325 | 305 | 59 | 146 | 0 |
| 2.0.5 | 62 | 92 | 326 | 306 | 59 | 146 | 0 |
| 2.0.6 | 62 | 92 | 328 | 306 | 59 | 148 | 0 |
| 2.0.7 | 62 | 92 | 329 | 306 | 60 | 152 | 0 |
| 2.0.8 | 65 | 96 | 332 | 312 | 55 | 147 | 0 |

TABLE V
ORO Characteristics.

We do not perform analysis that correlates the natural language in the comments with the semantics of the code it describes.

In the graphs in Section IV, we mainly compared commenting density against the size of the codebase in terms of methods; we did not perform an in-depth analysis of the comments relating to fields and data members of classes. In addition, COMTOR only captures Javadoc-style comments (i.e., not those starting with a double slash or a slash-asterisk). Also, code from Jakarta-based projects may not be representative of all large-scale, widely-used Java code (and commenting practices). The commenting practices found within this software may also differ from commenting practices in other languages and projects (e.g., the Apache web server, the Linux kernel).

We note that the code we examine is professional code in the sense that Jakarta is a large, well-known incubator of mature and widely-used Java projects; many developers of the software hosted by this organization are professional soft-

ware engineers contributing back to an open-source project. However, this code is not proprietary software produced by large software engineering firms, and may not represent code organization and commenting disciplines adopted by such organizations and companies (nevertheless, this code is publicly available and allows others to reproduce our approach). Finally, these projects are not representative of student code in certain aspects — they are typically larger, reflect the input of multiple people, and have a significant history.

IV. EVALUATION

This section discusses our measurement of the aforementioned Jakarta projects.

A. Results From Apache/Jakarta Code

We examined Ant versions from 1.6.x to 1.8.x. In this range of releases, there appear to exist two significant changes in the nature of the codebase: one from 1.6.5 to 1.7.x and again from

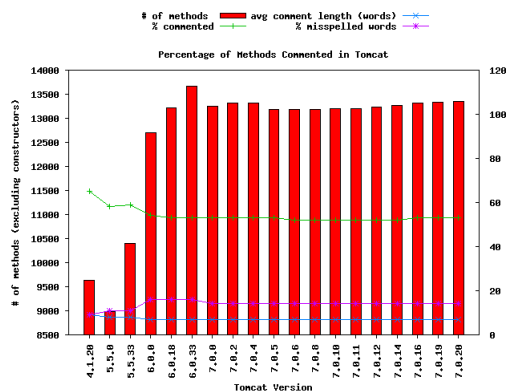


Fig. 2. *Tomcat Comment Characteristics*. The percentage of methods commented declines from 65% to 53%. Average comment size (in words) gradually decreases from 9 to 7. The existence of misspelled words increases from 9% to 14%.

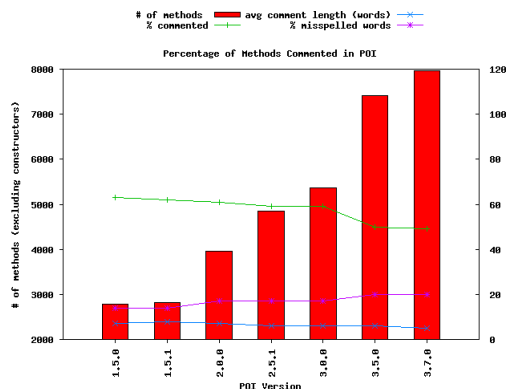


Fig. 3. *POI Comment Characteristics*. The percentage of methods commented starts above 60% but declines below 50%, particularly as more code is added in 3.5.0 and 3.7.0. The average size of each method comment (in words) gradually decreases from a high of 8 to 5. The existence of misspelled words increases to 20%.

1.7.x to 1.8.x. The density of commented methods increases until the second change; at this point, it looks like the addition of new methods either (1) didn't warrant the addition of new comments or (2) the developers did not keep up with documentation efforts. Nevertheless, of the three projects we examined, Ant has the best overall rate of commenting.

We performed a longitudinal study of Tomcat, covering a sampling of versions 3, 4, 5, and 6 as well as all point revisions of Tomcat 7. Tomcat had the largest codebase and maintained a fairly steady rate of around 50% of all methods commented.

We processed seven POI versions from 1.5.x to 3.7.x. We can see that the codebase generally increased in size, and that the density of comment coverage of methods decreased. Like other projects, the average comment size (in number of words) hovers in the high single digits. As in other projects, the percentage of misspelled words across all comments ranges in the high teens.

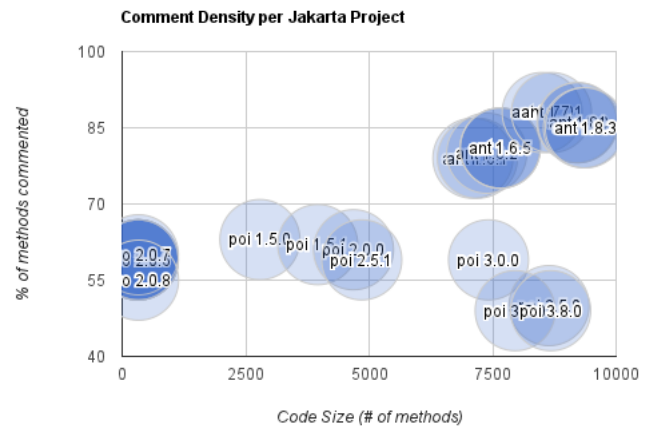


Fig. 4. *Project Code Density Clusters*.

B. Cross-Project

Most of the projects have the percentage of methods commented hover around 50% while Ant maintains a rate above 80%. We plotted the rate of change of a codebase size (in terms of methods added) versus the rate of change in percentage of methods commented as a way to depict how efficient the developers for each project were in keeping up with the addition of code. Figure 5 depicts this relationship and offers one way to perform a comment analysis across comments.

In Figure 5, the horizontal axis depicts time by enumerating releases; this axis does not depict real time, in that the first versions of Ant, POI, and Tomcat that we measured (1.6.0, 1.5.0, and 4.1.20, respectively) did not occur simultaneously. The vertical axis depicts the gain or loss in comment density (in terms of number of methods). A value of zero on the vertical axis means that the project "kept up" with the addition of code; a positive value means that the developers actually documented *more* than the number of methods that were added, and a negative value means that developers documented less than the number of methods added to the code.

V. PEDAGOGICAL USE

What did we learn about commenting best practices? What can we tell our students?

In early releases of Ant, even as code size increases, the percentage of methods commented increases, indicating that developers actively generated more comment coverage. After the shift to version 1.8.x, however, the percentage of methods commented decreased slightly. This is a good lesson for students: even in real-world code, large code changes can dominate efforts to generate or keep documentation relevant. Nevertheless, Ant seems to have a very high rate of documentation compared to other projects (around 80% compared to 50% for other projects).

We also learn that most method header comments are pithy, with an average of below ten words. This may be enough

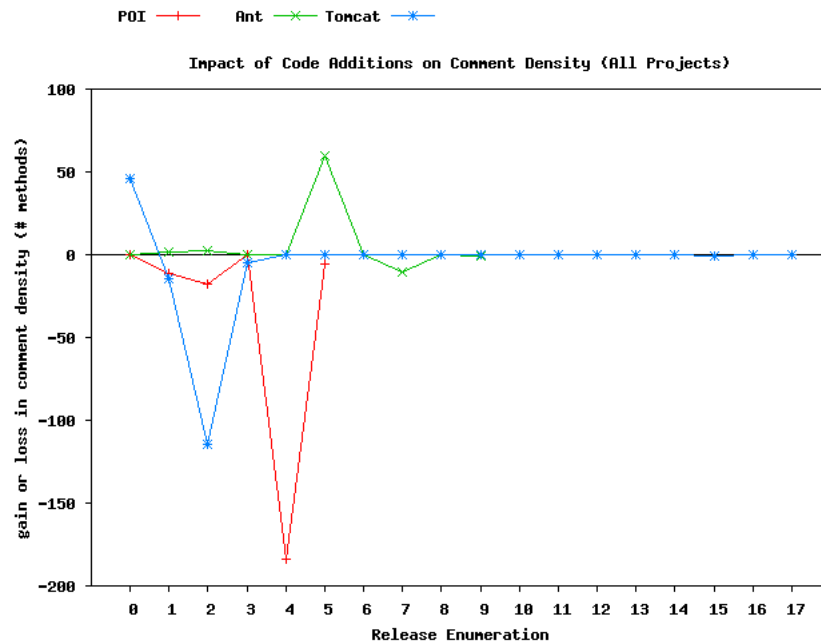


Fig. 5. *Impact of Code Size Changes on Comment Density.* This graph displays a cross-project comparison of how changes to code base size affect the density of comments. Both POI and Tomcat struggle with the addition of code but recover to maintain a balance. In contrast, Ant increased comment density, even after adding code, with only a slight dip for another code increase. A value of zero on the vertical axis means that developers kept up with the addition of code, negative values mean that added code remains uncommented, and positive values indicate that code beyond the new code was commented.

for a short, descriptive sentence, but hardly leaves room for discussion of underlying semantics or failure modes (which may partially be addressed by @throws clauses, @param descriptions, and one-line comments sprinkled throughout the method body).

Some project coding guidelines (e.g., the Linux kernel) recommend *not* writing extensive comments; they adopt this rational for several reasons, including (1) not “polluting” the source code with a large amount of extra text to sort through and (2) the perceived cost of keeping such comments up to date and in sync with the code it describes.

While the type of data that COMTOR generates from Jakarta code or student code is interesting from a software engineering perspective, and can help drive home what happens in the construction and maintenance of real-world software, the potential for analysis of this type of data in the classroom itself is quite large. For example, as Figure 5 shows, this type of analysis can be usefully applied back into the classroom to help analyze large, collaborative student projects and progress. Open source projects provide large amounts of data for analysis and visualization courses.

VI. CONCLUSION

This paper examines the design, development, and application of our tool for evaluating source code comments. Comments provide vital information about the semantics and behavior of code, yet little progress has been made on ways to help our students gain proficiency at writing high-quality documentation. In this paper, we examined a preliminary step: gathering information from open source projects about source

code comment properties. Such information can help form the basis of advice, recommendations, and best practices for our students. Through observations like this, students can learn to balance the tradeoffs involved in spending time and effort to document code.

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Work in Progress: International Experience in Semiconductor Product Engineering

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Abstract — This paper describes the effort of creating a joint international graduate program in the area of semiconductor product engineering and power electronics. As a first step, a joint summer course for undergraduate students is implemented with the intention to create a larger interest in the program among the current undergraduate population at Texas Tech University and the University of Applied Sciences, two of the institutions jointly offering this degree.

Keywords- *international experience, joint degree programs, graduate education.*

I. INTRODUCTION

The Program for Semiconductor Product Engineering (PSPE) has been in place at Texas Tech University for the past 14 years [1]. Its primary focus has been training MSEE product engineers and test engineers for the semiconductor industry. Although several companies (Intel, Advanced Micro Devices, Applied Materials, Freescale, Texas Instruments) have invested in the program from time to time, the majority of the financial and technical support has come from Texas Instruments (TI), and the preponderance of professional placements has been with TI. Indeed, the history of the program shows that approximately 80% of the students who participate in the program have been offered and have accepted full time positions with TI, and the total number of engineers thus placed exceeds 200. By most metrics, this would be regarded as a highly successful program with an enviable record.

Students are accepted into PSPE from a variety of backgrounds but most have baccalaureate degrees in Electrical Engineering, Computer Engineering, Physics, Mathematics, Mechanical Engineering, and Industrial Engineering. For those students in fields other than Electrical Engineering and Computer Engineering a few (<4) leveling courses generally suffice to ensure adequate preparation. A typical program of study includes three semesters of coursework and a 3 - 6 month cooperative education or internship experience. With less than 1% exception all students pursue the thesis option, usually based on work accomplished during the coop and directly relevant to the business unit sponsoring the student. Courses include Engineering Analysis (mathematical tools), Statistics, Microprocessor Architecture, Modeling and Simulation of Electronic Systems, Parametric and Functional Device Testing,

Analog Circuit Design, Advanced Digital Circuit Design, Testing of Digital Systems, Communication IC Design, Low Power VLSI Design, Solid State Devices, VLSI Processing, Power Semiconductor Devices, Power Converter Design and Test.

Texas Tech faculty meet with TI technical and management personnel on a regular basis to understand changing business environments and how they impact desired course content and demand for students. Flexibility in student schedules is important in matching students to opportunities. Most recently TI has indicated a desire to include undergraduates in a similar program that would lead to BSEE hires. A partnership with TI has resulted in funding in form of a National Science Foundation grant [2] to encourage undergraduates to consider careers in the semiconductor industry.

Partly due to the success of the program and partly in spite of this success, TTU is pursuing a different sort of expansion to include more companies and international partners. Students would benefit from exposure to diverse corporate cultures. A less narrow technical focus would also allow students to look at other positions and in other related industries. Finally, all involved agree that the increasingly global nature of industry demands exposure to other cultures, business models, and general perspectives. The achievements of PSPE at TTU have led our sponsors to attempt to adapt the model to other institutions, notably the University of Applied Sciences (UAS) Landshut in Germany. What started as an attempt to build a PSPE-like program between UAS Landshut and TI in Freising, Germany, has evolved into a partnership between UAS Landshut and TTU that includes TI Freising as one of many corporate contacts in the Greater Munich area. Faculty from TTU feel that their students will benefit from broader technical coverage in an electronic product engineering curriculum. UAS Landshut faculty feel their students will benefit from expertise at TTU in the areas of power electronics and testing and from the experiences made through PSPE. The commitment of TI Freising is important but all agree that including other industries is crucial for the successful implementation of the program.

II. JOINT SUMMER COURSE

This summer (August 2012) we will offer a short course in international product engineering at UAS Landshut that will be attended by students from TTU and UAS and will be taught by a faculty member from TTU. The content of the course includes the core of TTU's Parametric and Functional Device Testing and exposure to IC automated test equipment and will have a lab component accompanying the lecture. Courses will be held on the UAS campus and TTU students will live in UAS Landshut dormitories. Through the joint enrollment of students from both institutions and an instructor from TTU a personal look at the different education systems will be given to all participants. The preparation for this course included collaboration with TI Freising which will donate testing equipment to UAS Landshut. Participants from TTU will bring expertise in the usage of this instrument with them from prior usage at TTU and will share this knowledge with faculty and students from UAS Landshut. Excursions for all participants to semiconductor companies in the area are planned for at least 2 afternoons per week. The geographical area (Bavaria) is rich in German heritage and history, and participants will take advantage of this as well.

III. EVALUATION OF SUMMER PROGRAM

We will analyze the results of this program and report our preliminary findings at the conference in October. We are developing pre- and post- surveys to help determine changes in attitudes toward awareness of cultural differences, studying abroad, and interest in graduate school among the participants. Of course, we will examine students on technical content as well. For the TTU students, we will have an extended opportunity to work further in the fall semester to improve the offering. Funding opportunities with the National Science Foundation and German and European organizations will also be explored.

IV. JOINT GRADUATE PROGRAM IN ELECTRONIC PRODUCT ENGINEERING

The joint graduate program in electronic product engineering, which is currently under preparation will be open to students from Germany, the US, and Asia. It is motivated by the need of multinational companies (MNCs) operating manufacturing facilities in countries like Malaysia, Thailand, and Vietnam to also aim at innovative and applied research and development. The focus of the new program will be application oriented and driven by industry needs. Electronic Product Engineering (EPE) will be an executive postgraduate Master's program taught in English at UAS Landshut and TTU with an international student body mainly from South East Asian countries as well as US and German nationals. Students or their employers are required to pay tuition fees making the program self supporting.

To be admitted into the program, students must hold a bachelors degree in electrical engineering or a related field, have a minimum of one year practical experience, and be on sabbatical leave from their employer during term period.

Participants are anticipated to return to their employer after completing the program of studies.

The curriculum will consists of courses in electronic and system engineering, technology and production methods, quality and testing, customer relations, intercultural competence, and project management.

Educational objectives of the program are to train engineering graduates to the highest international level, train the next generation of university lecturers to the highest international level, and promote their personal development in order to contribute to the focal country's development.

V. CONCLUSIONS

Interest in the summer program among students has been high at TTU. Subscription filled the target number very early after the initial offering, and there have been lively conversations on social media sites regarding many aspects of the program. Much of this conversation has focused on the cultural aspects of the visit – where to go, what to do, etc., but there has also been a highly cooperative thread of discussion on the logistics of the flight to Germany.

Planning for the coursework is continuing. We will no doubt encounter issues with unfamiliar equipment, a different power system, laboratory layout, and other challenges to our assumptions but that is part of the program, and there is real value in exposing the students to these issues and to their participation in the development of solutions.

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Work in Progress: Student lab on graphics cards' multi buffer architecture implemented in an FPGA

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Abstract—This paper presents a laboratory assignment for a module in VHDL programming. The purpose of the laboratory is to demonstrate sophisticated, state of the art solutions to current challenges in digital hardware design. The goal is to avoid setting up tasks that have a complexity beyond what the students are able to handle, but at the same time keeping the essential parts of the solution. The laboratory assignment presents to the students the principal solution to a problem or challenge, and the students' task is to develop a practical implementation of this solution in an FPGA, with I/O units connected, that demonstrates the effectiveness of the solution.

Keywords—VHDL programming; digital hardware design; laboratory assignment.

I. INTRODUCTION

A continued challenge in giving engineering students up-to-date skills and knowledge on new developments and strategies is the continued development and sophistication of computer peripheral devices as computing power is moved from the main processor into the I/O devices. In the student assignment presented in this paper, the graphics card found in modern computers is used as an example of highly sophisticated functions implemented in complex digital hardware for handling challenges involved with data transfer between asynchronous processes. The assignment is given to bachelor students in their third and final year of their computer science course. The FPGA is chosen as the development platform in this paper, and the students are given an introductory module on this topic the year before. Problem based learning (PBL) is an attractive strategy when the tasks the students are set to solve have not one but infinitely many solutions. In [1] and [2] FPGAs are demonstrated to be very useful for this purpose as they provide a large, flexible solution space. Giving students hands-on experiences with the design and implementation of digital structures of this kind is considered important, but is a not a trivial task. In [3] the complexity of implementing a five-stage pipeline 32-bit MIPS design requires the use of active measures such as milestones to allow the students finish the assignment within the full nine weeks set aside for this in the sixteen week module. At the authors' university it is not possible to run a module for more than around 13 weeks, and the length of the assignment has to be reduced accordingly. In order for the students to be able to finish the laboratory work in time, an assignment will typically be a downscaled version of a full system. The challenge lies in how to reduce the size and

workload of the project without losing important elements that are part of the solutions to the original challenge. The project should also be inspiring for the students, adjustable for the actual skill level of different students, and low cost.

II. PROBLEM DESCRIPTION OF THE ASSIGNMENT

The student assignment will be an implementation of a downscaled version of the dual- and triple-buffer architecture [4] found in modern graphics cards, which is used to eliminate the problem of synchronizing the transfer of data between two asynchronous processes: The program running in the CPU used for generating the image, and the graphics card used to transfer the image to the computer screen (LCD). The challenge here is that the CPU uses a variable amount of time to generate a complete image, when the connected LCD requires a constant transfer rate. Three challenging situations are presented to the students: (i) the CPU generating images more slowly than the LCD can receive data, (ii) the CPU generating images faster than the LCD can receive data, and (iii) the CPU generating images at the same rate, but time shifted from the LCD writing process. The solution is basically to use two or three image buffers in the graphics card. One or two are used as back buffers for receiving the image data from the CPU, while the front buffer is used for transferring the image to the LCD, as described in the next sections.

A. The problem of flickering

When the process of transferring the image to the screen buffer is not properly synchronized with the image generation process, two effects are visible on the screen: tearing and flickering. Displaying a new or altered object requires changing a least some of the pixels. Instead of tracking the pixels that must be changed, the more efficient strategy of resetting all pixels and drawing the object only by setting the pixels covering the object, is chosen in practice. Modern graphics cards support hardware blanking, which is utilized here as it is more efficient than software blanking. A negative side effect of this is that the temporary image that appears just after the blanking, before the object is drawn, might appear on the screen. Although this happens in a very short timeframe, this is often visible to the user as flickering. This is resolved using a dual buffered graphics memory, where the image can be withheld in the back buffer, until the whole image is complete, i.e. all pixels are set correctly. The function of the two buffers

is switched when the CPU has finished updating the back buffer and the screen update from the front buffer is about to start a new update cycle. An important point here is that data are never copied from the back buffer to the front buffer. Rather the role or function of the two buffers is switched, so that when the image in the back buffer is completed, this buffer is used as the front buffer when a new update cycle is started. The front buffer is then made available for the CPU as a back buffer where a new image is drawn, after clearing the buffer.

B. The problem of tearing

Another problem associated with the single buffer architecture is the tearing effect. Images are transferred from the video ram to the screen from top to bottom, and left to right while the CPU can produce the different parts of an image in a random order. If a scene is produced where the viewer is performing a panning movement, all parts of the image should move simultaneously. If, for instance an object in the middle of the image is moved before the background is processed, it will appear as if the object is moving relative to the background instead of the viewers heading which is actually moving. The dual buffer solution contributes to reduce or remove this problem. A drawback of the dual buffer architecture can be found in situations where the current image has finished generating and the graphics card has just started a new transfer of the previous image to the screen. Now the CPU must wait for the graphics card to complete the screen update and then switch the two buffers before the CPU can start generating the new image. This means that valuable CPU processing power is lost due to waiting. In order to keep the CPU busy as much as possible, a triple buffer arrangement is introduced. In this arrangement there are two back buffers and one front buffer, so there is always a back buffer available for the CPU to store images that are being generated. The previous image is kept in the front buffer during data transfer until the complete image has been transferred to the screen, while the current image is stored in the first back buffer, and the new image under development is stored in the second back buffer.

III. ASSIGNMENT GIVEN TO THE STUDENTS

The creation of the memory modules used in this scheme is simple in FPGA/VHDL programming, and is not the challenging part of the assignment. By use of a small graphics display, the required size of the memory modules is small enough to fit within the FPGA, and the block-RAM modules will be used for this purpose. The challenge for the students is the design of the digital hardware needed for timing, synchronization and handshaking, allowing for successful data transfer.

The first task for the students is the implementation of the dual buffer according to the description of the architecture given in the previous sections in this paper. This involves the creation of two memory modules, and the synchronization of the modules external to this: the image processing unit and the LCD module. It is considered important that the students fully understand the problem and the solution as described in section II of this paper. At startup, the back buffer must accept data from the image processor and the front buffer must transfer its contents to the LCD module.

The latter process must be repeated until the image processor has finished producing a complete image in the back buffer. Now, the front buffer should complete the current transfer process while the image processor is stalled, whereupon the two buffers must be switched and the "new" back buffer is cleared, so that the image processor can start creating a new image into the "new" back buffer and the front buffer can start new cycles of transferring the current image to the LCD module. The second task is the addition of a second back buffer for temporary storage of the finished image, before it is transferred to the LCD. In this architecture, the function of the three buffers is circulated between front, first back and second back buffer. The control logic involved in managing a successful transfer of data is even more complex than in the dual buffer case, but is considered manageable for students.

In both of these tasks, the students start by drawing the chart for the algorithmic state machine (ASM) for the finite state machine with data path (FSMD). The overall purpose of the FSMD is to control the data transfer between the image processor and the LCD module. More specifically the FSMD will control the data transfer to and from the buffers, as well as perform the circulation of the functions of the individual buffers.

The system for which the system will be implemented, is an FPGA demo board from Avnet-Memec [5], with a custom designed add-on board where a simple monochrome graphics LCD (132x32 pixels) [6] and two incremental encoder knobs are mounted. The latter is used for input data to the image processor. The FPGA allows for easy demonstration of all different scenarios revealing any problems or faults of the implemented architecture.

IV. PRELIMINARY AND FURTHER WORK

A student laboratory platform for demonstration of sophisticated functions realized in complex digital hardware is suggested. The idea behind the hardware solution is that these functions should be realizable in an FPGA, within the timeframe of a student laboratory project, without losing the elements that identify the state-of-the-art of the technology. The hardware is designed, built and tested, and the laboratory will have a first run on a group of students in autumn 2012.

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Educational Software Tool for Signals and Systems Theory

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Abstract— One of the most important subjects in the educational background of electrical engineering as well as in other important scientific areas of knowledge is the Signals and Systems Theory (SST). Taking into account the connection of the SST with the algebraic representation and the mathematical understanding of physical problems –electromagnetic radiation, scattering and inverse problems in our particular case–, a generalized scheme of the SST (GSST) is currently under development. While the usual point of view of classical SST is valid for practical purposes, it usually avoids many important concepts which become fundamental in the generalization of the analysis of physical problems. Some examples of this generalization are concerned with representations of physical problems different from those in the usual time-frequency domains –using a general variable–, the description of the problem in terms of infinite dimensional vector spaces and the algebra associated, the description of the Dirac delta function in terms of the distribution theory, etc. The most important purpose of obtaining a GSST is to connect the usual SST with important mathematical representations that lead to obtain more general representations that may be rigorously applied to model general physical problems. This generalized theory is focused on the algebraic concepts of signals and operators spaces, identifying each problem into their corresponding vector spaces and representing it in terms of the GSST scheme. One important point within this generalization is the concept of the *Generalized Transform*. Choosing a set of functions which play the role of a base, each signal of the space may be expressed in terms of a *Generalized Linear Combination* operator of this base weighted by a set of coefficients which identify the transform –their expression is directly related to the metric defined initially in the associated algebra–. Spectral analysis of systems is also contemplated, representing the signals in terms of their coefficients once a set of basis functions is chosen. The generalized theory let to obtain integral characterizations of linear systems –invariant and non invariant–, leading to the *Generalized Spectral Analysis* concept, closely connected to the operator theory. While the mathematical analysis of the GSST and its application, for instance to generalize the Green's function theory, has already been presented in several symposium –like 2009 IEEE AP and URSI Meeting–, a software tool based on the GSST is being worked out in parallel to the theoretical works. The aim of this tool is to facilitate both students and practical scientific and engineers the understanding of the main algebraic concepts of this generalized scheme, providing some examples of many signals and many systems in

five different signal spaces. The user can select the signal and the system with their appropriate parameters and analyze the properties of the systems as well as the output signal both in real and different spectral domains. The last version of this tool, *SSTv4.5*, lets to analyze linear non invariant systems and to visualize the set of impulse responses as well as the spectral analysis under some transformations such as Fourier, Hilbert or Bessel Transforms –depending on the signal space–, thus exemplifying some particular cases of the *Generalized Spectral Analysis*. The description of the current version of this software tool is presented in this paper.

Keywords— *Signal Theory, Operators, Linear –invariant and non invariant– Systems, Software Tool, Infinite dimensions –countable or continuous–*

I. INTRODUCTION

Signals and Systems Theory (SST) plays a fundamental role in the educational and professional background of electrical engineering as well as in other scientific areas. Many references can be found about this topic, for instance [1]-[2]. But it is not difficult to realize that the way used to approach this theory avoids some important concepts that may lead to conceptual problems: the treatment of the Dirac delta function and the set of impulse responses without considering the theory of distributions, for instance, 0. The aim of our generalization of the SST (GSST), which is being carried out, is to avoid these problems as well as to be connected with the mathematical representation of physical problems in real and complex variable, [4]. The scheme is based on the algebra of infinite dimensional functions and operator spaces, together with the theory of distributions. This scheme is currently used to present the SST to both undergraduate (in a simplified form) and postgraduate students as well as to connect this theory with other important concepts in wave theory, for example the complexifications of time-space coordinates. Additionally, many research activities are directly related with this scheme, especially those involving Rigged Hilbert Spaces (RHS) theory, [5], the extension of the GSST to non linear operators, [6], the generalization of the Green's function theory, [7], or a generalized mathematical approach to inverse problems, [8].

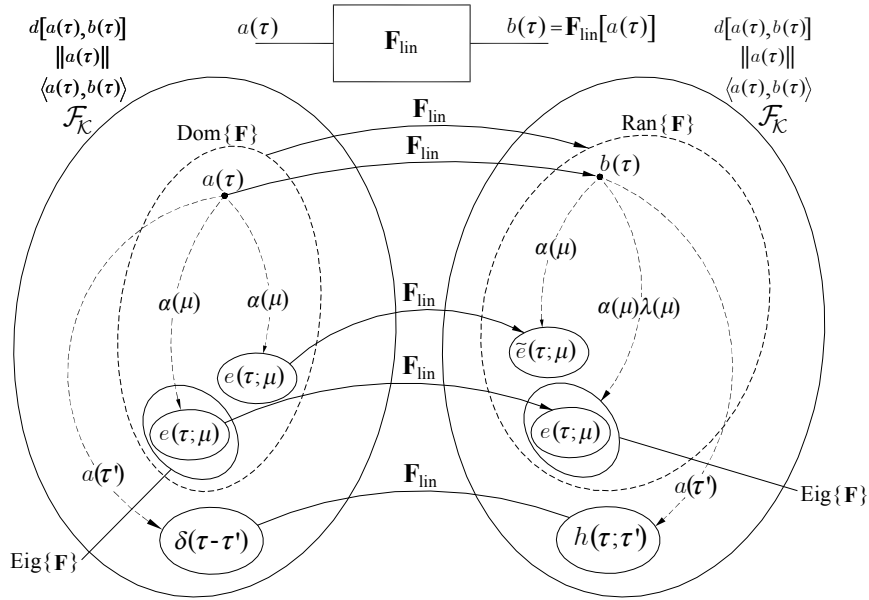


Figure 1. Graphical representation of the GSST scheme underlying the usual 'black box' representation in the usual schemes. Dashed lines identify generalized linear combination operators with coefficients those crossed by the lines. The input and output spaces are supposed to be the same only for simplicity.

With all this considerations in mind, a software tool where the user can learn and understand all these underlying concepts the GSST scheme is being developed. The current version is called *Signals & Systems Theory v4.5 (SSTv4.5)*, which is updated with the last and novel results of our research activities. This tool tries to emphasize the most important aspects of the generalization, emphasizing those that we consider more relevant from the educational point of view. In this sense, the tool becomes very significant because the students can appreciate more clearly the SST from a general point of view than the usual one appearing in the regular literature; even, the tool becomes important in order for the students to compare our GSST with the usual contents that they find in the usual bibliography, in particular those concerning: (i) the infinite dimensional vector space algebra under the GSST, (ii) the *Generalized Transform*, comparing different transformations (Fourier, Hilbert, ν -order Bessel, etc.), and (iii) the capability of the software to visualize not only regular functions but also generalized functions (distributions). Before presenting the potential of this tool, a brief summary of the GSST is presented in the next section. More details about this theory may be found in [9]-[10].

II. SUMMARY OF THE GSST

A. Initial Algebra

The most important concepts associated to the GSST are graphically summarized in Fig. 1. In the present paper, the mathematical developments will be avoided and only the most important expressions will be recalled in order to better understand the final aim under the software tool presented in this paper.

The theory is constructed considering an initial vector space \mathcal{F}_K of complex signals denoted by $a(\tau)$. The independent variable may represent either discrete or continuous variable ($\tau \equiv n \in \mathbb{Z}, \tau \equiv x \in \mathbb{R}$), representing any physical magnitude: time, space, frequency, etc. The dimension of the space can be discrete, countable-infinite or continuous-infinite. The algebraic structure of the space is built by the definition of the distance $d[\circ, \circ]$, the norm $\|\circ\|$ and the scalar product $\langle \circ, \circ \rangle$, which, together with the composition laws, determinate the vector space and the different associated ways of operating within the space. These definitions establish not only the way of measuring within the space \mathcal{F}_K but also it has an important influence in the definition of many distributions as the Dirac delta.

In this general scheme, a new parameter μ is introduced in order to identify a function into a subset. It can represent finite, countable-infinite or continuous-infinite subsets of functions; nevertheless it must be clear that this parameter μ is not initially a variable in the original problem, but it is an identification parameter which corresponds later in the usual cases with the so called "spectral variable". These subsets of functions will be denoted as $u(\tau; \mu)$, emphasizing that the semicolon indicates that the original variable is τ , while μ is just the parameter used to identify functions into the subset, instead of a usual comma which indicates a two variable function. Later analyses will lead to the possibility of understanding $u(\tau; \mu)$ as a surface-type function.

B. Linear Combinations and Generalized Transforms

The concept of a generalized linear combination may be introduced from the composition laws required in a vector space. Once a set of functions $e(\tau; \mu) \in \mathcal{F}_K$ –which play the role of a base–, is chosen, any element $a(\tau) \in \mathcal{F}_K$ can be described as a generalized linear combination operator in μ , \mathbf{LC}_μ , of this set of basis functions weighted by a set of coefficients $\alpha(\mu)$, as schematized in Fig. 1. The way to calculate $\alpha(\mu)$ directly depends on the definition of the distance, which lead to the next generalized representation:

$$a(\tau) = \mathbf{LC}_\mu [\alpha(\mu)e(\tau; \mu)], \quad (1)$$

$$d\{a(\tau), \mathbf{LC}_\mu [\alpha(\mu)e(\tau; \mu)]\} \rightarrow 0 \Rightarrow \alpha(\mu). \quad (2)$$

The pair of equations (1)-(2) represents the concept of the *Generalized Transform*. $\alpha(\mu)$ are not only the coefficients of $a(\tau)$ but also the so called direct transform of $a(\tau)$ in the $e(\tau; \mu)$ base. On the other hand, $a(\tau)$ in (1) is the inverse transform of $\alpha(\mu)$. In many cases –usually when $e(\tau; \mu)$ is an orthogonal subset with respect to the defined scalar product–, $\alpha(\mu)$ can be obtained by the orthogonal projection of the function $a(\tau)$ by each base function $e(\tau; \mu)$; in this case, (1)-(2) reduces to the pair of equations

$$a(\tau) = \mathbf{LC}_\mu [\alpha(\mu)e(\tau; \mu)], \quad (3)$$

$$\alpha(\mu) = \langle a(\tau), e(\tau; \mu) \rangle. \quad (4)$$

This representation can be particularized to any concrete transformation, either if τ represents a discrete or continuous variable; for instance, the well-known Fourier transform can be analyzed by this scheme taking into account the theory of distributions (both the usual and also the generalized Fourier transform).

Also, the general representation in (1)-(2), or the more specific in (3)-(4), takes into account that the generalized linear combination \mathbf{LC}_μ may be finite or infinite series, or continuous sums (Riemann or Lebesgue integration); also this representation connects with the theory of distributions.

C. Real Domain Characterization of Systems

One of the most typical set of basis functions is the ideal set of generalized delta functions, $e(\tau; \mu) = e(\tau; \tau') = \tilde{\delta}(\tau - \tau')$, where $\tilde{\delta}(\tau)$ denotes the Kronecker delta function in discrete variable or the Dirac delta distribution in continuous variable. Using this set, it is possible to represent the output of any linear system described by the operator \mathbf{F}_{lin} as

$$a(\tau) = \mathbf{LC}_{\tau'} [a(\tau')\tilde{\delta}(\tau - \tau')], \quad (5)$$

$$b(\tau) = \mathbf{F}_{\text{lin}}[a(\tau)] = \mathbf{LC}_{\tau'} [a(\tau')\mathbf{F}_{\text{lin}}[\tilde{\delta}(\tau - \tau')]]. \quad (6)$$

We will define the “set of impulse responses functions” of a linear system as

$$h(\tau; \tau') = \mathbf{F}_{\text{lin}}[\tilde{\delta}(\tau - \tau')]. \quad (7)$$

These functions define mathematically the physical properties of the system \mathbf{F}_{lin} . The equations (5)-(6) become a particular case of (1)-(2) being $\mu \equiv \tau'$ the spectral variable. In the case of dealing with continuous variable ($\tau \equiv x \in \mathbb{R}$), which is very common, the interpretation of the \mathbf{LC}_μ operator has to be understood under the theory of distributions. The rigorous relationship between functions and distributions are being studied through the RHS theory, [5], trying to incorporate them into the GSST scheme. The representation and interpretation of the real domain characterization of linear non invariant systems constitute the main incorporation in the last version of the software, *SSTv4.5*.

D. Spectral Characterization of Systems

Going back to equation (1), when a signal passes through a linear system \mathbf{F}_{lin} , the output can be expressed as

$$\mathbf{F}_{\text{lin}}[a(\tau)] = \mathbf{F}_{\text{lin}}\{\mathbf{LC}_\mu [\alpha(\mu)e(\tau; \mu)]\}, \quad (8)$$

$$b(\tau) = \mathbf{LC}_\mu \{\alpha(\mu)\mathbf{F}_{\text{lin}}[e(\tau; \mu)]\}. \quad (9)$$

Additionally, if the set of basis functions belongs to the subspace of eigenfunctions of \mathbf{F}_{lin} , $e(\tau; \mu) \in \text{Eig}\{\mathbf{F}_{\text{lin}}\}$, (9) reduces to

$$b(\tau) = \mathbf{LC}_\mu \{\alpha(\mu)\lambda(\mu)e(\tau; \mu)\}. \quad (10)$$

Thus, the product $\alpha(\mu)\lambda(\mu)$ is the spectral representation of the signal $a(\tau)$ under the base $e(\tau; \mu)$, where the coefficients $\lambda(\mu)$ are the eigenvalues of \mathbf{F}_{lin} associated to $e(\tau; \mu)$. Equation (10) describes the usual “spectral representation” of linear systems, which is frequently used to represent of linear invariant systems under the Fourier transform, due to the well-known properties of the complex exponential functions $e(x; \xi) = e^{j\xi x}$ which are eigenfunctions of any linear invariant system. If $e(\tau; \mu) \notin \text{Eig}\{\mathbf{F}_{\text{lin}}\}$, a *Generalized Spectral Analysis* may be defined expanding the usual interpretation under *Spectral Analysis* and redefining this concept, [11]-[12].

III. SOFTWARE TOOL

SSTv4.5 has been projected keeping in mind all this algebraic concepts, but focusing on including the representation of linear non invariant systems, especially those which representation requires three dimensions. The spaces, transforms and spectral analysis are the same of previous versions, which are summarized in table I.

A. Initial View

The software tool holds five different signal spaces implemented with different algebra, transformations and spectral analysis in each one. Although the norm and distance currently implemented are those induced by the usual definition of the scalar product for each space, the software is ready to implement any other algebraic definitions.

TABLE I. SPACES, TRANSFORMS AND SPECTRAL ANALYSIS IMPLEMENTED IN SSTv4.5

| Continuous variable signals - Functions and distributions | | |
|--|--|------------------------------------|
| $S(-\infty;\infty)$ | Fourier transform ($\mu \equiv \xi$): | $e(x;\xi) = e^{j\xi x}$ |
| $a(\tau) \equiv f(x)$ | Hilbert transform ($\mu \equiv x'$): | $e(x;x') = \frac{1}{\pi(x-x')}$ |
| Continuous variable signals - Functions and distributions | | |
| $S(0;\infty)$ | Bessel transform ($\mu \equiv \xi$ and order ν): | |
| $a(\tau) \equiv f(x)$ | $e_\nu(x;\xi) = \sqrt{\xi x} J_\nu(\xi x)$ | |
| Continuous variable periodic signals - Functions and distributions | | |
| $P(X_0)$ | Fourier series ($\mu \equiv m$): | $e(x;m) = e^{jm\frac{2\pi}{X_0}x}$ |
| $a(\tau) \equiv f_0(x)$ | | |
| Period X_0 | | |
| Discrete variable signals | | |
| $D(-\infty;\infty)$ | Fourier transform ($\mu \equiv \Omega$): | $e(n;\Omega) = e^{j\Omega n}$ |
| $a(\tau) \equiv x(n)$ | | |
| Discrete variable periodic signals | | |
| $D(N_0)$ | Fourier series ($\mu \equiv k$): | $e(n;k) = e^{jk\frac{2\pi}{N_0}n}$ |
| $a(\tau) \equiv x_0(n)$ | | |
| Period N_0 | | |

After the visualization of the presentation screen, the main window is displayed (Fig. 2). It is designed for having a similar appearance than the algebraic structure of the signals theory scheme. In this one it is possible to choose the working signal space. It is important to recall that the software tool has two different ways to return the results depending on the characteristics of the signal: (i) searching them into a theoretical database (infinite support functions and distributions), or (ii) implementing numerical methods (finite support functions).

B. Some illustrative cases

In order to give an idea about the most important capabilities of the last version of the software, some practical examples and visualizations of many signals and set of impulse responses are shown in this section. The most illustrative space is $S(-\infty, \infty)$, –continuous variable functions and

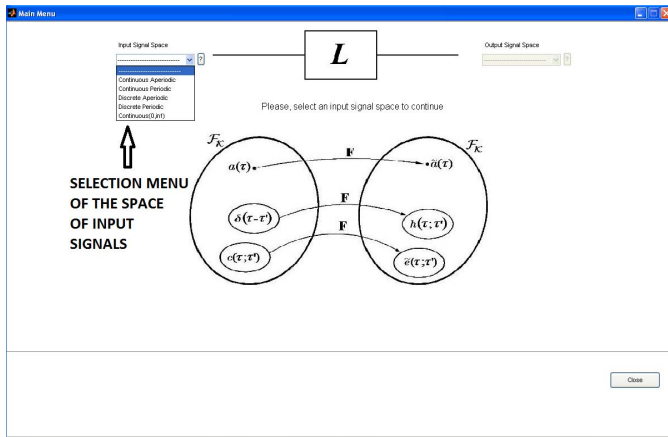


Figure 2. Main window of SSTv4.5.

distributions– but examples from other spaces are presented. Fig. 3 shows the interface window once the space $S(-\infty, \infty)$ is selected. It is divided into four main sections:

- SECTION 1 - *Input vector space*: the user selects the input signal with their parameters and the algebra of the space (some help buttons explain the definition of the algebra selected). The values of the norm and energy are shown in appropriate boxes.
- SECTION 2 - *System*: it is possible to choose between basic operations –such as addition, multiplication, etc.– and a specific operator, in which case, the main properties are shown (linearity, invariance, causality, stability, memory and invertibility). Different kinds of operators are available in the software, from basic operators –such as shifting, scaling, addition, etc– to more advanced operators –convolution, modulation, etc.– Moreover, some important transformations – Fourier, Hilbert, Bessel, etc.– seen as operators are implemented. If any other signal definition is required, the user can do it in this section like in section 1. An exemplification of the system in terms of a typical black box is shown on the top of this part.
- SECTION 3 - *Output vector space*: the space in this section is determined by the input vector spaces and the system. Input and output vector space may be different. The user can only select the algebra of the space (but currently there is only one algebra defined). The values of the norm and energy are shown in the appropriate boxes as well as the distance and scalar product if more than one signal is required to define the system.
- SECTION 4 - *Spectral Analysis*: the user can select the transform under he wants to visualize the spectral analysis of the system. A specific button gives access to the visualization window which is represented in Figs. 4 and 6. Here it is possible to clear general values or close the program too.

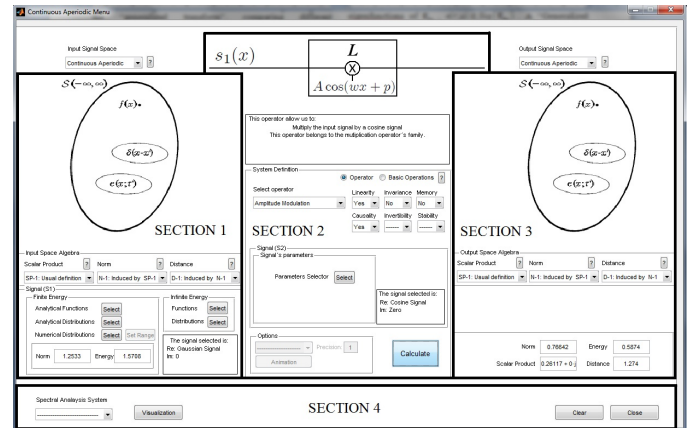


Figure 3. Interface window when the space $S(-\infty, \infty)$ is selected.

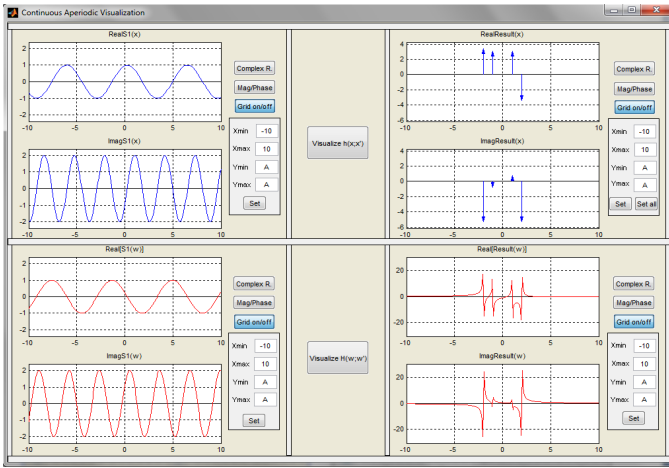


Figure 4. Visualization window when the space is $S(-\infty, \infty)$, the system is the Fourier transform operator, and the spectral analysis is performed under the Hilbert transform.

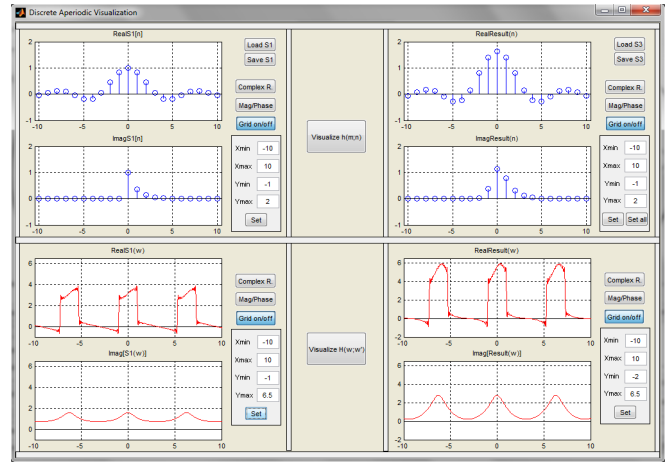


Figure 6. Visualization window when the space is $D(-\infty, \infty)$, the system is the convolution operator and the spectral analysis is performed under the Fourier transform.

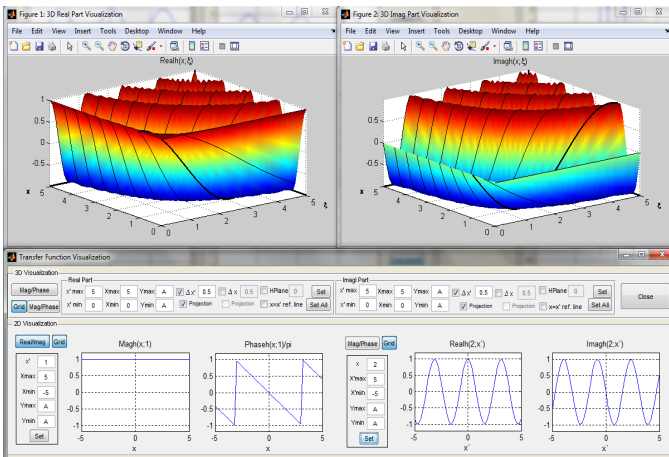


Figure 5. Set of impulse response functions when the the system chosen is the linear non invariant Fourier transform.

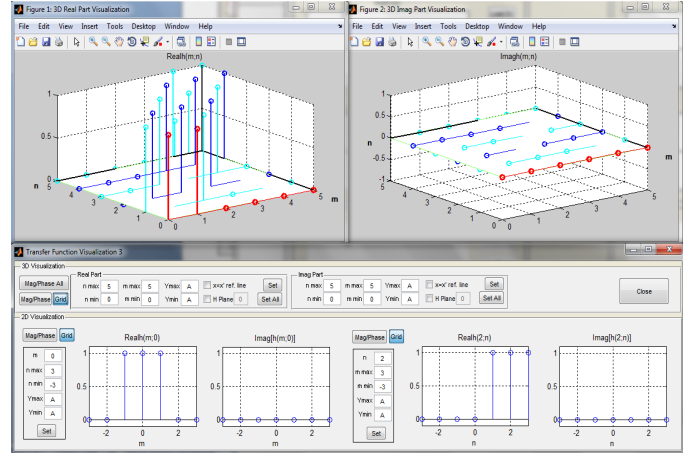


Figure 7. Set of impulse response functions when the systems chosen is convolution in the space is $D(-\infty, \infty)$.

Fig. 4 shows the representation when the Fourier transform is seen as a linear non invariant operator selected in the space $S(-\infty, \infty)$, and when the spectral analysis is performed under the Hilbert transform. The upper part of the window shows the real domain analysis –real and imaginary parts in this case– and the lower part shows the spectral domain analysis. In this example it is possible to visualize both functions and distributions. The set of impulse response functions in this example is shown in Fig. 5 –particularizing (6) as $h(\tau; \tau') = h(x; x') = e^{-jxx'}$ – where real and imaginary parts are displayed and some particularizations of any value of x or x' may be represented. This set only depends on the system.

Selecting the space $D(-\infty, \infty)$, an example of the convolution operator is provided in Fig. 6. The spectral analysis under the Fourier transform let see the spectral signal belonging to the space $P(2\pi)$. The set of impulse response functions –once (6) is particularized as $h(\tau; \tau') = h(n; m) = P_2(n - m)$ – are shown in Fig. 7 and

allow us to understand the invariance of the system due to the symmetry over the axis $m = n$.

There are other interesting capabilities, as the simulation in real time of the convolution, correlation and modulation (Fig. 8), complex representation (Fig. 9), switching the view of signals between real-imaginary parts and magnitude-phase, showing the grid, changing the definitions of the axis and saving or loading signals to external files.

C. Further implementations

Generalized Spectral Analysis has been developed recently and the theoretical results may be found in [11]-[13]. This analysis let to interpret any output signal in the spectral domain for linear invariant and non invariant systems and under any kind of transformation. The current version of the software is being extended nowadays in order to include this generalization of the spectral analysis for the systems and transforms defined up to date. In addition, more systems, even non linear ones, will be included in future versions of the software tool.

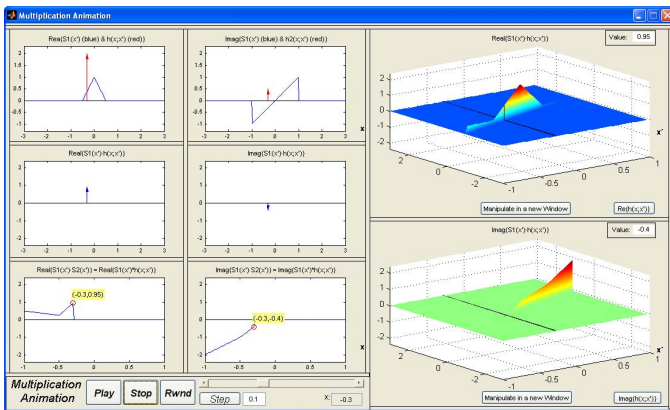


Figure 8. Real-time simulation of the modulation operator.

IV. CONCLUSIONS

A brief summary of the current development of the Generalized Signals and Systems Theory as well as the last version of the software *SSTv4.5* has been presented in this paper. The aim of it has been to present the most important characteristics of this theory through the implementation of that software tool, showing many practical examples where the GSST may be applied, most of them according to the actual level of undergraduate students (in particular Fourier and Hilbert analyses). The students can learn through this tool the way the GSST is constructed, observing some important and conceptual differences between the usual SST and our GSST, for instance, the differences between ordinary functions and generalized functions or distributions, which they can interpret it through their graphical representation, realizing that the visualization of the distributions are an intuitive representation of functions that really are not true functions. The theoretical analyses under the software tool are becoming increasingly important in research activities, especially those concerning wave problems and its connection with the Green's functions theory, as well as the extension of real variable problems to their complexified versions. It is also being important to understand the relation between functions and distributions through the RHS theory. Finally, nowadays it is being studied the possibility to include the analysis of non linear systems, very important in the interpretation of inverse problems. More details about the tool *Signals & Systems Theory* may be found in [14]-[15].

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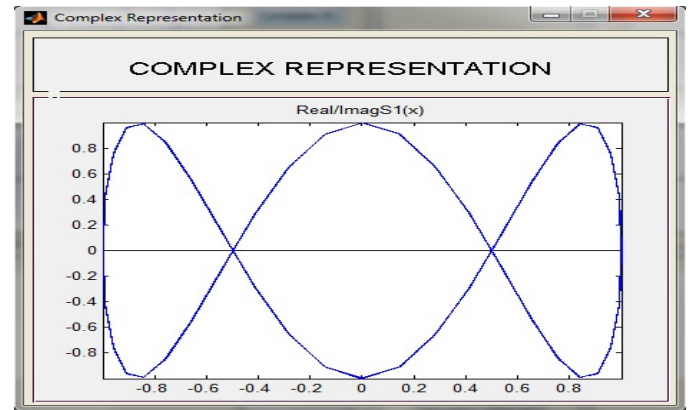


Figure 9. Example of a representation of a complex signal $f(x) = \cos(x) + j \sin(3x)$, into their complex plane.

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Work in Progress: Mesoscopic Analysis of Engineering Education Scholarship in Electrical and Computer Engineering, 2002-2011

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Abstract— Engineering education remains a relatively new and rapidly developing research field. As a result, there are significant variations in the quantity and kinds of engineering education research being conducted and published in different engineering disciplines and local/national contexts. Responding to a lack of systematic attempts to study such dynamics, this paper describes our ongoing efforts to investigate the quantity and nature of engineering education scholarship in Electrical and Computer Engineering (ECE) and allied fields over the last ten years. More specifically, we report preliminary results of an in-depth quantitative and qualitative analysis of journal articles (n=664) published in *IEEE Transactions on Education* from 2002 to 2011, including co-authorship patterns, geographic distribution of authors, and research funding reported. To help contextualize the study, the authors also discuss other studies of publication trends in engineering education research.

Keywords- ECE; electrical and computer engineering; engineering education; engineering education research; mesoscopic analysis

INTRODUCTION

As leading reformers contend, engineering education needs frequent evaluation and revision to keep pace with rapid changes in the profession [1]. Yet even well-established engineering education innovations are promoted and accepted with varying degrees of success [2]. Further, engineering education is a relatively new but rapidly developing research field, and there remain considerable gaps in this growing body of scholarship. According to Wankat, one of the reasons for these gaps is a lack of communication between engineering educators in different engineering disciplines [3]. To further explore these issues, we are investigating recent trends related to publication of education-related research and scholarship in electrical and computer engineering (ECE), one of the largest and fastest evolving engineering disciplines. Our efforts to highlight trends in ECE scholarship across the world will help: 1) bridge the communication gap between educators and researchers both within and beyond ECE, 2) reveal biases that may be unique to the disciplinary culture of ECE, and 3) explore strategies to perform “mesoscopic” analyses of other domains of engineering education. This paper describes our initial efforts to investigate and highlight the subjects and

contexts of scholarship in ECE education, as well as a variety of authorship trends. We begin with a review of related literature and then turn to methods and preliminary findings.

LITERATURE REVIEW

There have been a number of previous efforts to investigate general trends in engineering education research [4]. Wankat, for instance, performed content and citation analysis of every paper published in *Journal of Engineering Education (JEE)* from 1993 to 2002 [5]. This study also included investigation of funding trends for research in engineering education. Whitin and Sheppard similarly analyzed papers (n=398) published in *JEE* from 1996 to 2001 to identify topical and research trends [6]. Osorio and Osorio, on the other hand, performed quantitative and qualitative analysis of papers in *JEE* (n=212) and *European Journal of Engineering Education (EJEE)* (n=119) from 1998 to 2000 to highlight subject coverage, authorship characteristics, most common topics and types of scholarship [7]. Osorio later compared results of prior studies by Wankat [5], Whitin and Sheppard [6], and Osorio and Osorio [7] to discuss prevailing subjects, author demographic data, article types, and citation data [8]. Jesiek et al. [4] performed a similar analysis of more than 800 engineering education research papers published 2005-2008. Still other studies have looked at more specific domains. In 2001, Martin, Adams and Turns conducted citation analysis on five years of engineering design education papers [9], while Beddoes, Borrego and Jesiek performed bibliometric analysis of 60 papers concerned with gender [10]. Beddoes, Jesiek and Borrego also analyzed a large set of papers published 2005 to 2008 to report research trends in problem/project-based learning (PBL) in engineering [11].

Yet despite this growing body of research, Wankat was one of the first to deeply examine trends at the intersection of educational research and specific engineering fields through his study of papers published in major engineering education journals and proceedings during 2009 [3, 12]. He observed that dissemination and “cross-fertilization” of engineering education research and development is limited, which in turn hinders the research-practice cycle [3, 12]. As the author explained: “This is exactly the behavior we would expect if

there are silos in engineering education” [3, p. 521]. Our research extends this line of inquiry through in-depth investigation of education-related scholarship in one field.

METHODS

Our research involves the use of a “mesoscopic” approach to investigate the quantity and characteristic features of engineering education scholarship in ECE and allied fields [13]. The preliminary work reported here is based on in-depth quantitative and qualitative analysis of 664 journal articles published in *IEEE Transactions on Education* from 2002 to 2011. The initial themes addressed by our research are: 1) number of co-authors per paper; 2) geographical distribution of co-authors, and 3) research funding reported. Other themes will be addressed in future work. The lead author compiled all bibliographic data in Endnote, then moved to Microsoft Excel to perform analysis of relevant characteristics for all papers, e.g. recording country affiliations for each paper’s author(s).

RESULTS

The average number of authors per paper in our data set is 2.96. In addition, 144 of 664 papers (21.6%) were single authored, 151 papers had two authors, 166 papers had three authors, and 203 papers had four or more authors, up to a maximum of 25 authors. Further, 65 countries of author origin/affiliation are represented in the data set, with 255 papers (38.4%) listing one or more authors affiliated with institutions in the US. Authors affiliated with institutions in European Union (EU) member countries appear on 240 papers (36.1%). Top author locations in the EU are Spain (105 papers), the UK (36), and Greece (21). Other high-ranked countries are Taiwan (31 papers), Canada (22), Australia (18), Brazil (18), and India (18). Additionally, 64 papers (or 9.6%) have co-authors affiliated with institutions in two or more countries. Among these, the US has highest representation (30 papers), followed by the UK (14) and China (10). Of these 64 papers, 53 have co-authors from two different countries, with US-China and UK-Spain the most common pairs (4 papers each). Eight papers include authors from three countries, and two include authors from five countries. Finally, 17 papers (2.5%) had co-authors with private sector affiliations, and 262 papers (39.4%) acknowledged some source of funding.

DISCUSSION AND FUTURE WORK

Our analysis identifies the US and EU as particularly active in ECE education research, matching more general trends reported elsewhere [4]. In the EU, Spain is a very significant contributor, and Taiwan, Canada, Australia, Brazil, and India are also relatively active. The average number of authors per paper (2.96) shows that ECE education research is quite collaborative, as compared to an average of 2.6 found in a more general study of engineering education research literature [4]. There is evidence of significant funding acknowledged in many papers, which may help explain larger research teams and more co-authors. Multi-national

collaboration trends (9.6% of papers) are also notable, and consistent with an 8% general figure reported previously [4].

In future work we plan to investigate: 1) types of scholarship published in ECE education (e.g., descriptive vs. empirical work), 2) topical coverage of papers across ECE subfields, and 3) coverage of papers across major areas of educational research and practice (e.g., content, assessment, pedagogy, etc.). To analyze these themes, we are developing a taxonomy based on prior literature [e.g., 4, 5, 7, 14].

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Work in Progress: Implementation of Enhanced Guided Notes and Collaborative Note-taking in Learning Electric Circuit Concepts

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Abstract— The major aim of this research was to develop new instructional materials and strategies to support engineering students, who are not electrical engineering majors, to learn electric circuit concepts. The study focused on activity Phase #3 of the Work in Progress paper presented at the 41st Frontiers in Education conference. The implementation of this phase included: (1) implementing enhanced guided-notes (EGN) with a collaborative note-taking effort; and (2) evaluating students' notes shared in collaborative notebooks. Selected students were provided an iPad 2™ and an application which allowed editing of the EGN, while other students were provided hard copies of the different sets throughout the semester. Furthermore, students were asked to complete online social networking surveys at the beginning and end of the semester. The instructor developed EGN to facilitate note-taking and note-sharing during the semester. An online repository system was created to allow iPad-groups of students to complete and edit EGNs that were created to facilitate note-sharing submission. Students worked in groups of three or four to complete the EGN and self-evaluation sections beginning in EGN 6 and continuing to EGN 11.

Keywords—collaborative note-taking; enhanced guided notes; metacognition; electric circuit; social networks

I. INTRODUCTION

Research suggests that traditional classroom activity does not stimulate students to actively engage in learning. Instructors often experience difficulty in creating engaging learning environments, especially when dealing with large classes. Metacognitively passive students, characterized by merely listening, watching, and seldom thinking critically about the material being presented, are easily found during traditional lectures [1]. Chickering and Gamson suggested that instructors need to encourage students to engage in learning through discussion, practicing, and applying concepts and ideas that will improve academic experiences [2]. However, these activities require substantial effort in terms of lecture preparation and management. In view of the challenges, the use of guided notes has been perceived by engineering instructors and students to be useful in increasing concentration on the lecture content [3][4].

It is worth considering alternative note-taking techniques in that previous studies have proven a positive relationship

between note-taking and student performance on exams [5][6]. These new techniques may eliminate some of the shortcomings exhibited in student note-taking. Because encoding and external storage are central issues of the note-taking efforts, this study focused on 'semi-structured' or guided notes provided by the instructors. These notes reduce students' cognitive load, thereby helping them to engage in cognitive processing of lecture content, while developing relatively complete notes for later review.

II. THEORETICAL FOUNDATIONS: ENHANCED GUIDED NOTES AND COLLABORATIVE NOTE-TAKING

Standard guided notes have been used in classrooms for quite some time, and multiple studies have been conducted to evaluate their effectiveness. The guided notes consist of incomplete information with blank spaces available for student notes. They may consist of concepts, diagrams, problems, and conclusions. Previous studies revealed that students who used a guided note-taking method performed better on conceptual tests than students who did not and increased their attention level during lectures [3][4][7]. Kiewra argued that this effectiveness is associated with the increased encoding required by the students as they strive to complete the missing details [8]. Compared to standard guided notes, the enhanced guided notes (EGN) do not only contain blank spaces in which students need to provide detail information. The EGN of the current study, based upon lessons learned from previous research [3], included two new components that are not present in standard guided notes: (1) questions that prompt students to assess their metacognitive knowledge throughout the guided notes [9], and (2) the notes will be further enhanced through the inclusion of outside class activities.

This study added additional note-taking activities with a metacognitive knowledge component to the standard guided notes. Metacognition is a fundamental tool that enables learners to control their own cognition [10]. This leads learners to learn better [11]. By imposing note-sharing with others in the class and prompting metacognition of this collaborative process, we will further enhance the students' metacognition. Lehl and Fischer connected the information processing theory to the social constructivist theory introduced by Vygotsky, which suggested that learning occurs when students actively construct

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their knowledge based upon social interaction [12]. In educational practice, these interactions should assist students to become actively aware of their knowledge.

III. PURPOSE, GOALS, AND SIGNIFICANCE OF THIS STUDY

The purpose of this research was to develop new instructional materials and strategies to support engineering students, who are not electrical engineering majors, learning electric circuit concepts. The goals of the study were: (1) to develop, implement, evaluate, and understand the metacognitively and collaboratively EGN for classroom instruction in electric circuit concepts, and (2) to understand how students' note-taking is impacted by collaborative online note-taking activities and to develop guidelines for EGN.

The collaborative note-taking was added to our EGN for three reasons: (1) to help students explore other essential information that may not be included in the guided notes; (2) to become familiar with different views of interpreting information from other students; and (3) to expose students to alternative note-taking strategies. The first reason for including collaborative note-taking is that for each topic, there are aspects of the course materials that are not covered during the lecture. The materials may be part of the course materials, but insufficient time is available for detailed coverage during lectures. The second reason is to help students to become familiar with different views and clarify information with their classmates. When the faculty is unavailable, access to information occurs through the social networks. Moreover, the collaborative note-taking implemented electronically will give new learning experiences to students.

IV. THE STUDY

During the spring semester 2012, two activities were conducted: (1) implementing the EGN with a collaborative note-taking effort; and (2) evaluating students' notes shared in the collaborative notebooks. Furthermore, an online social networking survey was asked twice, at the beginning and end of the semester. The subjects for this research were 66 engineering students enrolled in the Fundamental Electronics for Engineers course at Utah State University. Twenty-six randomly selected students were provided an iPad 2TM and an application which allows editing of the EGN, while the remaining students were provided hardcopy version. In addition to the randomly-selected students, five students who had their own iPad and were interested in participating were assigned into the iPad-group students. Students worked in groups of three or four to complete the EGN.

Thirteen sets of EGN were developed for the class and six of them were selected (e.g., Network Theorems, Capacitance) to facilitate note-taking and note-sharing during the semester. A network attached storage (NAS)-based online system was created to allow the iPad-group students to complete and edit EGNs on PDF-formatted files and to facilitate note-sharing submission (see Figure 1). When homework was due, paper-group students submitted a single completed copy of the corresponding EGN represents their group to the instructor and each iPad-group member submitted their own copy through a

repository server. Centrality Social network analysis technique will be employed to examine the impact of collaborative, online note-taking activities on the students' informal social networks. Upon completion of this phase, we will answer 3 research questions: (1) Does the collaborative component of collaborative note-taking impact the social networks (and implicitly social capital) of the student learners?; (2) If the collaborative component impacts the social networks, does this change impact student performance?; and (3) Does the use of EGN with collaborative note-taking impact the contents and form of students' notes compared to EGN alone?

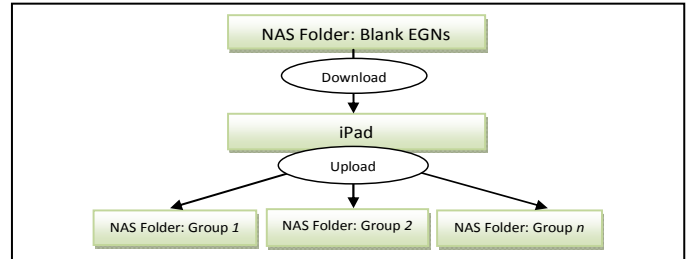


Figure 1. System architecture of EGN-based collaborative note-taking

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Tradeoffs Implementing Digital Control Systems for Electrical Engineering Course Projects

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Abstract - This paper discusses the tradeoffs of using two different approaches for designing and implementing digital control systems for electrical engineering course projects. The usage of an off-the-shelf microcontroller unit (MCU) is explored and contrasted to the more traditional approach based on personal computers (PCs), data acquisition cards (DaqCs), and programs like RTW, LabView, and Matlab/Simulink. We discuss how an MCU-based approach was developed and tested in the design and implementation of a two-loop digital feedback control system for a Ball-and-Beam mechanical system. Results show that by using an MCU it is possible to achieve a performance comparable to that of using PC's and data acquisition cards with the added advantage of exposing students to an experience closer to the actual way most digital control systems are implemented in practice.

Keywords – *Control systems education, ball-and-beam system, microcontroller applications, laboratory experiences.*

I. INTRODUCTION

Control systems education is one of the core education components in most accredited Electrical Engineering (EE) programs in the nation. An early study found that within a representative sample of EE programs in the US, roughly, 50% require at least one course in control systems, and from these, more than three quarters require laboratory work [1]. An informal search in the public information of schools in that study revealed that this pattern is still prevalent or has improved, highlighting the relevance of an experimental experience in control systems education.

The traditional way of carrying control systems laboratory experiences and implementation projects has revolved around the usage of personal computers (PCs) and software-based environments. Multiple evolving modalities have been reported through the years, ranging from command-line based interfaces to graphical user interfaces, including virtual and remote environments with diverse features and educational objectives [2-8].

A few implementations in the academic environment have reported the use of circuit components and digital controllers, mainly for demonstrational purposes [9-11].

PC's, data acquisition cards, programs like LabVIEW, Matlab/Simulink, and other similar tools are used because they make the implementation details transparent to students, requiring them to concentrate mainly on the control algorithms and mathematics behind a particular problem. While this proves convenient at introductory levels, for advanced courses like the senior capstone design project, where students shall be prepared for real-life experiences, using exclusively this approach for implementations might result limiting. Hiding details like dealing with data converters (ADC/DAC), sensor conditioning, and actuator drivers and their integration, might hinder student's practical abilities for dealing with real life problems, like those found in industry environments. Senior students need to recognize all the details behind a digital control system implementation.

In his paper we discuss tradeoffs of using several approaches for designing and implementing digital control systems for electrical engineering course projects. In particular, we have developed different implementations of the digital feedback control systems for a Ball-and-Beam mechanical system. We have been using the Ball-and-Beam system (BBS) as an educational tool in our Process Instrumentation and Control Laboratory since 1994. Originally, the digital controller implementation used LabVIEW, but since 1998 we moved to use WinConTM modules with data acquisition cards and personal computers running MATLAB/Simulink. WinCon runs Simulink generated code using a real-time environment (RTW). The alternative approach presented in this paper implements the controller directly on a commercially available microcontroller unit (MCU). Having the same application implemented both ways allowed us to analyze the pros and cons of having students familiarize with digital control systems by going through all the implementation details.

The rest of this document has been organized as follows. The next section provides information of the educational setting where this experience took place. Section III discusses the implementation experience using both, a Matlab/Simulink approach and an MCU. Section IV provides a comparative analysis of the technical merits of each implementation, to then discuss in the last two sections the lessons we learned with this experience and our concluding remarks.

II. BACKGROUND

A. Educational Background

The experience reported in this paper was developed in the Process Instrumentation and Control Laboratory (PICL) of the Electrical and Computer Engineering Department of the University of Puerto Rico at Mayagüez. The story of this laboratory was reported in [12] and later results on digital control design projects were reported in [13]. The laboratory is a workshop type environment for designing, simulating and implementing digital control systems for term projects of several control area courses. The educational goals of the laboratory are to provide a real implementation experience for students taking the courses.

B. Traditional Control System Education

The PICL serves both introductory and advanced level students. At the novice level, PICL supports the Introduction to Control Systems course (INEL 4505), a required core course for all EE students in our program. Students choosing Control Systems as emphasis area must also take the Digital Control Systems course (INEL 5508) as well as other advanced control systems courses. In this paper we focus primarily on these two courses.

In INEL 4505, students complete several homework problems and implement them in the laboratory; there is no term project requirement. The BBS is used as the system for these homework problems. In the first homework set, students develop the system's mathematical model, linearize its nonlinear equations, and determine the system's transfer functions in the s-domain. In the second homework set, students design, simulate, and implement a controller for the SRV02, a servomechanism developed by Quanser, Inc. which is used as the actuator of the BBS. In the fourth and last homework set, students design, simulate, and implement the controller for the BBS. These designs are done assuming that the controller will be implemented in continuous-time. The implementation is done using a digital computer with a fast sampling rate so that the effects of sampling are insignificant. This eases the implementation in a convenient way for students in an introductory course. Since digital control is not taught in this course, it is not necessary to enter into the issues of sampling effects.

In INEL 5508, a term project is assigned with the BBS. In this project, students have to take into account the effects of sampling. They select a sampling period to comply with the Shannon's sampling rate, discretize the continuous-time system, design a controller in the z-domain, simulate the controller performance, implement the controller in a digital computer, and validate the controller performance. Traditionally we have implemented these controllers using Simulink and WinCon. This approach works fine, but lacks the experience of dealing with a digital controller's hardware and directly implementing a difference equation in the hardware. Implementing the controller with a MCU adds this experience.

C. Alternative Approach

The alternative approach uses an MCU to implement the digital controllers. Using an MCU brings additional

experiences into the project. Students will not only need to concern about the traditional control concepts, but also will need to deal with signal conditioning issues, algorithm development, and MCU programming to implement the digital controllers. This experience is closer to the way digital controllers are implemented in industry.

To develop the BBS controller, the MCU selected was a Texas Instrument's MSP430. All control algorithms were written in C language using Code Composer Studio. In particular, the system was implemented on an MSP430FG4618/F2013 experimenter's board. This platform resulted particularly convenient due to its on-chip analog front-end. The availability of an embedded 12-bit DAC along with 12- and 16-bit ADCs in the MCU, plus plenty of timers and a friendly programming interface made the FG4618 an appropriate choice for this application.

III. IMPLEMENTATION EXPERIENCE

A. System Description

The Ball-and-Beam System is a classical application that provides a naturally unstable, nonlinear, open-loop system frequently used to teach modern control systems theory. Figure 1 shows a simplified diagram of a BBS mechanical assembly. We use a BBS unit developed by Quanser, Inc. [14].

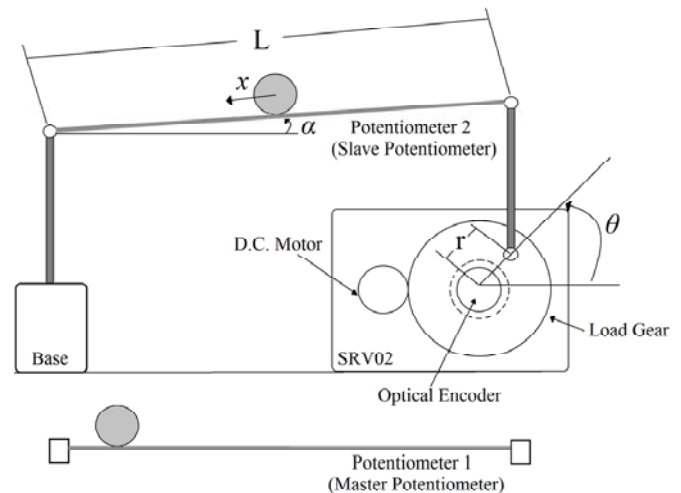


Figure 1: Diagram of the Ball & Beam System.

The BBS is equipped with two beams that form potentiometers when a metallic ball rolls over them. One of them, namely the master beam, is fixed while the other, designated the slave beam, is attached to a SRV02 DC motor with gears and sensors. When the SRV02 gears rotate, they tilt the slave beam, making the slave ball to roll over the beam. The angular position of the SRV02 gears is measured using a quadrature optical encoder. The control objective of this system is making the slave ball follow the trajectory of the master ball as closely as possible.

B. System Specifications

The system required an MCU with at least one ADC with two analog inputs to measure the voltage of the two

potentiometers and one DAC with one analog output to actuate the motor. Both the ADC and the DAC required a resolution of at least 12-bits. The MCU must also provide digital I/O ports, embedded timers, and interrupts. Since most MCU ADCs only accept positive voltages within their reference range, it was required to design signal conditioning circuits to rescale the analog signals from the potentiometers. Another signal conditioning circuit, an LS7084 from USDigital, was required to interface the output from the quadrature optical encoder. Tables I and II summarize the system hardware specifications.

TABLE I. MCU BALL & BEAM SYSTEM SPECIFICATIONS

| MCU | Specs | Developer |
|--|--|-------------------|
| MSP430FG4618/F2013 Experimenter's Board | 12-bit DAC 12-bit SAR ADC 16-bit Sigma Delta ADC | Texas Instruments |

TABLE II. SIGNAL CONDITIONING CIRCUIT SPECIFICATIONS FOR MCU

| Circuit Type | Specs | Description |
|--------------------------|--|---|
| Span and Zero Amplifiers | $V_i = \pm 5V$ $V_o = 0$ to $2.5V$ Summing Inverter Amp $A_v = 0.25$ V/V Inverter Amp with Unit Gain ($A_v = 1$ V/V) | Used for two potentiometers. (OP07 Op-amps) |
| Differential Amplifier | $V_i = 0$ to $2.5V$ $V_o = \pm 5V$ $A_v = 4$ V/V | Used for SRV02 D.C. motor. (OP07 Op-amps) |
| Optical Encoder Chip | $V_i = 5V$ (Logic "1") $V_i = 0V$ (Logic "0") | Used to read the optical encoder. (LS7084) |

C. Matlab/Simulink Implementation

In this implementation, the BBS digital feedback controller was implemented in a virtual instrument (VI) provided by Matlab/Simulink on a PC using a WinCon interface. This is the same implementation used in the Introduction to Control Systems course. The structure of the digital controller is shown in Figure 2. It used a two-loop feedback, where the inner-loop was a proportional-only compensator used to control the SRV02 and the outer-loop was a phase-lead compensator used to regulate and stabilize the whole BBS. The dashed box in Figure 2 indicates the blocks that were implemented inside the PC. Table III contains a description of the blocks in Figure 1.

TABLE III. BLOCK COMPONENTS DEFINITION

| Component | Definition |
|-----------|--|
| R | Desired response(master potentiometer) |
| C | Actual response(slave potentiometer) |
| G_{c1} | Outer loop phase-lead compensator |
| G_{c2} | Inner loop proportional compensator |
| G_m | SRV02 transfer function |
| G_b | Ball's dynamics transfer function |

$G_m(s)$ and $G_b(s)$ in Figure 2 correspond to the SRV02 and ball's dynamics transfer functions, respectively. These are derived using *Kirchhoff's Voltage Law* (KVL), Newton's laws of motion and parameters given in the Quanser's Ball and Beam Student Handout [14].

Two control approaches were used. The first used a digital control system with the outer-loop phase-lead compensator designed in the continuous-time domain and transformed to the discrete-time domain using a *bilinear transformation* (BLT). The second had the compensator directly in the discrete-time domain using the z-Transform. The design criteria for the BBS performance were: settling time less than or equal to 2 seconds and overshoot less than or equal to 20%. The results of these two approaches were evaluated by comparing the performance of controllers implemented in Matlab/Simulink with those implemented in the MCU.

For the first approach the system transfer function was obtained in the continuous-time domain without considering sampling and hold. This function is presented in (1), where all sub-functions are all in the "s" domain. Compensators $G_{c1}(s)$ and $G_{c2}(s)$ were designed using Matlab's Root Locus Tool GUI. Since compensator $G_{c2}(s)$ is a constant gain, it was implemented directly into the digital control system but $G_{c1}(s)$ needed to be transformed using the BLT. The sampling period for this approach was set to be $T = 17.5$ ms.

$$\frac{C(s)}{R(s)} = \frac{G_{c1}G_{c2}G_mG_b}{1 + G_{c1}\frac{G_{c2}G_mG_b}{1 + G_{c2}G_m}} \quad (1)$$

The structure of the phase-lead compensator is

$$G_{c1}(z) = \frac{K_d(z - z_0)}{(z - z_p)}, \quad (2)$$

where K_d is the gain, z_0 is the zero, and z_p is the pole of the compensator. Table IV shows the resulting discrete-time compensator designed in the continuous-time domain.

For the second approach, the effects of samplers and zero-order-hold (ZOH) were considered. The transfer function is presented in (3), where all terms are in the discrete-time or z-Transform domain and analysis techniques for sampled-data closed-loop systems were used.

TABLE IV. MCU BALL & BEAM SYSTEM SPECIFICATIONS

| Inner Loop Compensator $G_{c2}(z)$ | Value |
|------------------------------------|--------|
| $G_{c2}(z)$ | 5 |
| Outer Loop Compensator $G_{c1}(z)$ | Value |
| K_d | 94.882 |
| z_0 | 0.9792 |
| z_p | 0.7595 |

$$\frac{C(z)}{R(z)} = \frac{3 \left[\frac{G_b G_m}{s} \right] (1 - z^{-1}) G_{c2} G_{c1}}{1 + 3 \left[\frac{G_m}{s} \right] (1 - z^{-1}) G_{c2} + 3 \left[\frac{G_b G_m}{s} \right] (1 - z^{-1}) G_{c2} G_{c1}} \quad (3)$$

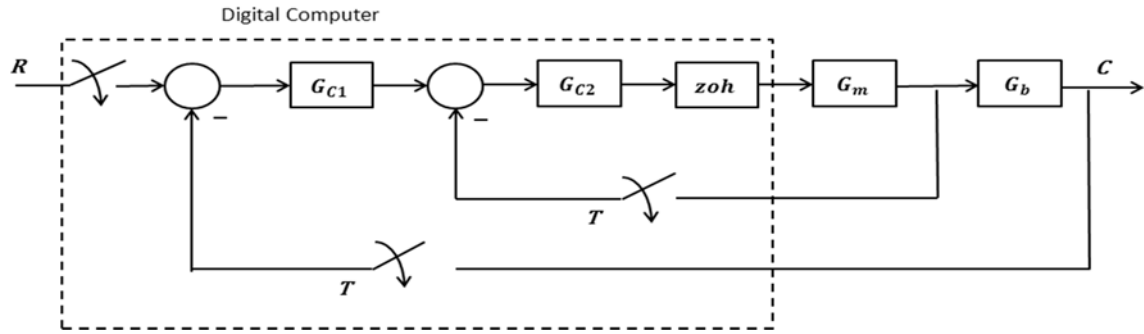


Figure 2. Digital control block diagram for the ball and beam system.

For designing controllers $G_{C1}(z)$ and $G_{C2}(z)$, the Root Locus method in the “Z” plane was used. The sampling period T for this approach was 28.6ms. The resulting compensator using this approach is shown in Table V.

TABLE V. DISCRETE TIME DESIGNED COMPENSATOR IN THE “Z” DOMAIN

| | |
|------------------------------------|--------|
| Inner Loop Compensator $G_{C2}(z)$ | Value |
| $G_{C2}(z)$ | 5 |
| Outer Loop Compensator $G_{C1}(z)$ | Value |
| k_d | 91.648 |
| z_0 | 0.9668 |
| z_p | 0.6196 |

D. MSP430 Implementation

The MCU BBS implementation consisted of two parts: the hardware components including the signal conditioning circuit; and the BBS compensators written in C-language.

The signal conditioning circuit consisted of two attenuators, one for each potentiometer; an amplifier for the motor output voltage, a low pass filter for the master potentiometer; and a quadrature clock converter to read the optical encoder. Figure 3 shows a block diagram of the hardware components. The attenuators were used to bring the -5V to 5V potentiometer outputs to the 0 to 2.5V accepted by the MCU. Since the motor operated with voltage in the range from -5 to 5V, an amplifier was necessary to raise the DAC voltage output. The low pass filter was used to reduce the master potentiometer noise output, improving the accuracy of the ADC readings.

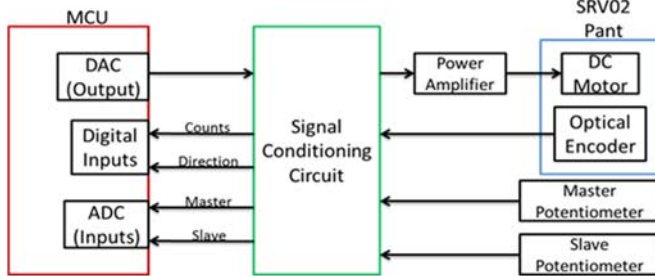


Figure 3. Block Diagram of MCU-Based BBS Implementation.

The algorithm for the software implementation was developed using the Code Composer Studio from Texas

Instruments. Figure 4 shows a flowchart of the designed control algorithm.

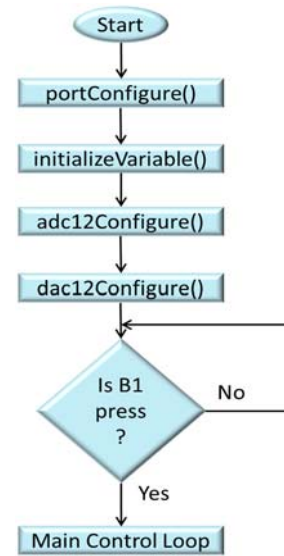


Figure 4. Control algorithm flow chart.

The program sequence is as follows: configure the necessary I/O ports, initialize the control variables, and configure the ADC to sample the potentiometers at the selected frequency and the DAC to command SRV02. The program then waits for a start button to be pressed for entering the main control loop where the sampling process and control actions take place.

In the main control loop, the algorithm starts the ADC and waits for one of two interrupts to occur: (1) ADC end-of-conversion, indicating the readings from the potentiometers are complete; (2) a quadrature encoder signal via port 2, indicating the wheel angle. Figure 5 shows a state diagram of the loop. Port2 ISR adjusts the rotation angle of SRV02 according to the sampled potentiometers' reading.

IV. COMPARATIVE ANALYSIS

Table VI shows the step-response performance characteristics for each design method and each implementation approach. Of the two design methods, the

best performance resulted from the z-Transform yielding smaller settling time and smaller steady-state error.

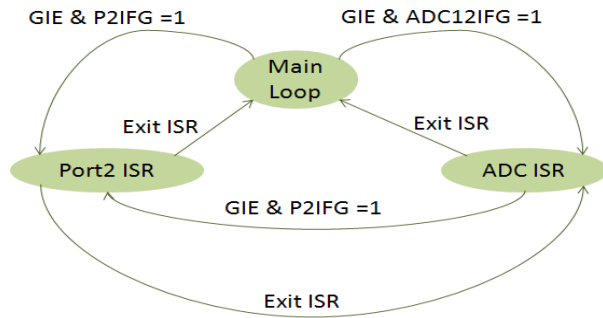


Figure 5. Main control loop state diagram.

TABLE VI. MATLAB/SIMULINK AND MCU IMPLEMENTED COMPENSATORS

| Design Method | Settling Time (sec) | | % Overshoot | | SS Error (m) | |
|---------------|---------------------|------|-------------|-------|--------------|-------|
| | MatLab | MCU | MatLab | MCU | MatLab | MCU |
| BLT | 2.59 | 1.77 | 4.78% | 1.25% | 0.004 | 0.001 |
| Z-Transf. | 2.54 | 1.50 | 3.77% | 2.72% | 0.001 | 0.001 |

A. Simulink Implementation

The step-response using the z-Transform designed phase-lead compensator running in Simulink is shown in Figure 6 where three signals are shown: (1) a step given by the master ball, representing the desired position in meters; (2) the simulated response obtained from a linear simulation of the model in Simulink, representing how the real response should ideally look; and (3) the actual response obtained from the slave ball. Neither compensator designed met the settling time requirement; but both met the overshoot and the steady-state error requirements. This suggests that the settling time requirement may have been too strict.

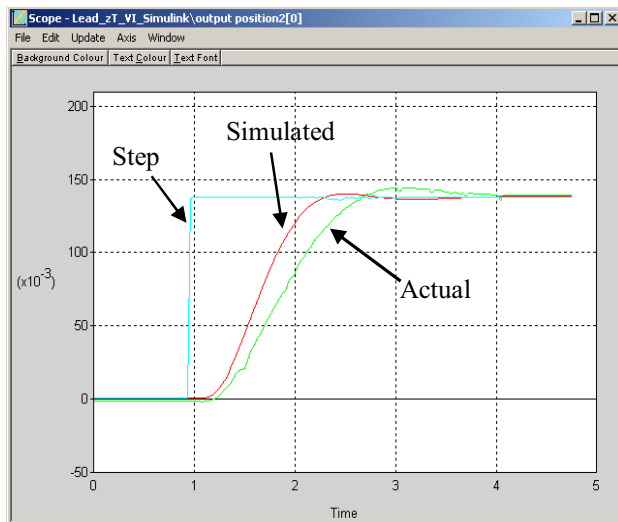


Figure 6. Z-Transform Lead Compensator Response Running in Simulink

B. Embedded System Implementation

The same compensators used on the Simulink implementation were also implemented in the embedded system through the MCU.

Table VI shows the step-response performance characteristics for the BLT and z-Transform designed phase-lead compensator running in the MCU. Both design methods accomplished the desired performance in contrast with the Simulink implementation for the same compensators. Both yielded approximately the same steady-state error and their percent overshoot was within the design requirements. The smallest settling time was achieved by the z-Transform designed compensator compared to other implementations. Figure 7 shows the step response of the system with the controller implemented in the MCU.

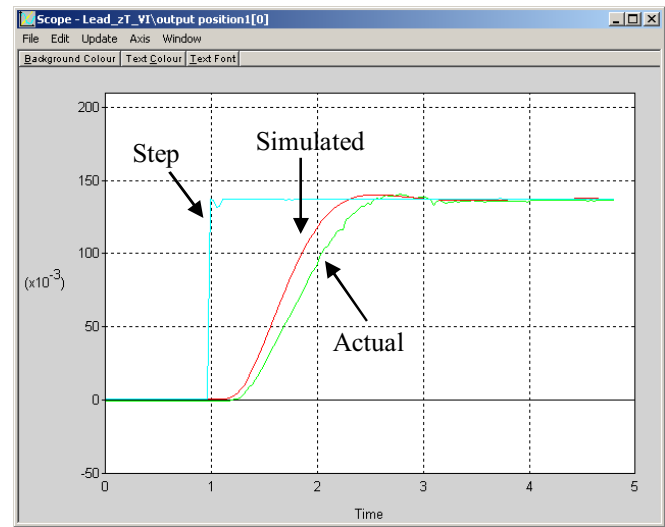


Figure 7. Z-Transform Lead Compensator Response Running in MCU.

C. Continuous-Time Domain

The first approach in both, embedded and Simulink implementations, was to design in the continuous-time domain and discretizing the compensators using the BLT. Even though the design is simpler using the BLT and similar performance was obtained, it was more difficult to accomplish the desired settling time. This is so because this approach is an approximation to the actual digital control implementation.

D. Discrete-Time Domain

In contrast to the continuous-time approach, in this method, the compensator was designed via Root Locus directly in z-domain resulting in a better performance. The performance is better because the design is done directly in the domain in which the controller is implemented.

E. Analysis

Both compensators implemented in the MCU, the BLT design and the z-Transform design, complied with all the required performance characteristics. Both simulated responses were similar; but not identical to the real

responses. The reason for this is that the simulated response comes from a linear simulation; but the real system is nonlinear.

The best performance characteristics were obtained from the z-Transform designed phase-lead compensator implemented in the MCU. The steady state-error that resulted from both implementations may be reduced even more with a lead-lag compensator; but this was not done for this project.

V. LESSONS LEARNED

A. Obstacles

The learning curve for the two students working on the project was a little slow. The project was developed in an undergraduate research setting. The students had to work with signal conditioning circuits, digital control algorithms, and MCU programming.

B. Benefits of each experience

We have had experience with the PC and data acquisition card implementation. This experience has proven to be suitable for introductory as well as for advanced undergraduate courses. However, the MCU implementation adds new dimensions to the implementation experience.

VI. CONCLUSION

We have presented several approaches for implementing digital control systems for electrical engineering projects. The Matlab/Simulink approach using PC's and data acquisition cards has proven suitable for introductory courses as well as for advanced undergraduate courses because it makes the implementation easier for the students. The MCU approach adds new dimensions to the implementation experience since it brings several new issues into the problem such as signal conditioning, digital control algorithms, and microcontroller programming. This approach is only recommended for advanced undergraduate courses such as INEL 5508. Next semester we will try the approach in the actual course with a reduced number of student teams.

VII. ACKNOWLEDGMENT

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Work in Progress: From Sage on the Stage to Guide on the Side: examining shifts in teaching practice through stories of open community participation

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Abstract – Many professors are reluctant to transform their teaching practices from "sage on the stage" to "guide on the side" for understandable reasons. Facilitating student work in a potentially unfamiliar setting has a steep learning curve and requires professors to relinquish control of their classrooms without assurance their career evaluations will benefit. However, professors who do transform their teaching practices continue to report exactly the same concerns – so how *does* the sage-to-guide shift occur? This work-in-progress paper describes early efforts in a grounded theory study whose initial participants are professors who have involved their classes in open software, hardware, and content communities, a choice which requires such a shift in teaching practices for successful student participation. Inspired by the radical transparency of the open communities our participants work with, the study itself is an open content project, creating a public compendium of teaching transformation stories that can be accessed by educators considering similar transformations to their own teaching practices.

Keywords: free and open source software (FOSS), teaching open source, storytelling, grounded theory

I. INTRODUCTION

Professors who involve their students in open communities – Free and Open Source Software (FOSS), hardware, and content projects – make an ideal population for a study on transforming teaching practices. While demographic characteristics such as institution type, discipline, and seniority vary widely between professors, the *types* of teaching practice transformations required to involve students in open projects are very similar, largely involving giving up predictability and control [1]. The radical transparency practices of open communities mean there are far fewer confidentiality issues in discussing a class's participation in a project, and some faculty members even blog or publish about their experiences [2][3][4], but the practice of "teaching open source" is new, so the literature is sparse and anecdotal. This work-in-progress paper is a first empirical investigation of the "teaching open source" faculty population that looks for themes that may illuminate teaching practice transformations in engineering education more broadly.

II. THE STUDY

A. Subjects

Our interviewees are members of teachingopen-source.org, a distributed community of practice [5] centered around an open mailing list and dedicated to supporting teachers in bringing open community participation into their classrooms. They are participating in this research voluntarily and without compensation. All participants have significantly modified their teaching practices for at least one undergraduate course (typically in STEM) without administrative mandates or departmental support. They range from new assistant professors to department chairs and teach everywhere from small private institutions to large public ones; their motivations include giving students a real-world project experience, broaden STEM participation demographics, and building student portfolios as well as their institution's public profile.

B. Research procedures

This project uses a grounded theory approach [6] to focus on shifts in teaching practice when open community participation is used in postsecondary STEM education. Each interview with a professor lasts approximately 90 minutes and is conducted in-person, taped, and transcribed. Interviewees are asked to tell the story of how they came to "teach open source" several times, focusing on different aspects with each pass: their motivations to incorporate open community participation into their courses, the concerns and challenges they faced throughout their journey and how they addressed them, the specific transformations they have noticed in their teaching practices as a result, and the resources they drew upon.

This project also uses a radically transparent research approach that mirrors the practices of the open communities our participants work with. Since our subject pool of faculty members already writes and collaborates publicly about their experiences in teaching open source, and is a non-vulnerable group already aware of research practices such as informed consent, we eschewed the usual practice of analyzing confidential, de-identified datasets behind closed doors. Instead, we assigned the copyright of interview transcripts to our interviewees, who then released "public" versions of their data under a Creative Commons license. At present, 3 transcripts have been released, with more in the pipeline for

2012. Only the public dataset is analyzed, and other artifacts of the grounded theory process such as open coding and memos are made available online under similarly open licenses, which allows participants and the open communities they work with to see – and contribute to – the “source code” of our research, allowing a broader population to engage in the project.

Participants are thus aware of each others' identities, and are prompted to refer to and compare their journeys with one another when possible, giving us multiple perspectives on an individual professor's path. Participants also pose questions they would like other interviewees to answer and respond to questions posed by prior interviewees. Responses to the radically transparent approach have been overwhelmingly positive, with participants reporting unexpected insights from going “behind the scenes” as well as changing their perspectives on the practice of research.

III. SOME PRELIMINARY FINDINGS

With only 3 interviews in the public dataset for analysis, it's too early to give definitive results; however, here are some examples of emerging codes and themes.

A. “Community” as a just-in-time enabler

Professors described the process of learning to trust that open communities will “be there” to support them and their students when problems arise, and finding that collaborative opportunism unlocked a different sort of potential in the classroom. As one participant described it, “[students] will learn so much more than if I teach them... I didn't want to be the limiting factor in learning.” This approach of instructors acting as mentors who understand (but aren't necessarily able to perform at) expert practice is common in cognitive apprenticeship models where students are encouraged to explore different directions and find “experts” themselves [7].

B. Add one new teaching practice idea at a time

The transformation process is incremental; faculty don't jump from lecturing-based instruction one semester to project-based FOSS group work in the next. The seemingly radical practice of “teaching open source” builds atop previously held values and teaching experiences. For instance, one professor's “old” class design used project-based teams and service learning, but worked with a local community rather than a distributed open one. Another used the software infrastructure of another faculty member's “open community” course before designing the use of the same tools into his own classes, and others “taught open source” to small groups of independent study students before bringing the experience into formal classes. Taking small steps can help faculty become more comfortable in working with open source communities and their working principles.

C. Accepting the tension of feeling “unprepared”

Despite holding PhDs in their field, all the professors we interviewed were concerned about not having the technical background needed to participate in open communities. Not having done *exactly* what their students were about to do was

a constant source of stress; they had to consciously adjust their expectations of themselves and their class to adapt to a teaching model where students regularly learned things the professor didn't know. Professors also wished for more time to the same learning experience similar as their students. As one said, “I will have less contributor experience [after the class] than my students do... the nitty-gritty detail is something that I would like to actually have more experience with too.” This is reminiscent Lave and Wenger's work in situated cognition, where the masters of apprentices are transformed through acting as colearners [8].

IV. FUTURE WORK

We continue to work through the grounded theory process of collecting and analyzing data and will move into selective coding, theoretical sampling, and reading of the literature over the next few months [9].

ACKNOWLEDGMENTS

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Stories of Change: How Educators Change Their Practice

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Abstract - Innovative tools and teaching practices often fail to be adopted by educators in the field, despite evidence of their effectiveness. Naïve models of educational change assume this lack of adoption arises from failure to properly disseminate promising work, but evidence suggests that dissemination via publication is simply not effective. Instead of studying the adoption or rejection of a particular intervention, this paper turns the problem around. We asked educators to describe changes they had made to their teaching practice and analyzed the resulting stories to learn more about: the kinds of changes being made, their motivations for changing their practice, and the means by which they learned of pedagogical innovations. Of the 99 change stories analyzed, only three demonstrate an active search for new practices or materials on the part of teachers, and published materials were consulted in just eight of the stories. Most of the changes occurred locally, without input from outside sources, or involved only personal interaction with other educators. These results have important implications for educational developers, or researchers wishing to propagate information about new teaching materials or techniques.

Index Terms – Change of practice, Change stories, Sharing practice, Education research

INTRODUCTION

The computing community continually creates and evaluates teaching tools and techniques, but these efforts are of reduced value unless promising practices are actually *adopted* by educators in the field. In recent years there has been a growing emphasis on dissemination efforts to help bridge this gap. The solicitation for the National Science Foundation's TUES program, for example, states that "transferability and dissemination are critical aspects for projects developing instructional materials and methods and should be considered throughout the project's lifetime. More advanced projects should involve efforts to facilitate adaptation at other sites."

Unfortunately, there is little evidence that enhanced efforts at dissemination are working. A report to the National Research Council in 2008 found that "NSF- and association-funded reforms at the classroom level, however well intentioned, have not led to the hoped for magnitude of change in student learning, retention in the major, and the

like in spite of empirical evidence of effectiveness" [1]. Failure to adopt effective practices is not limited to computing or education. A meta-analysis of 743 reports, books, and articles in 2005 found that dissemination alone was not an effective implementation method in human services, education, health, business, or manufacturing. [2]

But if dissemination is ineffective, how should the computing community maximize the impact of effective tools and practices? Previous work in computing education has studied how specific tools and approaches have been adopted (or ignored) [3]-[6], and the incorporation of teaching materials from repositories [7]-[8], but much remains to be learned about how instructors decide to change their practice and how those changes are informed, implemented, and evaluated.

This paper studies the problem from the other end of the adoption process: We asked educators to describe changes they had already made to their teaching practices, in an effort to shed light on mechanisms and approaches that led instructors to those changes. We then analyzed the resulting stories to learn more about the kinds of changes being made, instructors' motivations for changing their practice, and the means by which they learned of pedagogical innovations.

CHANGE STORIES

Stories of teachers changing practice were gathered in the context of the Sharing Practice¹ project. Stories were solicited in response to the prompt:

Can you think of a time when something—an event, an article, a conversation, a reflection, an idea, a meeting, a plan—caused you to make a change in your teaching? What was it? What happened?

102 stories were collected over four weeks in February and March 2011, of which 99 were usable. Stories were gathered via a webpage, and subsequently face-to-face, both individually and via a "story-circle" held at the ACM Special Interest Group on Computer Science Education (SIGCSE) Symposium in March 2011. Each contributor provided a story of their change, gave it a title, and attached keywords. Some contributors added several stories. Additionally, some demographic information was collected

¹ <http://www.sharingpractice.ac.uk>

for each contributor, including, age, gender, length of career, and length of time in current institution.

For each story, contributors were asked to indicate how they felt about the change in the story in respect to several questions that elicited meaningful metadata about the experience. These questions were presented as *polarities*, using the concept of *opposing negatives* where “a desired or anticipated quality of the field is identified and the two end labels are provided as the thing not present and alternatively the thing taken to excess” [9]. To give an example from this study: “The change this story describes is limited to individual practice” at one end to “The change this story describes involved programmatic change (QA)” at the other.

Contributors were asked to make a mark on the scale that “best described” change in their story; polarities did not have scales marked on them, so contributors were not selecting from fixed values. Contributors were also asked to select from lists of mutually exclusive options asking them: how they felt about the story, whom they thought should pay attention to it, and how long they would remember it.

CHARACTERISTICS AND LIMITATIONS OF THE SAMPLE

Because of the situation of the project, there is inbuilt bias in the sample. Most contributors were personally solicited, either by a member of the Sharing Practice project team, or from related projects – these related projects are mentioned in several stories. The majority of the contributors (56) taught Computer Science or a closely related subject (e.g. “information systems” or “databases”) and the majority of stories (82) were contributed by someone with more than 10 years teaching experience. The great majority of contributors (80) were over 40; the largest representation is in the 40-49 age group (36). 64 contributors had taught at their current institution for more than 5 years, 34 of those for more than 10.

The type of change described was also heavily skewed to the positive. There were only thirteen stories which contributors did not feel “glad” or “enthused” about, and only one which was unequivocally negative (and about which the contributor felt “angry”). This contrasted with our (anecdotal) experience where colleagues often talk of forced or imposed change, whether instituted because of resource constraints, management dictat or departmental fashion-following. At a Share project workshop, for example, a contributor told of their forced changes “Revamp the whole thing in two weeks!. There’s not even time for people to think about how they could adopt a different approach ...or make connections from different models”³. And, over the years, we have heard several versions of “we are all doing problem-based learning now” or “everything’s agile these days”. We brought these impressions to the data, and expected to find such stories reported there.

The story corpus was relatively evenly balanced in terms of gender with 54 male and 44 female contributors,

and also for institution-type with 28 research-intensive, 36 teaching-intensive and 31 mixed teaching-and-research institutions represented.

ANALYSIS OF POLARITIES

Analysis of the polarities revealed some interesting patterns. For example, when asked who was affected by the change in their story, there were notable differences in response dependent on how long the contributor had been teaching, and on the time a contributor had been at their current institution. In both cases the longer the time, the more the response moved from the change affecting individual practice only towards affecting other colleagues and then programmatic change. (See [10] for more details on the methodology used, and additional results.)

Work from the Effective Projectwork in Computer Science (EPCoS) project suggested that educators most easily adopt small pieces of practice — things that they can implement “under the radar”, without asking others’ permission, or involving QA procedures [11]. Evidence from this study, however, suggests that the observation from the EPCoS project may be more relevant for early-career, or less experienced, teachers. As teachers become established within a department it may be that they become increasingly involved in programmatic activities, or that they are more prepared to claim programmatic influence.

We also asked how teachers themselves felt about the change described in the stories, whether they considered it *addictive*, whether they *adapted to it* or whether they *distrusted* it. There was only one story that showed strong affinity with change being addictive. Those stories most strongly associated with “distrustful” were from teaching-intensive or mixed teaching-and-research institutions. At the same time, when we asked what the source of change was — individual agency, local culture or external driver — then those who said that the source was “individual agency” were mostly from research-intensive institutions. Teachers from research-intensive institutions were also most likely to claim a limited audience for their change — “no one special”, or sometimes “the department”. This may suggest that change is more likely to be imposed on staff at teaching-intensive institutions, and that staff in research-intensive institutions are more likely to “try things out” on their own cognizance.

When we questioned the nature of the change — whether it was new to the department, new to the discipline or totally new — there was a small, continuous, effect that the older the contributor and/or the longer they had been in their career (that is, the more years of experience they had) the more likely they were to say that the change their story described was “totally new”.

ANALYSIS OF STORY TEXT

We found that we had questions of the stories that the analysis of polarities could not address. We wanted to ask what had *triggered* the change that the stories reported, we were interested in what *sort of changes* they described, we wondered how instructors determined the *details* of their

³ This quotation is from the Active Learning in Computing Workshop, December 4th 2009.

change. To look at these questions we undertook a more traditional qualitative analysis, taking the story texts as our data. Four researchers independently coded the stories, each noting aspects of interest. Three explicitly sought the catalyst for the change. A fourth researcher noted the source used to inform change and how that source was discovered. Below we report our observations based on the content of the stories. Quotations from change stories are labeled with the corresponding story number (e.g. CS86 refers to change story 86).

Seeking solutions

The first, most notable, observation was one of absence. Across all the stories, there were only three that displayed a conscious “seeking for a solution” behaviour, two of which described finding information in published materials while the third found guidance from a presentation:

I was faced with designing a new grad AI course, but I did not look forward to straightforward lecturing from the book, so I looked for alternatives. I came across an article by L. Dee Fink, “A Self-Directed Guide to Designing Courses for Significant Learning”, and I also read the book “Drive” by Pink, on self-determination theory. I followed Fink’s design exercise while applying SDT principles. [CS86]

My response was to study the various disciplines that encompass learning science. Much is known about learning, and how we can support learning. I discovered that I had not been doing a good job in the classroom. I also found that the standard textbooks for my field don’t support learning well. [CS38]

I decided to change what I was doing, and looked around for what might work. I happened to go to a session on teaching using case study and so decided to try a case. I searched for some, but in the end wrote my own, brainstorming the ideas with my colleagues. [CS9]

The absence of conscious solution-seeking may be explained by the nature of our prompting question, in that the prompt does not emphasise an existing situation, but a process of change. However, the “seeking solution” behaviour is one commonly attributed to educators. Guzdial and Fossati “...propose to think about an ideal decision-making design process of instructors as composed of three parts: 1. Making a determination that a change is needed. 2. Either finding existing solutions or creating new interventions to address the desired change. 3. Evaluating the effectiveness of the solution and deciding whether to retain it or not.” [12].

It may be that decision-making in teaching, as in other professions, does not involve a problem-solving approach of incremental consideration of each step. It may more closely represent naturalistic decision-making, where professionals make non-analytic choices in situations marked by time pressure, high stakes outcomes, inadequate (or missing, or

unreliable or ambiguous) information, team and organizational constraints, changing conditions, and varying amounts of experience [13]. Whichever construction is a more accurate representation, “seeking solutions” was an extremely uncommon change-behaviour in our data.

Revelation

Because our request was not bounded in scale or time, contributors submitted stories that described change from a single piece of work in a single course to reflections that spanned decades of an entire career. Perhaps because of this open-endedness, the catalyst for change in several stories was a clearly-recalled moment of insight or revelation, often quite a time in the past.

Coup de foudre: a thunderbolt, a streak of lightning that lit up my skies and changed forever, not only me and my teaching, but also the way in which my students learned [CS27]

In some cases, the insight was the point of a story. The title of CS85 is “An Epiphany” and contains the revelatory moment:

I remember quite clearly about two years after I started teaching; I was in London for a meeting with my old PhD supervisor. We were talking about our classes and she said “I never do lectures”. “Never?” I said. “Really, never? So what do you do?” [CS85]

Such moments were often set in relation to a status quo, a set of assumptions, or state of mind:

When I began teaching in universities a quarter of a century ago I set students essay titles, because that’s what happened when I was a student. [CS15]

... it’s just I had never seen a class taught this way when I was an undergrad. I didn’t know people could do that :-) [CS85]

There were also stories that expected, even anticipated, this sort of change where it was not forthcoming:

I started sitting in on colleagues’ classes, but that didn’t help much. I didn’t see anything they were doing that was all that different from what I was doing. But I persevered. I wish I could tell you of some epiphany that helped, but I don’t think there was one. [CS21]

Daily Bread

The most populated catalyst category was of educators initiating change in response to students: in response to something they did, or something they said, or to a close observation of their attitudes and achievements.

I found that almost all the students who had gotten the “differentiate using the chain rule” question wrong had done terribly on the exam, and almost all the ones who had gotten it right had done quite well. After that, I doubled the amount of time spent teaching the chain rule. [CS5]

On a data structure and algorithms exam, I frequently gave students recursive code to do something in a binary tree and asked them to give me the output (there was typically some numeric calculation). I would get 80% incorrect answers. I observed that students would show very little work. I changed the instructions to the problem to include showing the execution tree. Making students show their work flip-flopped the percentages. Typically 80% get correct answers now. [CS18]

What made me change my practice is a student reminding me - "I have never done this before, I don't know what you want". [CS13]

The most recent experience I have of changing my practice comes from student feedback - some formal and some informal [CS26] (The title of this story is "Module Evaluations Work!")

Although sometimes the student-focused catalyst was negative:

But when I looked into their eyes halfway through the introduction I could see that a 15 month old example was no longer topical - indeed most had never heard of something that had been a lead news item a short while ago. I rescued the class by managing to work in a more recent example. But the experience was a bit of a shock. [CS20]

I had a student come to my office during my first term teaching. She was having a hard time in her 2nd year of University, was shifting from Science to Social Sciences, and was struggling. She was in an introductory Human Geography class, and she felt lost, not connecting to the material. We were touching on international issues, and she admitted to me that she JUST DIDN'T CARE. I was stunned that she was so honest, and could not respond to her honesty with anything but compassion, even though I was at a loss to imagine how an intelligent person could be so disconnected from social and environmental injustices and suffering that were our topics. [CS31]

Other Catalysts of Change

Many stories (13) report the influence of a named individual as causing them to change their teaching. For as many (18), participation in an event, or external training, or "getting out of the classroom" made the difference although often these are not reported as intentional acts: "I attended a keynote lecture about learning preferences" [CS25], "I was reading a book and stumbled upon a quote that was written in one of the margins" [CS40], "In the toy store, wandering about, I saw some baby toys called 'bear links.' That reminded me of the linked lists I was supposed to be worrying about for class ... so I decided to get them and use them in class." [CS53]. Finally, a least populated category was "external imposition" represented by only one story, entitled "Forced to conform" [CS11].

Sources of Change Details

In all but one of the stories (the "external imposition" story above), educators were in a position to control at least some of the details of the change they described. Our earlier analysis revealed that few stories reported the sort of deliberate search for solutions that had previously been hypothesized, so how *were* educators informing decisions about pedagogical change? In just over half of the stories (50), the instructor apparently formulated the details of their pedagogical change on their own, without consulting peers or other resources.

This abundance of "local change" stories is perhaps not surprising given that "change in response to students" was found to be the most common catalyst category. One might expect these sorts of changes to occur frequently, and be relatively small in scale, making it less likely that the teacher involved would seek outside counsel. Additionally, changes made in response to student feedback are often tightly tailored to local circumstances—the constraints of a classroom or the structure of a curriculum, for example—making it less likely that a literature search would discover appropriate interventions. Published work is necessarily abstracted away from its original context in an effort to generalize a result and enhance its transferability, but the further removed the practice described is from the particulars of local circumstance, the less obviously it is relevant and the more work must be done to adapt the practice to a new environment.

All of the change stories quoted in the *Daily Bread* section fall into the "local change" category. Not all locally formulated changes were the result of student feedback, however. Eight were the result of reflection on the part of the instructor:

The original format was that the assessor would fire questions at team members about the work. I thought this approach would disadvantage anyone with limited understanding of English so I changed the format. I put more time into setting up the assessment, giving information about the areas to be assessed and asked the students to take responsibility for the walkthrough and who would be explaining sections of the documentation. [CS63]

When the instructor who normally taught the class left, we were left with no one to teach it. I was one of two professors who decided to try teaching the course. Having been trained technically as a computer scientist, I was familiar with how to teach programming, data structures, etc., but it became clear to me that teaching students about ethics and the societal impact of computing would require a completely different style of teaching. I determined that it would have to be more discussion-based, readings-based, and writing-based. [CS57]

Other changes were driven by external circumstances.

Several years ago, I taught in a classroom with no white or chalkboards. So that I could write examples for the students, I started using a tablet PC and Classroom Presenter from the U. of Washington. This has evolved into a set of "guided slides" that are partially completed that I finish in lecture, and posted soon thereafter. [CS50]

In the remaining stories, authors reported obtaining change details via interactions with other educators (39 stories) or from published materials (8 stories). The mechanisms through which these sources were located are explored in more detail below.

Transmission

As was reported above, instructors rarely searched for information when considering change. At the other extreme, 12 stories described changes resulting from chance encounters with educators who shared or demonstrated details of their teaching practice. The authors of these stories had not intended to change their practice until they were exposed to a new approach.

I never would have made this change if it weren't for a trusted friend who told me to do this and I was sort of convinced. The change was to go from more or less traditional lecture with a handful of active learning activities punctuating it, to a completely or almost-completely question-driven style with peer-instruction. [CS70]

When I started university teaching I was very 'controlled' - all "chalk & talk". It took my colleague to loosen me up! We did team teaching together and he regularly inserted activities, interactive tasks, buzz groups, video snatches for students to comment on, role play, group work etc. Basically, the 'scales dropped from my eyes' and I saw how valuable these more discursive, open-ended, student-centred approaches were; and how memorable they were to us & to the students alike. [CS99]

The change in the examples above resulted from unplanned interactions between instructors. A larger group of change stories (31) involved *primed serendipity*, where the author encountered unanticipated information but while putting themselves in situations where they could reasonably expect to learn *something* about teaching practices (e.g. attending a conference or workshop, or browsing a journal issue). In five of these stories the author drew on published materials to inform their change in practice. The remaining 26 narratives in this category involved personal exchanges with groups or individuals.

Several years ago I read a book titled "Beyond Bullet Points" by Cliff Atkinson that kept mentioning Richard Meyer's work on multimedia learning theory. I read several of his papers and his book as well. Over a summer I revised all of my CS1 slides to incorporate his multimedia learning principles. [CS56]

I participated in a course on Teaching with Technology. Although I had always used technology where I could, this course exposed me to dozens of different tools and uses for these tools in the classroom. I now incorporate many of these tools in my teaching. [CS12]

I was travelling on holiday to Italy. I had taken Jenny Moon's book on reflective practice, just to re-read I chanced on mention of a teacher who had shared his own learning journal with his students. I knew that my Soc Sci students initially had problems with reflective journalling. I thought "Why don't I share mine with them?" [CS68]

I'm a member of a science education reading group on campus. One of the papers recently was on how to evaluate your assessments (specifically tests/exams). One person in our reading group was a psychologist who researches "psychometrics" and does extensive quantitative test analysis for her courses. Based on her experiences and advice, I was inspired to go over a test I was in the process of writing for my CS0 course the following week. [CS95]

DISCUSSION

The change stories provide a valuable window into the behaviour of educators as they change their practice. Our study is novel in that it collects stories from teachers in their own words, and makes no attempt to limit the scope of the project to the adoption of any particular intervention. Stories are a relatively unusual form of data for this sort of investigation. They are not responses to direct questions (as in interviews, surveys or questionnaires), they do not represent opinions on issues, nor statements of fact. They are, however, authentic communications which illuminate complex topics, and which can provide insight into complex spaces. There is always a point to telling a story, a reason for their emergence, something the teller wants to communicate.

Stories also have an effect on the audience: "The act of listening to a story told by another person creates a ... displacement of perspective that helps people see through new eyes into a different world of truth" [14]. The power of this collection of stories is demonstrated in their content, in the things the storytellers wanted us to know. And what they contributed were stories of success, of change making an improvement, most often an improvement to student learning. They also conveyed an abiding sense of personal satisfaction, of professional pride, of overcoming challenge and disappointment, in doing a good job. And in this, the contributed stories were entirely comparable even though they were from different countries, institutional contexts and academic disciplines.

Lessons for Education Developers and Researchers

In the change stories we analyzed, instructors very rarely performed the kind of deliberate, methodical search for

educational interventions that a naïve “changing practice” model implies. This has implications for educational developers and researchers wishing to propagate information about new teaching materials or techniques.

A review of the analysis above reveals that books or articles informed change in only *eight* of the 99 stories, despite the fact that part of the solicitation was via education research mailing lists, and a number of the stories were collected at an education-related conference: In other words, the participants are exactly the kinds of instructors one would *expect* to be reading the scholarly literature. Even within the group of eight, the majority found their source through primed serendipity instead of deliberate search. That is, they encountered the information while looking for something else, or while perusing a journal or proceedings.

Over 90% of the stories described changes that were either created without drawing on outside sources, or were informed by personal interactions with other educators. The relative prevalence of personal interactions as a vector for information on teaching practices is noteworthy: Instructors reported changing their practice as the result of personal interaction with a peer far more often than after reading an article or book. Peer interactions were so powerful, in fact, that in a dozen of the stories they caused instructors to make *unplanned* changes to their practice.

Research on diffusion of innovations has found that communication is more effective between similar individuals [15]. It is possible that instructors who know one another well enough to exchange information about teaching practices are similar in key respects, which could help explain the impact of the personal interactions we see in the change stories. Peers are perhaps also more likely to have similar teaching contexts — to come from similar institutions, teach the same sorts of courses, or have similar students, for example. Information coming from someone with a similar context can more immediately be recognized as relevant, and can be implemented more easily since little or no adaptation is required to employ the practice in a new setting.

Additional research will be required to illuminate the nature of the interactions between educators, but the role of personal interactions in the stories suggests that education developers would be wise to pay closer attention to the exchange of information within personal and professional networks. As Stephen Corey said in keynote talk to the National Society for the Study of Education in 1951 “I hesitate to say so, but I believe that we pedagogues tend to exaggerate greatly the amount of change in educational practice that results from reading what other people say should be done...”

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Peer Mentoring: Linking the value of a reflective activity to graduate student development

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Abstract—Traditional forms of mentoring offer graduate students a support system to assist them through their education. Many times these traditional forms of mentorship can be augmented by other support mechanisms. This phenomenon is especially true in engineering education because of the interdisciplinary nature of the discipline. In this work, we explore engineering education graduate students' self-reported value in regards to their participation in a multi-institution peer mentorship program. Further, we identify if and in what ways such a program supports graduate students' development towards becoming emerging scholars in the field of engineering education.

Keywords – Graduate Engineering Education Consortium for Sstudents (GEECS), peer mentoring, graduate students, identity

I. INTRODUCTION

Graduate school is often characterized as an isolated time during students' development towards becoming academic scholars. This challenging journey is sometimes interrupted by negative experiences (e.g., failed exam, rejected article, or a discouraging advisor). While these challenges can be opportunities for growth, they often cause graduate students to doubt their ability as emerging scholars. Negative experiences may even result in an attitude shift that leads graduate students to not acknowledge past accomplishments—often referred to as imposter syndrome [1]. Imposter syndrome “is characterized by strong feelings of intellectual and professional phoniness in high-achieving individuals. According to Clance and Imes, imposters entertain these thoughts and feelings despite evidence that suggests both outstanding academic and/or personal accomplishments” [1, p. 44]. Graduate students must avoid falling into the trap of feeling inadequate if they are to become successful engineering education researchers.

The identity development of graduate students in engineering education is particularly important because the field is rarely, if at all, defined by a specific pathway to becoming a scholar. The background of current faculty who identify their main area of research as engineering education range from engineering discipline specific degrees and industry experience to education, communication, and even specific

engineering education degrees. It is, therefore, important to understand and assess interventions that may impact engineering education graduate student development from multiple points of view. We are particularly interested in an alternative approach to mentorship through peer interactions. In this study we explore the impacts of the Graduate Engineering Education Consortium for Students (GEECS) peer mentorship program on graduate students' development as emerging engineering education scholars.

Peer mentoring [2] is a program developed, implemented, and sponsored by GEECS [3]; it provides a virtual space, via monthly conference calls and an online forum, for engineering education graduate students to support and challenge one another throughout their degree program. Our study investigates the following research questions to better understand the significance of GEECS peer mentoring:

1. What value do graduate students ascribe to GEECS peer mentoring?
2. Does GEECS peer mentoring support graduate students' development toward becoming an emerging scholar?

These research questions reflect our interest in identifying how this type of mentoring supplements more traditional avenues of mentorship (e.g., advisor/advisee relationships), keeping in mind that prior research has shown peer mentoring to be a promising avenue to address issues related to recruitment and retention of women in engineering [4, 5].

In the following sections, we situate our research in the literature, explain our methods, explore the quantitative and qualitative results, discuss the findings in light of literature, and conclude with study implications.

II. PEER MENTORSHIP: AN ALTERNATIVE PERSPECTIVE TO MENTORING

GEECS peer mentoring offers an alternative perspective to traditional mentoring [6, 7]. While graduate students often engage in mentoring through a variety of avenues (e.g., advisor, faculty members, supervisors, parents, or friends),

these traditional approaches to mentorship are characterized and defined by one-on-one relationships. While these general mentoring relationships are valuable and irreplaceable, there exists an opportunity to supplement this mentoring with further support through peer mentoring.

Research in engineering about mentorship suggests a specific need and benefit for women, which has the potential to address issues related to the recruitment and retention of women in engineering [4, 5]. Chesler & Chesler's [4] work on exploring alternative mentorship for women in engineering provides three alternative models to the traditional single mentor model. In the first alternative model, they suggest that students construct a "mentoring community," "mentoring team," or "distributed mentorship" that is a composition of a range of mentors (e.g., senior and junior faculty members or industry leaders) designed by the mentee. In the second mentorship model, the authors suggest peer mentoring that "simultaneously builds community and de-emphasizes seniority and hierarchy" [4, p. 52]. In the third mentorship approach, the community takes a "collective mentoring" mindset, which is developed and implemented by the specific department or community.

GEECS peer mentoring is an example of the second approach. We focus on this approach as a promising avenue for the development of emerging engineering education researchers. Through this lens, we characterize and analyze the GEECS peer mentoring as a plausible mentorship model that has value toward professional and personal development, and supports these graduate students as emerging scholars in the field.

III. THEORETICAL FRAMEWORK

We frame our analysis of peer mentoring through the lenses of associated value and identity development.

A. Associated Value

Mentoring opportunities are designed to provide mentors and mentees with personally valuable interactions. The inherent value embedded in mentorship ranges for each individual based on how they gauge value from the activity. According to Expectancy Value Theory, behavior is a function of the value one places on achieving a goal [8]. The interest, attainment, utility, and cost associated with a given activity results in a perceived overall positive or negative sense of importance.

Initial findings from an auto-narrative analysis [2] suggest that peer mentoring for engineering education research students is a valuable undertaking. Peer mentorship increased the value participants placed on community support toward their teaching, research, service, and personal goals. We believe that strong value placed on mentorship is an important factor that can help students succeed as engineering education researchers, especially for students who lack a community at their home institution. In this way, peer mentorship also helps the growth of the engineering education research community.

B. Supporting Identity Development

There is an opportunity to examine this type of social networking beyond general characterization and potential value. The auto-narrative analysis [2] also suggested that peer

mentoring offers an environment that supports graduate students during a time in which they internally struggle with their identity both professionally and personally. Developing an identity within a field of study is an essential step in graduating to become a professional. Peer mentoring has the potential to be a supportive environment that helps engineering education graduate students grapple with identity development.

In general, various stages of graduate education can offer a variety of challenges to one's identity development. Early stages of identity development can be difficult for graduate students who often feel lost and overwhelmed as new members of their lab or research group. Graduate student reflections of their experiences suggest a feeling of being overwhelmed with high expectations for background knowledge. Mid-process students expressed anxiety and stress with qualifying exams, but also discussed peer-groups or comparable groups as a coping mechanism to commiserate with. Even in latter stages of graduate study, students expressed being challenged to compete with others for critical first step career options [9].

The overall theoretical underpinnings, consisting of associated value and identity development, meld well in providing a solid foundation to explore how a reflective activity like peer mentoring can be important to graduate student development.

IV. METHODS

In order to better understand the effects of this program, our subsequent analysis of the GEECS PEER Mentoring Program includes an assessment on the impact of perceived value and identity development. This exploratory work used an online survey to examine the value graduate students assigned to their participation in peer mentoring and the identity support students acknowledge from the experience. The following describes the peer mentoring structure, and data collection and analysis approaches.

A. Peer Mentoring Structure

In small groups (i.e., four to six participants), ten current and recently graduated engineering education graduate students participated in GEECS peer mentoring during the 2010 – 2011 academic year. Monthly conference call meetings were structured to focus on goal setting/monitoring and providing feedback on each other's work. Preparation for these sessions was augmented by participants monitoring and updating their goals in an online database (i.e., GoogleDocs spreadsheet) (see Table 1 for an example).

TABLE I. EXAMPLE GOAL SETTING AND MONITORING SPREADSHEET.

| | January Goal Setting | January Goal Update |
|-----------------|---|--|
| Research | Write the first chapter of my dissertation | Completed the first chapter and submitted to my advisor |
| Teaching | Visit a K-12 classroom once per week to teach engineering design | Participated in K-12 outreach through twice a month classroom visits |
| Service | Fulfill my role as an executive board member of the ASEE Student Division | Procured money for the upcoming conference |
| Personal | Go to the gym twice a | Visited the gym or played a |

| | | |
|--|------|-----------------------------|
| | week | sport at least twice a week |
|--|------|-----------------------------|

B. Peer Mentoring Participants

The two peer mentoring groups were each led by one doctoral-level student leader. A PhD candidate in Engineering Education at Purdue University led one group, while a PhD candidate in Human Centered Design & Engineering from the University of Washington (first author of this paper) led the other. The remaining members of the two groups included:

- four 1st year (now all 2nd year) graduate students – one Aerospace Engineering PhD student from Georgia Tech, one Engineering and Science Education PhD student from Clemson University, one Engineering Education PhD student from Purdue University, and one Engineering Education PhD student from Virginia Tech
- a 2nd year (now 3rd year) Engineering Education PhD candidate from Virginia Tech (third author of this paper)
- a recent Electrical and Computer Engineering PhD graduate from the University of Illinois at Urbana-Champaign; now post-doctoral research associate at Purdue University's Engineering Education Department
- a post-doctoral research associate at Arizona State University (ASU) with a PhD in Education from Tufts University (second author of this paper); now an assistant professor of Engineering at ASU and an assistant teaching professor of Business at the University of Missouri who is a recent Industrial Engineering PhD graduate from Iowa State University.

The current and recently graduated students all met through their involvement in the ASEE Student Division and their mutual interest in creating GEECS.

In this study consideration was paid to the influence of the researchers on the participants. The researchers in this paper were also participants in the peer mentoring groups included in the study. Special effort was made to avoid internal bias in the construction of the qualitative questions in the survey. Responses to survey questions also indicated that no significant bias as evidenced by negative critiques of the peer mentoring experience and the program. Participants were honest and unreserved in their feedback and critique. The authors also considered their own perspectives of peer mentoring and bracketed those ideas in the data analysis process.

C. Data Collection and Analysis

GEECS peer mentoring participants were surveyed after a year of participating in the program in order to understand better their experience. Two sets of data were collected using one survey to provide the primary data source for this study. The survey included fourteen fixed item questions pertaining to value and nine open-ended items pertaining to identity.

Student perceptions of value associated with the peer mentoring experience were measured quantitatively using fixed item questions. Questions were designed to address two areas of validity: 1) content and 2) construct [see 10, 11]. Content validity was addressed by framing the questions around the purpose and goals of peer mentoring. Construct validity was

addressed by designing questions that incorporated the four areas of value—interest, attainment, utility, and cost—suggested by expectancy-value theory [12-14]. Quantitative data was assessed using IBM® SPSS® Software and Microsoft® Excel®.

The fourteen items of the associated value survey were separated into three factors according to previously unpublished factor analyses. The three factors included interest/attainment value, utility value, and cost. The fixed-items were presented to students using a four-point agree-disagree scale including *completely agree*, *somewhat agree*, *somewhat disagree*, and *completely disagree*. To simplify the results, all agree and all disagree responses were separately pooled together (see Tables II – IV).

Identity questions were situated in student identity and imposter syndrome theories in order to target this dimension. The qualitative survey questions were analyzed through an open coding process [15] considering the major themes that were established in this group's prior work [2]. We used deductive reasoning to understand the participants' responses within the context of identity development and imposter syndrome. This approach confirmed what is known about peer mentoring and uncovered the theme of participants' views of peer mentoring. Once the three themes were identified, an axial coding process [14] was used to identify important subcategories to further understand participants' experiences with identity, imposter syndrome, and their view of peer mentoring within the GEECS program.

The authors' experiences as participants in peer mentoring served as confirmation of emerging themes.

V. RESULTS

This study examines students' reported experiences in relationship to associated value and identity development. These areas of interest were used to support one another. We first established a foundation using associated value to gain an understanding of the participants' peer mentoring experience. These general impressions were used to frame the relationship between peer mentoring and identity development.

A. Associated Value

1) *Interest/Attainment Value*: Interest or intrinsic value is an individual's anticipated enjoyment of engaging in a particular activity. Related to interest value is attainment value or an individual's perception of how the activity contributes to the conception of who he or she is fundamentally. Results suggest that students found peer mentoring to be motivating and helpful in effectively gaging what they've learned as graduate students. The remaining interest/attainment items produced mixed results suggesting that GEECS peer mentoring is generally interesting and beneficial to exploring who the student is, but that changes should be made to improve the program (more detail provided in the *Views of Peer Mentoring sub-section*).

TABLE II. INTEREST/ATTAINMENT VALUE RESULTS

| Interest/Attainment Value | Agree | Disagree |
|---|-------|----------|
| motivated me to do well as a graduate student | 6 | 1 |
| was an effective way to gauge what I have learned as a graduate student | 5 | 2 |
| helped me understand my own learning | 3 | 4 |
| helped me to understand the knowledge I have gained as a graduate student | 4 | 3 |
| increased my enjoyment with my graduate studies | 4 | 3 |

2) *Utility Value*: Utility value is an individual's perception of the advantages that result from engaging in the task for future goals or rewards. Results suggest that students generally found utility from the peer mentoring program. Only one aspect of the program, *representing a real world experience*, was viewed with mixed perceptions.

TABLE III. UTILITY VALUE RESULTS

| Utility Value | Agree | Disagree |
|--|-------|----------|
| will help me towards reaching my future career goals | 6 | 1 |
| was useful in my pursuit of other goals | 5 | 2 |
| increased my level of responsibility for my graduate studies | 5 | 2 |
| represented a real world experience | 3 | 4 |
| will help me towards reaching my future goals as a student | 6 | 1 |

3) *Cost*: Cost represents an individual's perception of the sacrifices required, including effort, time, and psychological impact, for successful impact of an activity. Results suggest that students generally found the peer mentoring program to cost them very little in terms of personal sacrifice.

TABLE IV. COST RESULTS

| Cost | Agree | Disagree |
|--|-------|----------|
| required too much effort | 0 | 7 |
| made me frustrated and anxious | 1 | 6 |
| required too much time | 2 | 5 |
| limited my ability to be a successful graduate student | 0 | 7 |
| required too much effort | 0 | 7 |

B. Identity and Impostor Syndrome

Within the context of peer mentoring, the results suggest that these graduate students grappled with their identity as an individual and situated within the field.

1) *Identity*: Peer mentors expressed their experience with the program on two main levels: affinity within the field and individually on a personal and professional level. Participants explained that the peer mentoring experience helped them to feel a part of the field and often motivated their desire to continue developing relationships with graduate students in

their peer mentoring group. Students discussed developing a network in the field, which assisted with understanding the diversity within engineering education and what it means to become an engineering education researcher. While students began to feel like part of a community, they were also recognizing the rapid expansion of the field, which results in competition:

"I think this field is going to be a lot more competitive than I thought it would be initially."

The students overall felt that the experience helped them make connections, some of which resulted in developing research collaborations, feeling a part of the field, and making friends in engineering education beyond their own departments. Peer mentoring was seen as a way to benefit from others in the field:

"Even though I have a large support network of people [at my own institution] in engineering education it was still beneficial to me to talk with others at different schools. It provided a unique perspective."

Individually, participants identified personal skill sets and values related to the peer mentoring experience. Participants saw themselves as mentors and wanted to contribute to others. One participant who expressed some frustration with the peer mentoring experience desired to lead their own peer mentoring group. Professional identity was also a major part of participants' discussion of the experience. A strong desire and motivation to become an excellent researcher was also a major topic of discussion:

"I am constantly learning the 'tools of the trade' for developing scholarly work in the area of engineering education. More specifically, I am learning what counts as rigorous research in this field and am dedicated to generating research that meets these high standards."

Another participant explained that the field does not provide a clear path to post graduate work. The peer mentoring experience helped them gain valuable insight into the various paths:

"I also learned that being a graduate student studying engineering education can be tough at times since there isn't always a clearly-paved road ahead."

The design of the peer mentoring program emphasizes balance as a graduate student and maintaining a personal life. Many participants felt that peer mentoring helped them achieve personal goals that are not directly related to graduate school. For example, discussing non-school related goals, such as maintaining a healthy lifestyle, spending time with friends and family, were very useful pieces of information about post-graduate work.

2) *Impostor Syndrome*: Some of the behaviors associated with impostor syndrome were overcome by peer mentoring participants. Participants' comments related to impostor syndrome behaviors were categorized as shared or similar experiences and self-affirmation. Shared experiences were related to the challenges of graduate school, such as exams, research difficulties and preparing for a career. One participant explained it this way:

"This uncertainty about what happens after graduation can, in some ways, make graduate students (studying engineering education) very anxious. This anxiety is in addition to normal stresses of graduate student life. It was not until I was part of a peer mentoring group that I saw how widely-shared this experience is."

Developing camaraderie in misery is a way to overcome imposter feelings, especially through peer mentoring groups with students from different institutions. Participants also felt more a part of the engineering education community through participation in peer mentoring, as they found others with interests similar to their own. Responses that were coded as self-affirmation referred to how students felt about their past decisions, especially entering engineering education and making an uncertain career choice. Participants also expressed increased confidence in their knowledge of engineering education.

3) *Views of Peer Mentoring:* Piggybacking off the associated value survey, participants were asked questions about their views of the peer mentoring experience. Themes of value and group accountability arose. Participants valued feedback that they gained from peer mentors as well as attempting to recreate peer mentoring groups in the future or in other contexts. In a sense, mentoring became a process involved in forming their identity. Most of the value associated with peer mentoring was related to feedback from multiple parties. One participant explained it this way:

"I once thought that my advisor (and other professors) were always the ones to go to for guidance, feedback, and insight. However, this experience has shown that my peers have a wealth of knowledge and, in some aspects, are just as capable of providing the dialogue I need."

Group dynamics and the commitment of others in the peer mentoring group was also very important to the participants, and influenced how they viewed the experience overall. For some of the participants, the need to report to others regarding goal progress was a motivator and helped increase their own accountability. Participants also felt accountability to each other to review current work and participate in meetings. Some comments indicated that groups that had lower levels of accountability or less stable participation left some wanting more from their peer mentoring experience.

VI. DISCUSSION

The results of this study suggest that engineering education graduate students found peer mentoring to be a positive experience, especially in regards to associated value, utility value, and cost. These students reported peer mentoring as an opportunity to engage in identity work. While these students generally characterized peer mentoring as a positive addition to their graduate experience, students also offered various changes and additions for potential improvement and growth of the program.

The quantitative associated value findings suggest that students generally found the mentor program to have utility and cost very little to them personally in terms of time and effort. These findings encourage the continued use of peer mentoring with engineering education graduate students associated with

GEECS, and with engineering education graduate students more generally. These findings suggest that such a program could have possible use in other disciplines where graduate students face a similar challenge of isolation (e.g., interdisciplinary programs).

Interest/attainment was not as positively scored with the quantitative data, as students seemed to have mixed perceptions as to whether the program was interesting and if it effected them on a personal level of identity. However, the qualitative data suggests an alternative perspective. Students reported that their professional identity as an individual and as a part of the field was positively influenced by the peer mentoring experience. Participants were also able to overcome self doubt and imposter beliefs through sharing relatable experiences of other graduate students in the field of engineering education. Participants deducted that the individual and group value associated with peer mentoring was accountable by the overall peer mentoring technique and indicated the intent to use the model again in the future. Participants experiencing a successful peer mentorship also expressed equal commitment to providing feedback to each other and building connections between each other for the experience to be successful.

In connecting these results back to our theoretical framework, peer mentoring is a promising mechanism through which to support graduate student development throughout their program. In relationship to Expectancy-Value Theory these results indicate that students' behavior towards individual degree progress and community situatedness grew in the positive direction. In relationship to identity theory, these results connect to both the development of one's identity personally, as well as one's identity situated within the community.

VII. CONCLUDING REMARKS

Our initial findings suggest that the reflective activity of peer mentoring leads to engaging in identity construction. For example, these participants began to recognize themselves as capable academics, and in some cases began grappling with and even overcoming their feelings of being an impostor. Through interactions with peers at various stages in their graduate education, these students were able to validate one another's accomplishments.

While this program is a strong initial step towards supporting engineering education graduate students, there were clearly areas for improvement. For example, the program can be strengthened through more consistent communication. Initial logistics of planning meetings often led to a delay in peer mentor opportunities. Furthermore, groups became quite dependent on the group leader/organizer. The group often struggled if and/or when this person became too overcommitted with other graduate student responsibilities.

Our results suggest that GEECS should maintain peer mentoring efforts with an eye towards checking-in at least annually with all participants. Growth of the program will require additional monitoring to ensure that the experience is valuable for all involved. It will also need leadership to think broadly about the associated benefits. One suggestion is to have larger departments develop a peer mentoring type of program

within institutions and across institutions as part of the GEECS program. The more students that we can involve and associate with GEECS peer mentoring will mean sustainable success for the program in the future.

The findings in this study can guide future program development in several ways. Participants indicated that the program did not necessarily help them in understanding their own learning. The structure of peer mentoring goal setting may need to be adjusted in the future to better help participants understand their own learning, especially in the early phases of their graduate career. Participants also indicated that peer mentoring did not represent a real world experience. While peer mentoring often does not formally at some institutions, participants may be gaining skills to continue this type of mentorship into their career. Peer mentoring can be a useful method, but emphasis on the possibilities of the program beyond graduate school will need to be increased to identify applicability during pre-tenure and as a pedagogical strategy. The continuous improvement model being implemented with peer mentoring movies designed to help participants as they move into faculty and other professional roles in their careers. In the future this group will examine the longitudinal effects of the program on participants and their use of the strategies gained in other contexts.

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Implementing & Evaluating Undergraduate Research in Renewable Energy at Colorado School of Mines

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Abstract - In 2011 Colorado School of Mines hosted 20 students in a Research Experiences for Undergraduates (REU) program in renewable energy. Students participated in weekly technical seminars, professional development sessions, laboratory tours, social activities, and an end-of-summer poster session with other nearby students in the National Nanotechnology Infrastructure Network program at the University of Colorado, Boulder. The REU also joined the 2011 cohort of the Cornell Office for Research on Evaluation (CORE) Evaluation Partnership program, which stressed intensive modeling centered on stakeholder interviews. A CSM faculty member led this modeling effort and determined that diversity and integration of community members were as important as an individual's research experience. Moreover, it was thought that successfully controlling these REU parameters would lead to a better understanding of what role community plays in student attitudes and could inform a set of best practices for arbitrary REU communities. From this perspective, a set of mixed-method measures was constructed leading to an introductory evaluation of program aspects. This paper provides an overview of the Colorado School of Mines' renewable energy REU, the evaluation protocols applied to the program, and their implications that will be integrated into the second year of the project.

Index Terms – renewable energy, research experiences for undergraduates, REU evaluation, REU implementation.

IMPLEMENTATION

The following section discusses the implementation of the renewable energy REU summer program at Colorado School of Mines (CSM).

I. NSF REU Site Grant

In January 2011, the National Science Foundation's (NSF) Division of Materials Research awarded CSM a 3-year grant [1] for \$270,000 to establish a Research Experiences for Undergraduates (REU) Site to support 8 students a year in a renewable energy REU program. Consistent with NSF's mission and purpose, the goals of this REU are to

- provide participating students with high quality research experiences in renewable energy, and
- increase undergraduate students' interest in pursuing advanced degrees in the discipline.

The following objectives target the first goal: a) introducing talented undergraduate students to the excitement of discovery through participation on a vibrant research team; b) enhancing

undergraduate students' technical expertise by providing them with a rich and engaging research experience; and c) providing undergraduate students with training and independence in a research environment. Increasing female, underrepresented minority, and non-traditional students' interests in pursuing advanced degrees in renewable energy achieve the second goal. Table I lists the funds budgeted in our NSF REU Site Grant [1] to support one student in our 10-week summer program.

TABLE I
COST TO SUPPORT ONE STUDENT IN 10-WEEK 2011 REU PROGRAM

| Description | Cost |
|---|----------------|
| Stipend (\$11.25 per hour) | \$4,500 |
| Roundtrip Travel from Home to REU, then REU to Home | \$500 |
| Housing in Campus Apartments | \$1,190 |
| Weekly Meals | \$750 |
| Working Meals | \$100 |
| Materials and Supplies | \$60 |
| Publication / Documentation / Dissemination | \$75 |
| Hotel, Registration, Travel (to present at future conference) | \$1,250 |
| Subtotal | \$8,425 |
| Administrative Allowance (25% of Stipend) | \$1,125 |
| Grand Total | \$9,550 |

As shown in Table II, the REU Site Grant supported 8 students, while a variety of other funding sources supported 12 additional students, allowing us to host a total of 20 participants in our 2011 REU program.

TABLE II
FUNDING SOURCES FOR 20 PARTICIPANTS IN 2011 REU PROGRAM

| Funding Source | # Supported |
|--|-------------|
| CSM Sources | |
| Louis Stokes Colorado Alliance for Minority Participation – Bridge to the Doctorate Program [2] | 0.34 |
| Multicultural Engineering Program [3] | 2.00 |
| Office of Graduate Studies [4] | 0.33 |
| Oil Shale Symposium Sponsorship [5] | 1.00 |
| Renewable Energy Materials Research Science and Engineering Center [6] | 4.33 |
| Research discretionary funds from physics professor | 1.00 |
| NSF Sources | |
| REU Site Grant [1] | 8.00 |
| Supplement to NSF Award DMR-0907409 [7] | 1.00 |
| Other Sources | |
| Center for Revolutionary Solar Photoconversion [8] | 1.00 |
| Pat McAdam Scholarship in Chemical and Bioprocess Engineering from University College Dublin [9] | 1.00 |

II. 2011 REU Participants and Mentors

Due to overwhelming campus support, our 2011 REU hosted 20 students from 14 different institutions (12 national, 2 international) in a 10-week summer program that strove for

gender balance (11 females, 9 males) and diversity (3 underrepresented minorities, 1 non-traditional student), as well as a balance between participants from research institutions and from institutions where research opportunities for students are limited. Table III displays features of our student population, while Table IV lists student's home institutions.

TABLE III
FEATURES OF 20 STUDENT PARTICIPANTS IN 2011 REU PROGRAM

| Demographic Profile | |
|-----------------------------|-----------------------------------|
| Age | 19 to 28 years old (one over 25) |
| Citizenship | France (1), Ireland (1), US (18) |
| Disability | None |
| Ethnicity | Hispanic (2), Not Hispanic (18) |
| Gender | Female (11), Male (9) |
| Race | Black/AfricanAm (1), White (19) |
| Diversity Profile | |
| Non-Traditional Students | Age over 25 years old (1) |
| Underrepresented Minorities | Black/AfricanAm (1), Hispanic (2) |
| Scholastic Profile | |
| Average Grade Point Average | 3.69 |
| Graduate School Plans | 17 of 20 |
| Representation | 14 Institutions / 8 Majors |
| Year of School Completed | Fr (3), So (6), Jr (9), Sr (2) |

TABLE IV
HOME INSTITUTIONS OF 20 STUDENT PARTICIPANTS IN 2011 REU PROGRAM

| Home Institution | Participants |
|--|--------------|
| National Schools | |
| Binghamton University – Binghamton, NY | 2 |
| Carthage College – Kenosha, WI | 1 |
| College of Idaho – Caldwell, ID | 1 |
| Colorado School of Mines – Golden, CO | 6 |
| Colorado State University – Fort Collins, CO | 1 |
| Colorado Technical University – Colorado Springs, CO | 1 |
| Furman University – Greenville, SC | 1 |
| Kansas State University – Manhattan, KS | 1 |
| Mount Holyoke College – South Hadley, MA | 1 |
| Northeastern Illinois University – Chicago, IL | 1 |
| Smith College – Northampton, MA | 1 |
| University of Colorado – Boulder, CO | 1 |
| International Schools | |
| Ecole des Mines – Albi, France | 1 |
| University College Dublin – Dublin, Ireland | 1 |

Faculty mentors and research staff provided valuable roles in shaping the behavior, beliefs, communication skills, laboratory talents, presentation abilities, safety habits, and work ethic of our REU students as they developed as professional researchers. Each REU student was assigned a primary faculty mentor and a primary student contact within their research team. Both the primary faculty mentor and the primary student contact were available throughout the program to support the REU student. The primary student contact acted as a “near-peer” role model and as an approachable resource, and was either a graduate student or an undergraduate alumnus of the REU program. As novice researchers, many undergraduate students hesitate to ask scientific questions of their faculty mentors, fearing that the topic is something they should already know. The availability of another student addresses this concern. Additionally, our student contacts had considerable knowledge and experience within the university environment; they were aware of social events and activities that were available and appealing to college-age students, and knew how to work with the various “systems” in and around campus.

Table V lists the number of faculty, staff, and scientific mentors that contributed to the success of our 2011 REU program.

TABLE V
FACULTY, STAFF, AND SCIENTIFIC MENTORS IN 2011 REU PROGRAM

| Group | Mentors |
|--|---------|
| CSM Faculty | |
| Applied Mathematics and Statistics | 1 |
| Chemical and Biological Engineering | 6 |
| Chemistry and Geochemistry | 3 |
| Engineering Physics | 7 |
| Environmental Science and Engineering | 2 |
| Geology and Geological Engineering | 1 |
| High Performance Computing | 1 |
| Liberal Arts and International Studies | 1 |
| Metallurgical and Materials Engineering | 1 |
| Renewable Energy Materials Research Science and Engineering Center [6] | 18 |
| CSM Staff | |
| Colorado Energy Research Institute | 1 |
| Environmental Health and Safety | 1 |
| Multicultural Engineering Program [3] | 1 |
| Office of Graduate Studies [4] | 1 |
| Outdoor Recreation Center | 1 |
| Renewable Energy Materials Research Science and Engineering Center [6] | 2 |
| Residence Life | 1 |
| Women in Science Engineering & Mathematics Program | 1 |
| External Collaborators | |
| National Nanotechnology Infrastructure Network at University of Colorado – Boulder, CO | 2 |
| National Renewable Energy Laboratory – Golden, CO | 4 |

III. 2011 REU Program Elements

An interdisciplinary team of ~ 40 engineering and science faculty at CSM, as well as staff from the Colorado Energy Research Institute and the National Renewable Energy Laboratory (NREL), mentored 20 students in renewable energy research projects. These projects addressed the performance of next-generation photovoltaic devices; microstructural design of composite membranes; hydrogen storage in clathrate hydrates; social and ethical implications of climate change, renewable energy, sustainability & education; hybrid energy systems for oil shale production; and optimizing computational tools for energy science.

Students attended weekly technical seminars that spanned photovoltaics, energy storage materials, the role of catalysts in fuel cells, computational energy science, and challenges & opportunities with biofuels. These technical seminars exposed the students to a renewable energy curriculum that provided them with appropriate depth and breadth in the subject. Students demonstrated an appreciation for how and why an advanced degree in an engineering or science discipline is beneficial to further advances in renewable energy. Professional development sessions covered Ethics and the Responsible Conduct of Research; Learning, Teaching, & Working Across Generations; Being a Role Model, Finding a Mentor; Careers in Renewable Energy; and Graduate Schools & Fellowship Opportunities. Student “Snapshots” Sessions allowed participants to informally share their research results in a weekly open-learning environment.

After a mandatory laboratory safety training program, students enjoyed field trips to the National Nanotechnology

Infrastructure Network (NNIN), NREL, and the Renewable Energy Materials Research Science and Engineering Center. Each program included facility tours; lunch with other REU students; workshops on graduate studies, renewable energy careers, and laboratory jobs; networking with scientific leaders; and technical seminars with respective lab directors.

Nine NNIN REU students joined our 20 REU students in an end-of-summer Poster Session held at CSM. About 150 people attended including students, faculty, post-doctoral scholars, research staff, upper-level campus administrators, and NREL scientists. Judges awarded prizes for Best Presentation (acknowledging one student that best communicated the nature, impact, and results of his or her research) and Best Technical Achievement (recognizing one student's remarkable scientific results).

Social activities included an Orientation Day, a trip to the Teva Mountain Games, two barbecue dinners with CSM's Society of Physics Students, a Coors Brewery tour, a tour of a local Catholic shrine, a picnic at a local mountain park, attending a major league baseball game, a tour of "The Sustainable Museum of Sustainable Transportation", and an outdoor concert at Red Rocks Amphitheatre.

IV. 2011 REU Student Achievements

At the end of our program, videos [10-12] of three students' research projects were recorded to provide the general public and prospective applicants insights on our REU. Each video features a different student (KS, AS, DF) describing his or her renewable energy project in the context of one's academic background and summer experience.

In fall 2011, three other students presented their research results at national scientific conferences. One student (JTF) presented his work "Recovery of Iodine from Produced Water Through Anion Resin Exchange" at the Joint Meeting of the National Society of Black Physicists and National Society of Hispanic Physicists held September 21-24, 2011 in Austin, TX. Two other students (JC, SG) presented their results on "The Effect of Environmental Aging on the Mechanical Properties of PMMA Material Used in Concentrating Photovoltaics" and "Characterization of Defect Density of Varying Crystal Volume Fraction in Nanocrystalline Silicon" at the Conference of Research Experiences for Undergraduates Student Scholarship, hosted by the Council on Undergraduate Research, held October 16-17, 2011 in Arlington, VA.

A seventh student (MJ) won the Student Poster Competition at the Front Range High Performance Computing Symposium held September 23-24, 2011 in Golden, CO for his REU research on "High Performance Computing Applications for Material Physics." He also received an all-expenses paid trip to the SuperComputing 11 Conference held November 12-18, 2011 in Seattle, WA.

An eighth student (HH) won third place and \$1000 for her REU research on "Molecular Monolayer Optimization of the Interface in Nanostructured Organic/Inorganic Composites" in the University of Notre Dame's *NDConnect Undergraduate Nanoscience and Nanoengineering Research Competition* on September 30, 2011.

EVALUATION

The following section discusses the role of the Cornell Office for Research on Evaluation (CORE) Evaluation Partnership (EP) program on our renewable energy REU.

V. CORE Systems Evaluation Protocol (SEP)

Throughout 2011, one of the authors (Strong) was trained in the CORE Systems Evaluation Protocol (SEP) [13]. The SEP is intended to serve several purposes: it is first and foremost designed to be a step-by-step guide for evaluation professionals who wish to integrate a systems evaluation perspective into their work with organizations in order to enhance the quality and appropriateness of program evaluations. This Protocol was specifically created in the context of education and outreach programs generally and specifically for programs in Science, Technology, Engineering, and Mathematics (STEM) education and outreach sponsored by NSF and in programs sponsored by Cornell Cooperative Extension [13]. This SEP training and corresponding work effort helped us design a Logic Model [14] (that outlined our program's inputs, activities, outputs, outcomes, context, and assumptions) and a Pathway Model [14] (a graphical representation of the activities and outcomes that make up a program and how they are interrelated), resulting in a comprehensive model of our REU along with an associated evaluation plan. Collectively, these models revealed the important role *community* plays in the overall success of our REU. This evaluation section discusses how we applied the SEP to our REU to develop our Logic and Pathway Models, how we plan to use these elements to evaluate our 2012 REU, and how these results might be extended to other programs.

VI. SEP Phase I (Evaluation Planning)

Thoughtful evaluation plans can help long-term programs efficiently and meaningfully evolve. As an example, directors wishing to sustain or grow their programs must allocate their limited resources to those areas that need improvement or are critical to program outcomes. These areas may be obscured by microscopic and macroscopic struggles within the program, as well as human attachment to the status quo. Secondly, program resources are typically secured through benefactors or funding agencies that need to understand the program and its outcomes. In order to assure these stakeholders of the program's capabilities and vitality, they must clearly understand the program's structure so their involvement is as transparent as possible. While these are compelling reasons for a robust evaluation plan, a lack of resources and trained evaluators often force programs to adopt improvised or rudimentary evaluation schemes.

CORE developed SEP to enhance STEM program evaluation, placing an emphasis on program modeling. SEP includes three broad phases, subdivided into stages [15]:

- Phase I (Evaluation Planning): Stage 1 – Preparation, Stage 2 – Modeling, Stage 3 – Evaluation Plan Creation
- Phase II (Evaluation Implementation): Stage 1 – Implementation Preparation, Stage 2 – Data Collection and Management, Stage 3 – Data Analysis
- Phase III (Evaluation Utilization): Stage 1 – Reflection and Plan Revisions, Stage 2 – Reporting

During 2011, our REU evaluator completed Phase I, Stages 1 and 2, and is now completing Stage 3 in preparation for our 2012 REU program. CORE investigators have not yet finished developing Phases II and III of the Protocol.

VII. SEP Phase I, Stage 1 (Preparation)

The Preparation stage acquaints evaluators with the SEP and the CORE EP arrangement, and helps them identify current evaluation resources. Preparation involves (1) connecting with key program decision makers to discuss the evaluator's expected commitment to the EP and expected deliverables; (2) developing a *Memorandum of Understanding* that describes the roles and responsibilities of participants in the EP and a timeline of project activities and completion; (3) identifying internal stakeholders (program personnel who should be involved in evaluation planning); (4) identifying working group members (program personnel who will play a key role in developing the evaluation plan); and (5) assessing the program's evaluation capacity. Our evaluator completed these Stage 1 activities in early 2011.

VIII. SEP Phase I, Stage 2 (Modeling)

The Modeling stage enhances the evaluator's knowledge of evaluation concepts and provides aids to help identify how one's program "works." This stage requires the evaluator to produce program Logic and Pathway Models that are used to guide Stage 3 (Evaluation Plan Creation). The Modeling stage involves ten steps summarized as (1) performing a **Stakeholder Analysis** to determine the potential people and organizations that may have a stake in the program; (2) an introduction to the **Program Model Development Process** (the core evaluation concepts that will be needed to complete the SEP); (3) a primer on how to perform a **Program Review** to gain a firm understanding of the components and characteristics of one's program, including how it operates and whom it serves; (4) a **Program Boundary Analysis** to determine the conceptual limits of the program; (5) a **Lifecycle Analysis** to determine the maturity of the program and how its level of evolution influences evaluation capacity and method choices; (6) the production of a **Logic Model** (that includes the program's assumptions; context; inputs; activities; outputs; and short-term, medium-term, and long-term outcomes); (7) the generation of a **Pathway Model** that articulates clear and direct linkages between program activities and outcomes; (8) formulating an **Evaluation Scope** that determines the specific components of the Pathway Model that will be the focus of the upcoming evaluation cycle; (9) developing **Program-System Links** which introduce tools and strategies for finding similar programs and shared outcomes; and (10) a **Program Logic Model Synthesis** that finalizes the Logic and Pathway Models and assesses these from the perspectives of key stakeholders while staying within the guidelines established by the Program Boundary and Lifecycle Analyses.

Performing the Stakeholder Analysis is the first step in developing the Logic and Pathway Models. The evaluator identifies all entities having a stake in the program, their associated investment and interconnections, and through them, seeks to define the program. This provides an overarching view

of the program, but not specific elements critical to more heavily vested stakeholders. The evaluator seeks to interview stakeholders that have an understanding of "how the program works" so the evaluator can understand the subordinate parts of the program (for example, how these parts operate and who they serve). Four stakeholders (the REU Director, the REU administrative assistant, an REU senior faculty mentor, and the Chair of CSM's Committee on Diversity) were interviewed and asked the following open-ended questions:

- What does the REU do, and what do you want it to do?
- Where do you see the REU in three years from now?

An analysis of these interviews defined four general themes: (1) deliver a high-quality research experience, (2) devise a generalized REU construct, (3) maximize student diversity, and (4) enhance the local and regional scientific community. The first theme was expected, and though the second theme was not expected, it remains as a long-term goal of both the REU and its evaluation. The third and fourth themes emerged in all four interviews and were, to the evaluator, unexpected. Central to both themes (3) and (4) is the idea of an REU *community*, which struck the evaluator as extremely significant because evaluations from two renewable energy pilot REUs (offered during 2009 and 2010) [16-17] identified a lack of community. Increased focus should be paid to this important program aspect, and at this point, it is likely that this data will broadly and deeply define both the nature of the program evaluation and its elements. Thus, it is important to complete these preliminary Modeling steps by determining the program's conceptual limits.

As an example of Program Boundary Analysis, consider that K-12 STEM outreach seeks to "close the loop" by injecting higher-education system program gains back into the K-12 system. While some stakeholders may identify the effects and outcome such a program has on the parents of K-12 students, the evaluator must consider whether parents are participants of the program and if unique outcomes are connected to specific program activities. Analyzing such matters defines programmatic boundaries and helps to identify the statements and claims central to the evaluation. As a result, Program Boundary Analysis serves to define the program with respect to the evaluation, and does not necessarily include or exclude stakeholder-defined elements. Once stakeholder data is analyzed, the evaluator may step in and define the evaluation boundaries for the program, which makes the accumulated data manageable. Regardless of whether an element falls into or out of these boundaries, it will find a place in the overall program model. In the case of the renewable energy REU, the evaluator chose to create boundaries that would include the student participants but exclude the faculty, staff, and scientific mentors listed in Table V, even though they play important roles in the REU.

With a clear picture of both the overall mission and the internal elements of the REU, the evaluator's next task is to develop the Logic Model that captures these findings. Most program elements fall into four categories: inputs, activities, outputs, and outcomes [short-term (ST), medium-term (MT), and long-term (LT) outcomes]. Elements that do not fall into one of these four categories are listed as program assumptions or context. As the program evolves, topics from these

assumptions and context areas may find their way into program elements, so it is important to include them in the model development process. The Logic Model evolves as the evaluator frames the program and clarifies the evaluation scope. When completed, the Logic Model simply communicates program elements. Figure 1 shows an image from Netway [18], a CORE-developed online tool that helps evaluators build program logic models. The model in Figure 1 includes elements important to the community aspects of the renewable energy REU and constitutes a portion of the larger, overall REU Logic Model. Absent from Figure 1 are the context and assumptions which includes the faculty, staff, and scientific mentors listed in Table V (context), and an organized NSF-funded REU site (assumptions).

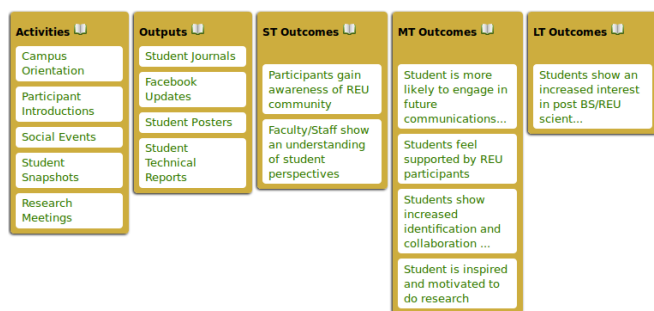


FIGURE 1
LOGIC MODEL FOR 2012 REU PROGRAM

Once the Logic Model is constructed the evaluator seeks to establish interdependencies between the activities and short-term outcomes. From this point, short-term outcomes can be connected to one another and to medium-term outcomes. This continues until specific long-term outcomes are established as terminal outcomes. The principle focus here is on the interconnections between program elements – the evaluator must consider the logical connectedness of the elements and whether an outcome is observable. For instance, broadening the K-12 STEM outreach example previously mentioned, it is expected that higher-education outreach into K-12 education will equip educators with STEM skills. However, no one would believe that a classroom demonstration constructed in higher-education and delivered to K-12 educators and students would manifest a radical improvement in the educators’ STEM skill-set. Instead, it is more likely that several such short-term demonstrations, in conjunction with several medium-term activities, will elicit the desired long-term outcome.

Careful analysis of these interdependencies creates a natural flow within a Logic Model whose graphical representation is called a Pathway Model. The Pathway Model tells the story of how the given program “works,” and it is at this point an evaluator sees the fruits of his or her modeling labor. Figure 2 is the Pathway Model created by Netway [18] that is associated with the Logic Model for the 2012 REU program shown in Figure 1. This Pathway Model describes only a portion of the larger, overall REU Pathway Model. The analysis and description of these larger, overall REU Logic and Pathway Models is beyond the scope of this paper. Suffice it to say that this is yet another point in the SEP where the evaluator

must again scrutinize the program model and separate essential from non-essential elements.

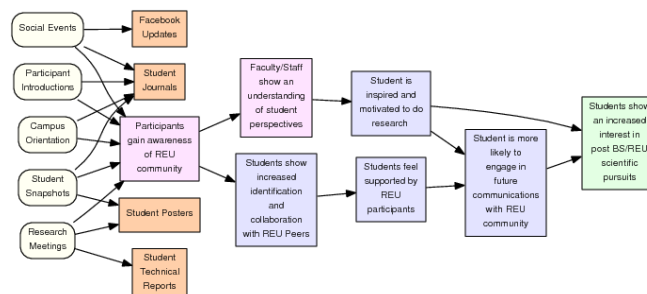


FIGURE 2
PATHWAY MODEL FOR 2012 REU PROGRAM

While the outcomes of the Pathway Model define those quantities an evaluator could measure, it does not say what should be measured. A program’s Lifecycle Analysis informs the decision on what should be measured. For relatively new programs the evaluator should concentrate on developing evaluation questions associated with short-term outcomes, and as the program evolves, so should the evaluation questions. This serves to define the scope of the evaluation and places the evaluator in a prime position to construct an effective evaluation plan.

IX. SEP Phase I, Stage 3 (Evaluation Plan Creation)

The Evaluation Plan Creation stage focuses on the development of an evaluation plan that will guide the implementation of the evaluation. This stage requires the following 9 steps: (1) introducing the concept and components of an Evaluation Plan; (2) developing evaluation questions based on the Logic and Pathway Models, Lifecycle Analysis, Stakeholder Analysis, and program insights (these evaluation questions will function as the core determinants of all the evaluation plan components and enable the evaluator to develop an Evaluation Purpose Statement); (3) developing a Sampling Plan that defines the population of interest, sampling frame and sample, and the sources of the evaluation data; (4) identifying measures already being used in evaluating the program and assess them for quality and feasibility; identify other existing measures that might fit the program evaluation needs; and/or develop any new measures that are needed; (5) developing an Evaluation Design that describes how the samples, interventions, and measures will be coordinated over time; (6) developing an Analysis Plan for analyzing evaluation data and describing how data will be managed; (7) developing an Evaluation Reporting Plan for reporting the results of the evaluation to key stakeholders; (8) developing an Implementation Plan and Schedule for the evaluation and key implementation milestones; and (9) generating a Final Evaluation Plan to share with leaders in the program and other relevant stakeholders.

The CORE EP occurred concurrently with the 2011 REU program. Consequently, much of the evaluation plan described here did not make it into the 2011 evaluation. That said, it was seen in the 2011 evaluation that a wealth of information was contained within the qualitative data associated with bi-weekly student updates. Specifically, students updated their progress to

the evaluator by responding to open-ended questions concerning the status, direction, and impediments of their research. At the same time, quantitative data was acquired via surveys that charted frequency and types of student-student interactions. Journaling exercises provided texture that complemented the previously described data. In summary, it appeared that success in the REU was correlated to overall student engagement. However, since the evaluation had not been focused on this engagement, a clear conclusion could not be drawn.

Our experience with two renewable energy pilot REUs (offered during 2009 and 2010) [16-17] enabled our 2011 NSF-funded REU Site to begin as a generally mature program. However, the evaluation of its community aspects is relatively new, and we can only hope to meaningfully measure short-term outcomes with our Pathway Model. We expect these aspects to be difficult to quantify and are again planning on exploiting the data found in student journaling. Specifically, we seek to address how REU participants characterize their interactions with their research groups and with each other. In order to increase the relevance of the information contained within their journals, we plan to add an additional question specifically asking them about their research group and REU interactions. The evaluator will analyze the qualitative data coming from these journals for themes important to the REU community. Also, the students will be asked to self-report their data in the form of an REU summary sheet, which will outline for each student memorable events and interactions of their REU experience.

SEP applied to our renewable energy REU has led to a detailed model of the program and revealed the importance of community in the developing scientist. If we wish to nurture this in our students, then we must well-understand its mechanisms. To accomplish this, the 2012 implementation of our Evaluation Plan seeks to investigate this from the students' perspectives. Surveys, the backbone of many evaluations, will be used in conjunction with journaling exercises to triangulate quantitative survey data. These journals will be analyzed thematically and also provide the basis of student self-reports. Our hope is that this data will not only inform the 2013 REU Evaluation Plan, but also begin the process of constructing a set of best practices en route to the development of a general REU construct.

SUMMARY

In 2011 Colorado School of Mines hosted 20 students in an NSF-funded REU program in renewable energy. To provide a measure of program evaluation, the REU joined the 2011 cohort of the Cornell Office for Research on Evaluation that trained an evaluator in Phase I (Evaluation Planning) of its Systems Evaluation Protocol. With a clear picture of both the overall mission and the internal elements of our REU, the evaluator developed Logic and Pathway Models that informed the creation of an evaluation plan that will be used in our 2012 REU program. Student success and satisfaction in our 2011 REU were closely linked to overall student engagement and a sense of community within the program's research and social environments. To better understand and nurture this sense of community, our 2012 Evaluation Plan will use journaling

exercises to triangulate quantitative survey data. The Cornell partnership has enhanced the evaluation skills and leadership of our REU Site, and built our capacity for extending our evaluation method to additional on-campus research programs.

ACKNOWLEDGMENT

NSF has generously supported renewable energy education at CSM through its awards NSF DMR-1063150, *REU Site: Research Experiences for Undergraduates in Renewable Energy* [1] and NSF DMR-0820518, *Renewable Energy Materials Research Science and Engineering Center* [6]. In January 2011, our REU Site was selected as one of five to participate in the 2011 cohort of the Cornell Office for Research on Evaluation (CORE) Evaluation Partnership (EP) project supported by NSF DRL-0814364, *A Phase II Trial of the Systems Evaluation Protocol for Assessing and Improving STEM Education Evaluation* [19].

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The Effectiveness of Undergraduate Research Programs: A Follow-up Study

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Abstract—Graduate work, especially the Ph.D., requires extensive research, a skill not often emphasized in undergraduate programs. Although not much is known about all the factors that influence undergraduate students' decision to pursue or not pursue graduate studies, particularly in science, technology, engineering and mathematics, recent research indicates that many undergraduates feel unprepared for graduate studies and view the research requirement as a deterrent. Opportunities for undergraduates to engage in research have increased recently as a result of federally funded programs including Research Experiences for Undergraduates (REUs), McNair Achievement Programs and Bioengineering and Bioinformatics Summer Institutes (BBSI). Students work in research laboratories during the summer, interact with faculty and graduate students, learning hands-on how to do research. The Attitudes toward Graduate Studies Survey was developed to help evaluate the effectiveness of these programs at New Jersey Institute of Technology. Students who participate in these programs show increases in their attitudes toward graduate studies and have significantly higher attitudes than students who do not participate. Often students indicate confidence in their ability to pursue graduate studies but only a small percentage think that they will have the skills necessary to begin a Ph.D. program when they complete their undergraduate degree. A possible conclusion is that even though students feel confident in their academic abilities they do not feel confident enough about their research skills to complete a Ph.D. program, making research programs such as REU's, BBSI and McNair, necessary. A follow-up study of students who attended these programs at NJIT over the last decade has found that participation in these programs increases attendance in graduate programs.

Index Terms— Attitudes toward Engineering, Attitudes toward Graduate Studies, Research Experiences for Undergraduates (REU), BIOMEMS, McNair.

I. INTRODUCTION

The need for a more highly qualified workforce continues to grow rapidly [1] but the number of students entering college programs in technological fields including science, mathematics and engineering (STEM) has only recently begun to increase [2]. Considerable research has been conducted to develop effective methods of encouraging more students to pursue careers in STEM, particularly engineering [3-7] so this increase has been expected, but there does not appear to be a corresponding increase in students engaging in more advanced, post-graduate studies, especially in engineering.

Research has shown that most students lack basic knowledge about what engineering is what engineers actually do [8]. Research has also shown that many students develop negative attitudes towards engineers and the field of engineering [9-10] and do not see the connections to their science and mathematics lessons. One approach has been to determine how the presence of engineering can be increased in K-12 school curriculum [11] and more recently greater attention has been given to students' attitudes toward STEM and engineering in particular, in an effort to steer more students into undergraduate engineering programs [12-13] and careers in engineering.

The factors that influence students' decisions about whether to attend college, which college to attend and their choice of career paths have also been studied [14-17]. However, far fewer studies have investigated the factors that influence undergraduate students' decisions to pursue or not pursue graduate studies, or their attitudes toward graduate studies, which could be an important factor in undergraduate engineering students' decisions of whether or not to pursue graduate studies [18-20].

Among the many reasons found for why undergraduate students decide not to begin graduate studies are the desire to get some practical experience first and being tired of attending school. Many students also indicate that although they believe the research requirements for a graduate degree would be beneficial in a STEM career, especially engineering, they admit the research requirement necessary to complete a graduate degree, a skill not often emphasized in undergraduate engineering programs, is a deterrent [19-20].

Another troubling fact is that while most students will agree they are confident in their ability to pursue graduate studies only a small percentage think that they will have the skills necessary to begin graduate studies, particularly a Ph.D. program by the time they complete their undergraduate degree [19-20]. One conclusion is that even though students feel confident in their own academic abilities they do not feel confident enough about their research skills.

Research opportunities for undergraduates in the United States have expanded over the past several years with the initiation of federally funded programs such as Research Experiences for Undergraduates (REUs) funded by the National Science Foundation (NSF) [21], the Ronald E. McNair Post-baccalaureate Achievement Program (McNair) funded by the Department of Education [22] and

Bioengineering and Bioinformatics Summer Institutes (BBSI) [23] funded by NSF and National Institutes of Health (NIH). Research programs such as these are intended to prepare students for graduate studies by teaching many of the necessary skills, but primarily research. Students work in research laboratories throughout the summer, interacting with faculty mentors and graduate students, learning hands-on how to do research. Students are required to make a presentation of their experience and participate in conference-style poster sessions. Often these programs extend into the academic year where students attend seminars, receive help in resume writing, interview skills and graduate school applications.

II. ATTITUDES TOWARDS GRADUATE STUDIES

Over the last decade New Jersey Institute of Technology (NJIT) has hosted the McNair program consistently, several different NSF funded REU programs across multiple years and the BBSI program [26] funded by NSF. Although these programs typically include students from other scientific disciplines, a majority of the students who participate in these programs at NJIT are engineering majors. As part of the effort to evaluate the effectiveness of these programs, the Attitudes toward Graduate Studies Survey (AGSS) [19-20, 24] has been developed to measure the impact the research experience has on students' attitudes towards pursuing graduate studies, especially a Ph.D. degree. The AGSS, the psychometric properties of which are published elsewhere [20], uses Likert-type attitudinal scales to measure undergraduate students' attitudes toward graduate studies, their engineering skills self-efficacy, and their level of school-related self-confidence.

Students participating in REUs and the McNair programs at NJIT during the last seven years complete the Attitudes to Graduate Studies at the beginning and end of the program to evaluate the impact of the research experience on their attitudes toward pursuing graduate studies [19]. Students indicate the degree to which they agree or disagree with a total of 30 statements about careers in engineering, the benefits and or disadvantages of graduate studies, their desire to pursue graduate studies and the obstacles students face in pursuing advanced degrees. Agreement is measured on a five-point scale where 1 indicates strong disagreement and 5 indicates strong agreement. For example, one item states "The research requirements necessary to complete a graduate degree are undesirable". Since students typically participate between their junior and senior years students are also asked whether they have applied or intend to apply to graduate school to see if participation in the program influences their immediate plans.

Over the past few years, the survey has also been given to a large heterogeneous sample of other students at NJIT and students in REU programs at other universities in addition to the students in the REU, BBSI and McNair program at NJIT [20, 24]. Overall, less than 25% of all students who responded to the AGSS indicated they were considering advanced graduate studies. Many students expressed financial concerns or a desire to get out into the world and gain experience. Many students felt that they were not adequately prepared to pursue an advanced degree, particularly a PhD. in engineering.

In contrast, the students who participated in one of the summer research programs were found to have significantly more positive attitudes toward graduate studies, appeared more confident in their abilities and indicated they felt more prepared for graduate studies at the end of the program than they did before beginning the program [24, 25].

A. Difference between Male and Female Students

Some interesting significant differences have been found between male and female students, consistently. There are several items on the survey intended to measure gender equity including but not limited to; "To be successful, it is more important for women to attend graduate school than for men", "Women can succeed in a STEM career as easily as men of similar ability" and "Women are more likely to be accepted into competitive graduate programs than men of similar ability".

Female students agree more strongly that women could "succeed in a STEM career" than the male students. And although females students agreed more strongly than the males students that it was "more important for women to attend graduate school than for men", male students more strongly agreed that "Women are more likely to be accepted into competitive graduate programs". From this it is possible to conclude that most female students feel they are equal to male students and are being evaluated equally while male students do not think women are equal even though they feel women are accepted more often into competitive graduate programs.

III. FOLLOW UP

An alumni version of the survey for students who have completed their undergraduate degree has been developed to begin collecting information about what students actually do during the years immediately following graduation, how working or attending graduate school may affect students' attitudes, and how their attitudes toward graduate studies may be different from students who have not yet graduated.

The alumni version of the AGSS has been sent out to students who participated in the REU, BSSI and McNair programs at NJIT and a random sample of alumni who did not participate in any of these programs for comparison purposes. The response rate has been very slow and because students often relocate, large numbers of survey are returned as undeliverable.

Preliminary results from the small number of students who have responded to date indicate that 30% are enrolled in Ph.D. programs most of which are students who participated in one of the research programs but the sample is too small to draw strong conclusions. The authors need to wait for more responses and find other ways of locating the desired students before completing the final analyses including a summary of the attitudinal responses. Perhaps a follow-up reminder letter needs to be sent out to help increase the responses rate.

In an effort to get a more immediate estimate of how many of the students who attended the research programs are currently enrolled in or have completed graduate programs the authors traced the academic status of students who attended an REU, BSSI or McNair programs at NJIT during the period from

1999 through 2010, using the National Student Clearing House. The McNair program began at NJIT during 1999 and has run continually. Seven different REUs, some concurrently, were run during the years from 2006 through 2009 and the BSSI ran from 2003 through 2009. Because students typically attend these types of research programs prior to their senior year most students who attended through 2010 would have completed their undergraduate degree and had an opportunity to apply to or begin a graduate program. Those who attended in 2011 would not be expected to even complete their undergraduate degree until 2012.

Seventy-one undergraduate students attended an REU, 63 attended the BSSI and 121 were enrolled in the McNair program at NJIT during the time period from 1999 to 2010 for a total of 255. There were four students who could not be located through the National Student Clearing House, therefore the summary of students' post undergraduate activity in Table I is for the 251 students that information was available for. Across the three programs the ratio of females to males was 36% to 64% which is higher than the 27% to 73% reflected in the current STEM workforce [1].

TABLE I. SUMMARY OF POST-GRADUATE ACTIVITY

| Program | Withdrew | Currently Enrolled | Completed | Percent |
|----------------|-----------|--------------------|------------|------------|
| None * | | | | 25% |
| Masters | 3% | 5% | 31% | |
| Ph.D. | 6% | 20% | 3% | |
| Medical Degree | - | 4% | 2% | |
| Law Degree | - | <1% | 1% | |
| Total | 9% | 29% | 37% | 25% |

* No post-graduate activity was found

Based on the 251 students identified through the National Student Clearing house, 25% terminated their education with a bachelors degree and 75% began a graduate program, although 9% withdrew after beginning. Therefore, to date 66% of the students who attended one of the summer research programs at NJIT is either currently enrolled or complete a graduate degree; 29% are currently enrolled and 37% have completed their program, a percentage that is much higher than for those students who do not attend such programs [1, 27].

Five of the 31% who completed their Masters degree had begun a Ph.D. program but withdrew with a Masters degree. Another 6% began a Ph.D. program and withdrew with no degree. From this one can conclude that even though only 23% are currently enrolled or have completed a Ph.D. (20% + 3%, see Table I) 34% of the students at least began a Ph.D. A smaller percentage of students who began a Masters Degree program withdrew without completing their degree. A follow-up study to determine why students begin but do not complete their degree could be informative.

All but one of the students who are attending or attended either Law School or Medical school received their bachelors degree in Biomedical engineering the other in Chemical

engineering. The two students who have completed their Law Degree received their Juris Doctor in Patent Law.

Several students complete more than one Masters Degree rather than a Ph.D. One students' second Masters Degree was in Education which is encouraging in that this student probably went into education and might help advance STEM education in this country.

Many of the students who are still currently enrolled in graduate programs did not begin their programs immediately after completing their undergraduate degree but rather 2 or 3 years later. This fact is consistent with the high frequency with which students who responded to the Attitudes to Graduate Study Survey indicated they "thought it was a good to work for a couple of years to gain experience".

IV. DISCUSSION AND CONCLUSIONS

Research into undergraduate students' decisions of whether or not to pursue graduate studies, especially in engineering has found that less than 25% of students consider advanced graduate studies by the end of their junior year [19-20, 24]. Many students express financial concerns or a desire to get out into the world and gain experience, but more often indicate that they do not feel they are adequately prepared to pursue an advanced degree, particularly a PhD.

In contrast, students who participate in a summer research program, such as an REU, the BSSI or McNair appeared more confident in their abilities and felt more prepared for graduate studies at the end of the program than they did before beginning the program [19, 24-25]. Further research is necessary to explore more fully the reasons students do not feel they are prepared for graduate studies or why they withdraw after beginning a program (i.e. are there other reasons besides inadequate research skills?).

Female students in STEM programs appear to see themselves as more capable than the male students perceive them to be. Male students seemed to think it is more important for female students to attend graduate school to be successful and that female students are more likely to be accepted into competitive graduate programs. Future research on engineering students' attitudes to graduate studies should include a more in-depth examination of the differences between male and female students and possible explanations for the differences.

Location of students through the National Student Clearing House has been informative in allowing us to estimate the proportion of students who attended summer research programs at NJIT have either entered or completed graduate programs after completing their undergraduate degree; 64% which is much greater than for students who do not attend such programs. Although tracking these students provides confirmation that there programs are effective in encouraging and preparing students to pursue graduate studies it has also led to more questions, such as why students withdraw after beginning or why they take several years to begin their studies?

The authors intend to step up efforts to reach the students who attended REUs, the BSSI and McNair personally and ask

them to complete the Alumni version of the Attitudes toward Graduate Studies Survey. Perhaps an incentive to answer is necessary. The response rate should also improve since location of students through the clearing house has provided more current contact information for students whose original surveys were returned as undeliverable.

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An Engineering Curriculum Track for IT for Sustainability

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Abstract—Information technology (IT) forms a crucial foundation for designing, building and managing future sustainable cities. This paper proposes a model to innovate the engineering and computing curriculum to include sustainability and IT topics in order to develop the skills and competencies that future professionals will need to design, build and manage future cities. Rather than developing a new program, we propose a curriculum model – called SustainIT – adapted from the successful 2006 US NAE Gordon Prize engineering curriculum innovation, The Learning Factory – as a possible roadmap to reform and complement existing Bachelors of Science (BS) degrees in engineering. By providing a series of guided electives, any engineering program may offer engineering, and/or computer science students the opportunity to learn about and become specialized in IT for Sustainability. Multidisciplinary topics include traditional ecological engineering; life-cycle design; design and application of resource microgrids; pervasive sensing and data aggregation; knowledge discovery, data mining and visualization; and, policy based control and operation for resource provisioning.

Keywords - curriculum innovation, engineering education, BS, sustainability, information technology (IT), future cities.

I. INTRODUCTION

A. Motivation

Environmental sustainability is top-of-mind for many university faculty and administrators today, as well as for countries, industry and citizens. Growing concern, both in the developed and developing world, regarding the impact of resource consumption challenges stems from various drivers. The world's population is expected to reach 9 billion by 2050 [1]. How do we deal with the increasing strain that the economic growth is placing on our dwindling natural resources? Can we expect to meet the needs of society by solely relying on replicating and extending the existing physical infrastructure to cope with economic and population growth? Indeed, anecdotal evidence of the strain that society is placing on the supply side—the resources used for goods and services—is apparent: rising prices for critical materials, such as copper and steel; the dramatic reduction in petroleum output around the world; and limitations in city scale waste disposal. Increasing costs for basic resources required for population growth and social services will have a negative impact on economic growth in many geographies. Furthermore, externalities such as environmental pollution, natural disasters and military conflicts are increasingly becoming a burden to society. As many of the costs for environmental externalities are being imposed, consumers and producers are being forced to internalize and allocate the environmental costs associated with their consumption and production. We cannot expect to meet the future needs of society

simply by extending existing infrastructures or conducting business as usual with a reactive stance towards environmental concerns. Finally, extensive literature around the world cites the constant need of renovating existing engineering curricula to better respond to stakeholder needs. We still have learning systems that were developed in the 18th century with little change in content and student learning experiences.

B. Urban Transformation and Sustainable Cities

The concept of “cities of the future” sparks the human imagination. From Orbit City and aerocars in the Jetsons cartoons to fantastical real-world constructions in modern Dubai, our vision for urban architecture and infrastructure has driven amazing innovation. But while our imagination is abundant, the earth's energy and physical resources are not. As a result, we may no longer simply ask, “is it faster, more capable, more powerful?” but rather, we must consider the global environmental challenge and ask, “is it part of the problem...or part of the solution?”

Our very definition of breakthrough innovation for future cities must evolve [2]:

- to apply the experiences of our ancestors, who in the days before mechanized mass transportation, built cities that utilized local resources (the supply side) to meet the demands of their inhabitants;
- to gather lessons from ancient cities to assimilate traditional engineering knowledge;
- to apply fundamentals of social and physical sciences; and
- to examine the role of information technology, using ubiquitous connectivity for the collection of data, data mining, and its analysis for effective and efficient decision making.

Planning of future cities will require the integration of the IT ecosystem into the fabric of a city's infrastructure to enable necessary societal and business activities to take place without unduly taxing the supply side and the environment. Consider, for example, the supply side physical infrastructure made up of roads and vehicles. We cannot expect to meet the needs of the society (the demand) by solely relying on extending the physical infrastructure to cope with population growth. Thus, as populations increase and resources dwindle, how will we design and build fully sustainable cities of the future? We must apply tools and methodologies that enable systemic analysis, design, and management based on integrated management of supply and demand [2]. Section II. B discusses a possible framework to address these challenges.

II. ROLE OF IT IN SUSTAINABLE CITIES

According to Infolific (www.infolific.com) information technology in the broadest sense “refers to both the hardware and software that are used to store, retrieve, and manipulate information.” Moreover, we are experiencing a fundamental shift from focus on the “technology” to the “information.” The new value chain in human information spans from sensing – physical, personal, and social – to storage, to analysis, to visualization; to the ability to securely access and share information and insights. We believe that information technology can transform future cities along the following two axes:

- **IT Services:** Driving the next generation of IT services will be the millions of citizens who will avail themselves of IT services to address their fundamental needs and improve their quality of life. We have the opportunity to transform the world by deconstructing conventional supply-chains and replacing them with sustainable IT services. This transformation can be delivered by an ecosystem made up of trillions of sensors, billions of handhelds and printers, millions of systems, thousands of data centers and print factories [18], [19], [20].
- **Management of Resources:** With data centers at the hub, and pervasive connectivity, the IT ecosystem can enable integrated supply-demand management of critical resources such as power, water, waste, etc.

Interestingly, the IT-led transformation noted above can only occur if IT itself is sustainable. As an example, as energy drives the total cost of ownership of a data center, there is a need for a new paradigm in design and management of the data center that minimizes energy used across its lifetime – from “cradle to cradle”. The need for a “least lifetime energy data center” is further compounded as a result of the projected increase in cost of energy [3] and imposition of regulations that address environmental externalities. An architecture for a sustainable data center that delivers on total cost of ownership goals and has the long-term view of addressing the environmental externalities such as carbon dioxide emissions is needed. Indeed, the authors contend [2] that contrary to the oft held view of sustainability as “paying more to be green”, sustainable data centers – built on a framework that focuses on supply and demand management - are the lowest cost data centers.

A. HP Labs Research on Sustainable Data Centers

Recent studies indicate data center and associated facility energy use currently account for approximately 1.3% of global energy consumption. In the US alone, this share of consumption increases to approximately 2% [17]. The massive-scale, intelligent infrastructure required to power modern business can and should be sustainable. A sustainable data center is one in which end-to-end resource consumption, from material extraction and manufacturing, to operation and end of life, is minimized. Since data centers provide useful services, a sustainable data center must also satisfy the performance requirements - known generally as Service Level Agreements (SLAs) - of the hosted services, while reducing the Total Cost of Ownership (TCO) and emissions.

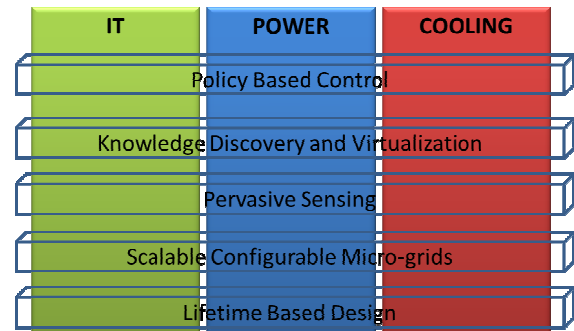


Figure 1. Architecture of Sustainable Data Centers

As shown in **Figure 1**, at HP Labs we have identified five principal areas for integrated design and management to enable a sustainable data center [18]. Each of the five subject areas span the three primary infrastructure components found in data center designs: IT infrastructure (including compute, storage and networking), power delivery infrastructure (including backup power generation and storage, transformers, UPS etc.) and cooling infrastructure which is responsible for removing the heat generated by the IT and Power infrastructures and conditioning the thermal environment for reliable operation. Recently, we’ve shown how this architecture can be used to design and operate data centers using renewable resources in a manner that consumes no net energy from the public utility grid [19],[20]. Such “net-zero energy” data centers represent the future of sustainable computing. Given the diverse expertise required for designing and operating of each infrastructure element in Fig. 1, multi-disciplinary teams are required for research, design and operation of such facilities. In the sections below, we first elaborate on the content of the curriculum (the five principal subject areas), then on the skills engineering students should possess, to finally propose a learning model.

- **Lifetime Based Design.** Existing data center design approaches are focused on assimilation of discrete components into an operational infrastructure that meets runtime objectives, such as performance and cost targets. From a sustainability perspective, however, the environmental impacts are distributed across the lifecycle of the data center – including the extraction of raw materials, manufacturing of the components and building, transportation, operation, and end-of-life. An integrated approach is needed that incorporates Design for Environment (DfE) principles across the lifecycle, while allowing the data center designer to evaluate the necessary runtime objectives. Such an approach requires expertise in subjects like the environmental sciences as well as software development.
- **Scalable, Configurable Resource Micro-grids.** The data center is built with flexible components within each infrastructure that provide the ability to vary resource use dynamically according to demand. Examples include variable speed fans and pumps in the cooling infrastructure, and virtualization in the IT infrastructure. Necessary subject-matter expertise spans mechanical and electrical engineering to computer science.
- **Pervasive Sensing** continuously monitors the entire data center. There are many measures of interest in a data center - measures that are required to gauge and affect demand-side usage.
- **Knowledge Discovery and Visualization.** Knowledge discovery and visualization (or visual analytics) is a family of mathematical tools for detecting, predicting and visualizing

patterns and anomalies, and can provide better insight to the administrators and agents that manage a data center [4],[5]. Subject matter expertise ranges from data mining and analytics, to domain knowledge.

- **Policy-Based Control.** There are some decisions that must be made too frequently or that are too complex for humans to be effective arbiters. A policy-based control system enables real-time control of data center infrastructure components – IT, power and cooling – based on control theoretic techniques. It utilizes each of the previous layers to control and provision resource use across the data center based on sustainable operating policies (like minimization of energy consumption or emissions). Subject matter expertise includes control theory and domain expertise from mechanical and electrical engineering to computer science.

B. Beyond the Sustainable Data Center: Sustainable Cities Enabled by Supply and Demand Management

Just like the sustainable data center, resource management in urban infrastructure relates to holistic management of physical infrastructure at city scale through IT technologies. Unlike industrial age generations, where cities were built predominantly focusing on cost and functionality desired by inhabitants, sustainable cities will require a comprehensive life-cycle view, where systems are designed not just for operation but for optimality across resource extraction, manufacturing and transport, operation, and end-of-life. However, like ancient cities, we suggest a return to traditional engineering knowledge as a foundation of new cities but strengthened with sustainability and IT learning experiences. Indeed, researchers such as S. Ramakrishnan (2001) refer to this as “traditional ecological knowledge” [6] and explore the riches of tribal knowledge in North East India. Examples abound in historical monuments: the Amber Fort in Jaipur, Rajasthan, India, for example, is in an arid region and was built with intricate water harvesting to enable a local micro-grid of water [7].

Our **supply side perspective** calls for using pools of resources of available energy, alongside design and management that minimizes the energy required to extract, manufacture, mitigate waste, transport, operate and reclaim components. This suggests creating numerous “micro-grids” that incorporate various sources of locally-sourced energy, such as solar electricity or wind turbines, that complement centrally-sourced electrical energy. Indeed, seeking available energy in waste streams to augment the distributed energy resources is key to improving efficiency, e.g. using methane from waste water, or methane derived from manure in local farms [8]. These micro-grids need to be scalable and flexible in order to enable a balance in supply and demand.

The **demand side perspective** requires provisioning resources based on the needs of the user by applying sensing, communications, knowledge discovery and policy-based control to the flexible building blocks. Akin to the sustainable data center, the flexible building blocks are micro-grids and other means for generating and distributing resources in the city. An integrated supply-demand system can enable a city to operate and maintain an optimal balance of demand and supply [2].

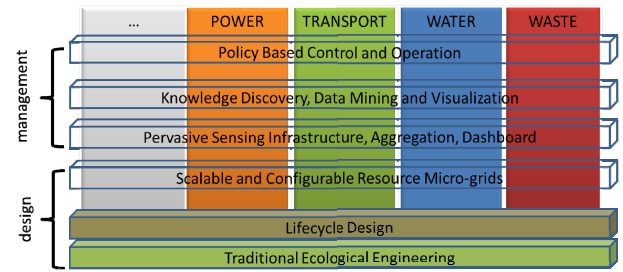


Figure 2. IT-Enabled Architecture for Sustainable Cities

Given this framework, we need a new breed of engineering professionals trained in the engineering fundamentals and the role IT plays in the challenge of building the sustainable cities of the future. In addition, these engineers need to have learning experiences on how work in multidisciplinary teams and are capable of optimizing solutions with input from many perspectives, including those not technically related, like social, historic and economic issues.

III. IT AND SUSTAINABILITY CURRICULUM

A Google search on the keywords “sustainability and IT curriculum” yields over 13,200,000 resultsⁱ covering a wide spectrum of answers covering all levels of education. One can also find extensive dialogue and discussions regarding ‘sustainability across the curriculum’ aiming at integrating the theme/topic into existing curricula [9]. Yet, among the first few dozen results, none address the curriculum needed to develop the engineering/technical professional in which IT and its role in sustainability are part of the learning experience.

Nevertheless, there is a significant amount of activity in curriculum development and innovation around the world to address sustainability issues. We present a detailed review of existing programs in our prior work [10]. Curriculum development was one of the key topics presented and discussed at the inaugural meeting of the European Platform of Universities Engaged in Energy Research, Education and Training (EPUE), held in TU Delft, in the Netherlands in February 2012. Again, none of the presentations included the topic of IT as fundamental for curriculum innovation.ⁱⁱ Yet, of the hundreds of papers presented in this year’s ASEE Annual Conference, there was only one (1) session pertaining to integrating sustainability into the curriculum [11].

Our key findings are that while high-quality sustainability curricula already exist today, the majority are focused on environmental or social issues and are housed in departments such as Environmental Engineering or Urban Planning. Few incorporate coursework related to computing or IT for sustainability.

We believe that IT is among the very basic disciplines required to design, build and manage cities of the future. Moreover, to build, manage and make effective decisions, a unique professional

ⁱ Google search conducted January 19, 2012

ⁱⁱ <http://www.eua.be/events/past/2012/epue-inaugural-event/presentations.aspx>

is needed: one with a blend of knowledge and skills in computer science, mechanical and electrical engineering, economics, social and environmental sciences, and economics, among others.

A. Innovating the Curriculum

The curriculum is one of the many variables that help universities achieve their mission and comprises the set of experiences a student has to go through to acquire knowledge and develop skills, in other words, competencies.

We believe innovating or reforming the curriculum is a more efficient approach to respond to ecosystem needs than developing a new curriculum from scratch. In this paper we propose a very well known, effective and efficient process to be used by engineering and computing educators to undertake curriculum innovation: applying the engineering problem solving approach to innovate the curriculum. We provide a more detailed discussion in our prior work [10],[11], including an overview of the *Learning Factory* curriculum innovation model, co-developed by one of the authors of this paper (Morell), and which won the US National Academy of Engineering Gordon Prize of 2006 [13],[14]. This multidisciplinary curricular innovation was successfully conceptualized, developed and implemented in three major US universities in a record time of 2 years. The program was designed and implemented in response to industry needs for an engineer with focused knowledge of product design and manufacturing. It involved course development, learning/laboratory facilities for student hands-on practice based activities, industry collaboration and outcomes assessment. Since its creation, the Learning Factory model (or some of its components) has been adopted by other disciplines in many institutions around the world.

B. IT and Sustainability Curriculum – The Need

The first step in curriculum innovation is establishing the need. As we described in section II, IT will become a fundamental tool for the efficient management of scarce resources that have an impact on society, such as water, energy, waste management, or transportation. But as we begin to understand the technical requirements of such a holistic solution for the development of sustainable cities, the need for engineers trained in the disciplines required for each of these competencies becomes apparent. The need for multi-disciplinarity and knowledge of disciplines outside the traditional engineering discipline realm also becomes apparent.

In **Figure 2**, we illustrate how the supply- and demand-side framework of design and management principles developed for Sustainable Datacenters may be applied to sustainable cities as horizontal activities that, in turn, can be used to optimize city “vertical” services such as power (energy) or transportation. Each of these **horizontal and vertical activities** will require engineers that are trained in a set of distinct competencies:

- **Policy-Based Control and Operation:** Control theory from a Mechanical and Electrical Engineering point of view; Industrial Engineering to understand operations and optimization at multi-megawatt scales; understanding of electrical power design; and understanding of mechanical design. This implies a “control systems thread” taught by an Electrical Engineering department or Mechanical Engineering department that combines Computer Science, Mechanical Engineering and Industrial Engineering.
- **Knowledge Discovery, Data Mining, Visualization:** Analytics of this form will become the backbone of many solutions in the sustainability age. The learning will be derived from Mathematics (Advanced Statistics); Computer Science with a focus on data mining and visualization for

analytics; and Machine Intelligence. In addition, as many of the devices that will be addressed will be made up of fluid movers, compressors, and so on, knowledge of fluid mechanics and thermodynamics will be important.

- **Pervasive Sensing Infrastructure, Aggregation, Dashboards:** Electrical and Mechanical Engineering principles will be required to understand a variety of methods for sensing and calibration. These will need to be combined with communications to gather data using both wireless and wired networks. Overlapping with Knowledge Discovery, students of this area will specialize in data aggregation leveraging a variety of data mining principles in their “toolkit”. Knowledge of the current generation of software methodologies for creating user interfaces will also be necessary to build usable dashboards for network operations centers.
- **Scalable and Configurable Resource Microgrids:** Fundamental principles of Mechanical Engineering and Electrical Engineering, specifically power systems, will drive this area. In addition, strong knowledge of Thermodynamics, Principles of Electricity and Magnetism will be needed to understand energy conversion. Mechanical and Electrical design principles will be needed to understand how to make power grids flexible. Computer Science and Electrical Engineering principles will be needed to understand the means of communication with the physical grids.
- **Life-cycle Design:** This area will require personnel trained in Engineering Economics, Environmental Economics, Materials Science, and Principles of Mechanical Engineering. All these areas will need help from Computer Science learning to build design tools e.g. software and database solutions.
- **Traditional Ecological Engineering:** This foundational area will require understanding of Social Sciences, Environmental Economics and a new area of traditional knowledge gleaned from textbooks of the past. Understanding of Anthropology, Botanical Sciences and Agriculture will be critical. While not specifically addressing traditional engineering, an understanding of the evolution of environmental policy matters over the years will also be crucial for future professionals.

In addition to this list of knowledge, engineering students will also need to continue to develop professional skills that have been identified by accreditation agencies such as ABET [15] and professional societies. These include skills like working in multidisciplinary teams, ability to communicate effectively, awareness of business and environment needs, agility and flexibility, among others. These skills become ever more important for engineers in the sustainability area.

IV. SUSTAINIT: A PROPOSAL TO INNOVATE THE BACHELOR IN SCIENCE IN ENGINEERING (BS) DEGREE

We propose opening a dialogue among the computing and engineering education community focused on the development of a curriculum for the sustainability age at the BS level. We present the first two phases of the process: needs identification and curriculum design. Implementation and outcomes assessment, important components of the process – would need to be considered at a later stage.

A. The Sustain IT Undergraduate Curriculum

First, at the undergraduate level, the **SustainIT** curriculum relies on engineering fundamentals in the various engineering

disciplines. Degree programs naturally inclined to provide fundamental coursework towards this specialization (with their respective required technical courses), include:

- **Computer Science and Engineering:** Software Development; Programming; Operating Systems; Databases; Systems Architecture; Data Storage; Networking;
- **Electrical and Electronics Engineering:** Power Generation; Grids and Micro-grids; Power Transmission; Failure Analysis; Semi-conductor Physics; Chip and System Packaging; Control Theory;
- **Mechanical and Civil Engineering:** Thermal Sciences; Engineering Design; Solid Mechanics; Structures; Manufacturing; Statics and Dynamics; Quality and Reliability;
- **Environmental Science and Sustainability:** Sustainability Basics; Macroeconomics; Microeconomics; Environmental Accounting; Development Theory; Waste Management; Public Policy and Standards; Introduction to Anthropology;
- **Industrial Engineering:** Supply Chains; Operations management; Engineering Economics; Optimization.

Second, students wishing to earn a specialization in *SustainIT* would then be required to take a series of guided electives offered across the program, as well as complete other requirements described below. Following the components of the Learning Factory, the *SustainIT* curriculum would have the following three features: 1) an IT and Sustainability specialization, track, minor or optionⁱⁱⁱ within existing engineering disciplines (consisting of a series of *Sustain-IT* electives available to all engineering students to be taken across the program); 2) hands-on learning experiences that would include industry-based projects and could entail an internship in industry or a government facility; and, 3) a multidisciplinary capstone design project focused on an IT for Sustainability theme.

In keeping with the IT-enabled architecture for sustainable cities described in **Figure 2**, the following is our recommendation for a series of guided multidisciplinary electives in the *SustainIT* specialization:

1. Fundamental course in IT and Sustainability that would be required for all students wishing to complete the specialization in each of the disciplines.
2. Six directed multidisciplinary electives focused on IT for Sustainability, available to all engineering disciplines:
 - a. Policy-based Control and Operation
 - b. Knowledge Discovery, Data Mining and Visualization
 - c. Pervasive Sensing Infrastructure, Aggregation, Dashboards
 - d. Scalable and Configurable Resource Microgrids
 - e. Life-cycle design
 - f. Traditional Ecological Engineering
3. Other optional electives such as: History of Urban Development, Ecological Engineering, and/or other relevant social science courses in economics, public policy, anthropology, or demographics.

This proposal acknowledges the uniqueness and particularities of each institution. We propose a framework to innovate the engineering and computing curriculum. Each institution or program has the flexibility to develop these (and other courses)

ⁱⁱⁱ Curriculum innovation alternatives are dependent on each university/program's regulations.

that might address the need, and to adapt the ideas presented here to their particular needs and regulations.

For example, engineering disciplines at University X would determine the minimum credits (and number of courses), student experiences, capstone design projects, etc. needed for the minor. The Mechanical Engineering program might suggest the following sequence of courses and experiences to students wishing to earn the *SustainIT* specialization:

1. Fundamental *SustainIT* course (3 credits)
2. Life-cycle design (3 credits)
3. Traditional Ecological Engineering (2 credits)
4. Scalable and Configurable Resource Microgrids (3 credits)
5. *SustainIT* focused Capstone Design Project (3 credits)

Similarly, Computer Science/Engineering might suggest the following sequence:

1. Fundamental *SustainIT* course (3 credits)
2. Policy-based Control and Operation (3 credits)
3. Knowledge Discovery, Data Mining and Visualization (3 credits)
4. Pervasive Sensing Infrastructure, Aggregation, Dashboards (3 credits)
5. *SustainIT* focused Capstone Design Project (3 credits)
6. Industry internship (2 credits)

Figure 3 illustrates the various components of the *SustainIT* curriculum model. As with the Learning Factory model, teaching/learning methods must also be reformed to center on the student's learning and skills development. Hands-on practice-based activities, industry projects, and other activities should be designed and integrated into the learning experience. Finally, and as mentioned earlier, tools and rubrics to assess student learning will also be required to continuously enhance the quality of the program.

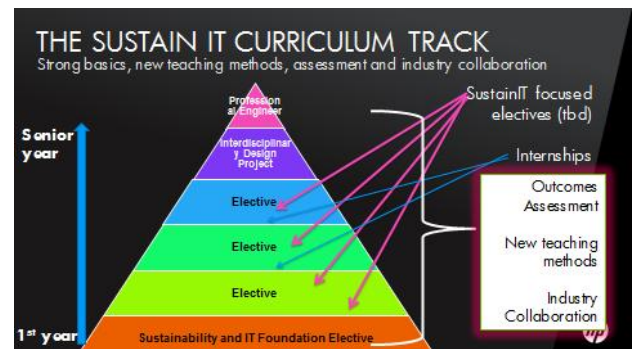


Figure 3: Sustain-IT Curriculum Track

B. Industry-University-Government Partnerships

The *SustainIT* curricula require students to have hands-on, practice-based experiences, as well as participate in real life industry-based projects. These are a crucial component for developing the kind of engineers that future cities will need.

Industry and governments have a vested interest in collaborating with academic institutions in developing these types of curricular innovations. They will need talent to help design, build and manage future cities. Therefore, collaboration among industry, government, and non-profit organizations is at the heart of the proposed model. They can assist professors in defining the desired profile of the graduating student; provide students with real life projects and provide students and faculty with internship

opportunities in real-life engineering settings; and share state-of-the-art technologies being developed in research labs that could influence curricula [16].

V. CONCLUSIONS AND RECOMMENDATIONS

Higher education is responsible for formally preparing the next generation of business leaders, technical professionals, government officials and educators, and plays a central role in our increasingly technology-based societies and in addressing local, regional and global challenges. The education of computing professionals and engineers must prepare them for the multi-disciplinary nature of the problems they will face.

IT is an important foundation to design, build and manage cities of the future. There is a need to initiate a dialogue around the globe to develop the human resources desired to address future requirements in these areas. As a first step in curriculum innovation, the authors have described the needs for curriculum innovation for the sustainability age and propose a roadmap for innovating the engineering and computing curriculum at the Bachelor's level, called *SustainIT*. This paper is intended as a baseline and foundation for dialogue among the engineering education community of stakeholders. We encourage not only dialogue around the creation of a novel curriculum model such as the one we describe here, but also a dialogue around a re-emphasis on fundamental engineering principals that includes hands-on learning experiences and experiments that teach problem solving and design, and that provide a solid basis for multi-disciplinary engineers who can integrate traditional engineering with information technology to address the new sustainability challenges facing our society.

The authors recognize that more in-depth research around the world must still be done on 1) integration with existing sustainability and IT curricula and, 2) current and future employers' needs. In addition, curriculum options in sustainability and IT should be developed at the Philosophy Doctorate (PhD) and Masters (MS) degree levels to complement the Bachelor's (BS) degree proposed herein. The latter will be critical to advancing this burgeoning research innovation agenda.

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The Impact of Real–World Topic Labs on Student Performance in CS1

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Abstract—We examine the impact of using lab exercises based on real–world topics in the CS1 course at the University of Texas – Pan American. In Fall 2010 and Spring 2011 we used drill style exercises. For Fall 2011 and Spring 2012 we created a new set of lab exercises that are based on real-world problems. In this paper we examine impact of the new lab exercises on the number of students who complete the exercises, on the students’ grades on the exams, and on the final course grade. For the new lab exercises, the students are provided with an example program that contains extensive comments describing the skills targeted in that lab. Then they complete a similar program on their own. Whenever possible, we used games for the programs. When we could not devise a game exercise, we used problems that the students are likely to encounter in the real world. Sometimes we reused the same game/problem in multiple exercises. We found that many more students completed the lab exercises and the overall course performance improved when we used the new labs.

I. INTRODUCTION

The University of Texas – Pan American (UTPA) is a Hispanic serving institution located in South Texas. There are over 19,000 students enrolled at UTPA, with 88% of those students being Hispanic, and 68% of the students being first generation college students. The university as a whole is pursuing student retention initiatives in order to increase the percentage of students who graduate in six years, which now stands at 42%.

In 2011 (spring and fall combined) 13 Computer Science and 15 Computer Engineering students graduated from UTPA. Our Engineering Computer Science I (CS1) course, which focuses on introductory programming in C++, is required for both the Computer Science and Computer Engineering majors. Each section of the course usually has between 25 and 35 students enrolled. In the fall semester we usually offer three sections of CS1, and we usually offer two sections in the spring semester. We note the significant difference in the number of students entering the majors with the number graduating. There are non-majors who take CS1, but there are usually only a few per section because we have a separate introduction to programming course for non-majors.

Like many other schools, our introductory computer science courses have a high fail/drop rate and we are actively seeking solutions for this problem. We observed that because the laboratory portion of the course contributes to 30% of the course

grade, those students who were not completing many lab exercises were less likely to succeed in the class. Additionally, the students who do not complete lab exercises do not get the programming practice provided by these exercises and may have poorer performance on the more complex programming assignments and exams.

In this paper we present an initiative to increase participation in the laboratory component of the course by creating lab exercises that focus on topics that we think would engage student interest. We used games for the lab exercises as much as possible, and used other real–world problems for the remaining exercises. Although we focus our study on the CS1 course, we encourage others to study the impact of using real–world topic assignments in other computer science courses, and in engineering courses in general.

This paper is organized as follows. In Section II we describe other research that is related to our work and that provided the inspiration for our study. We then describe the lab exercises we designed in Section III. The comparison of student performance in the course when we used the original labs versus when we used the new labs is presented in Section IV. Finally, we conclude our study and discuss avenues for future work in Section V.

II. RELATED WORK

It has been widely acknowledged that using game-themed assignments in introductory programming classes helps to engage students. When using games in introductory programming classes, students should be learning computer science concepts through the use of games, as opposed to learning how to program games or about game related algorithms [1]. Some of the prior research has examined the use of video-games as CS1 assignments, while others have used board games. The research generally acknowledges that graphical games are better than text-based games in engaging students, but that the graphical games can require significant development time on the instructor’s behalf. A major motivation for using game-themed assignments is that students can easily relate to the topic [2].

Drake and Sung [3] examined the use of board games for programming assignments in CS1 and CS2. They used well known games such as tic-tac-toe, hangman, and backgammon,

TABLE I
COMPONENTS OF CS1 COURSE GRADE

| Component | Weight |
|-------------------------|--------|
| Class Participation | 10% |
| Programming Assignments | 20% |
| Exams | 40% |
| Lab Exercises | 30% |

as well as more obscure games, including European board games that are gaining in popularity in the United States. They provide suggestions for the right type of game to use as a programming assignment. The game should have simple, but not trivial, rules. Games where the boards form complex graphs or that involve many different pieces should be avoided. The game should take five to fifteen minutes to play, and it is best to use games that require two players. Because both players will be sharing the same computer screen, games that require hidden information, such as a hand of cards, should be avoided. All of the games presented in their paper can be implemented using a text-only interface, but the authors acknowledge that students generally prefer a graphical user interface. They provide a Java library that supports both text-based and GUI programs. They utilized the board game assignments in a CS2 course at a small liberal arts college and received many positive comments about these assignments on the student evaluations.

While GUI-based games are thought to be more engaging to students than text-based console games, it is also acknowledged that GUI-based games require extra effort and knowledge from the faculty member. Some libraries have been developed for GUI-based games in Java [3] and in C# [1]. There is an introductory C++ textbook that uses games and graphics [4]. Most of the assignments in this textbook that we could use for our CS1 course are ones where the students write programs that draw rudimentary graphics on the screen and do not involve interactive play.

III. DESCRIPTION OF LAB EXERCISES

The CS1 course at UTPA has a co-requisite lab course. The students attend lab one day per week for two hours and forty minutes. The students' task during the lab class is to complete programming exercises. There are teaching assistants on hand to describe the programming exercises and to assist the students while they work on the exercises.

For grading, we treat the three credit lecture course and one credit lab course as a single four credit course by assigning a student the same grade in both courses. The grade is calculated as a combination of the exams, major programming assignments, class participation, and the labs, as shown in Table I. Because the labs count as 30% of the course grade, they contribute to a major portion of a student's grade.

A. Original Lab Exercises

In Fall 2010 and Spring 2011 we assigned lab exercises that are formatted as drills where the students are given certain skills to practice. The students are given a C++ program to

complete. The program contains a demonstration of the types of skills students will use to complete the lab. For the most part, these lab exercises do not have a specific topic or goal for the program. The purpose of the programs is for the students to practice and demonstrate the specified skills. All of the description and documentation for the lab exercise is contained within the provided code skeleton. Some of the example code in the exercises contains skills that the students have not yet learned. Note that the original lab exercises were not written by the instructor who was using them. The instructor who wrote the labs may have taught topics in a different order, or briefly introduced more advanced topics earlier in the semester.

The students completed a total of 24 lab exercises, usually two per week. We provide some examples of these exercises, chosen for the purpose of comparison between these original and the new lab exercises:

- **Lab 1 (week 1) - Hello World and simple math:** The demonstration code first uses basic console I/O to interact with the user. Then, based on user input regarding the student's projected course grade, it uses if-else statements to print the corresponding letter grade. Note that our students had not yet been exposed to decision making statements. Finally, the lab demonstrates basic addition and then asks the student to write code that performs subtraction, multiplication, and division.
- **Lab 3 (week 2) - Type conversion, named constants:** The demonstration code shows integer division, casting, overflow, and underflow. Then the students are asked to use a named constant to compute the area of a circle with a user supplied radius. The code supplied to the students uses a function to generate a menu where the user chooses which operation they would like to demonstrate, if statements to perform the chosen operation, and uses an infinite for loop to continue the program until the user chooses to quit. At this point in the semester, we had not covered the use of functions, decision making, or looping.
- **Lab 6 (week 3) - if statements:** In this lab, the student is asked to input their score in the course, and the code uses if statements to determine the corresponding letter grade. The lab consists of three steps: using only if statements, using if-else statements, and using nested if-else statements. For each step, the student is provided with example code that determines the score that corresponds with the grades A and B, and the student completes the code for the remaining letter grades.
- **Lab 7 (week 4) - switch statement vs. if-else:** In this lab, the student is provided with code that asks the user to input a letter between a and d, and shows how if-else statements can be used to print a different phrase for each letter that the user could enter. The student is then asked to re-write the code using switch statements with an integer condition that selects what to print. Then they are asked to re-write that switch statement as a series of if-else statements. Note that the example code uses an infinite while loop to keep repeating the user

selection until the user chooses to quit (at which point it executes a break statement). At this point in the semester the students had not yet learned about looping.

- **Lab 14 (week 7) - Functions:** The example code for this lab demonstrates writing and calling both value returning and void functions, with and without parameters. The functions take the sum of two numbers, sometimes obtaining the numbers as parameters and other times retrieving the numbers from user input. The students are then asked to write similar functions that ask the user for their first and last name, then print the name.

B. New Lab Exercises

For Fall 2011 and Spring 2012 we implemented new lab exercises [5] where the students were asked to use particular skills to solve a given problem. Our goal when designing these labs was to make them something that the students could relate to and that they would be more likely to be interested in completing. Whenever possible we used games for the programming exercises. When we were not able to devise a programming exercise using a game, we focused the exercise on a problem that the students are likely to encounter during their daily lives.

The lab exercises are all console-based programs. We chose this format because we are not familiar with graphical programming in C++. We wanted to quickly develop new lab exercises so stayed with the format we are familiar with. As discussed in Section II, it has been shown that using graphical programming assignments engages student interest and we will consider exploring the use of graphical programs in the future.

All of the labs have a similar format. The lab is described on a web page that contains links to example programs and the program skeleton for the lab exercise. First, the students are given an example program to review. The example program demonstrates the skills the students are practicing in this lab and contains extensive comments describing these skills as they are encountered in the example program. Then the students are asked to complete their own program. For most labs, they are given a skeleton of the program with preliminary code and comments that guide them on how to complete the lab. They are also provided with sample output from the correctly completed lab exercise.

The students completed a total of 21 exercises. In the early part of the semester, they completed two or three exercises per week. From the middle of the semester onward, an individual lab exercise was generally more complex than those from earlier in the semester and the students completed one exercise per week. We have chosen a sample of the lab exercises to present in this paper, generally those that provide a good illustration of our design or those that are a good comparison with the original lab exercises.

- **Lab 1 (week 1) - First C++ program:** The purpose of this lab is to teach the students the basic principles of using Visual C++ (the IDE we use) and running a simple “Hello World” type program. The example program is “Hello World”, and the students complete a program

where they print their name. The only C++ skills required for this lab are basic statements and console output.

- **Lab 2 (week 1) - Basic Debugging:** In this lab, the students are provided with a version of the “Hello World” program that will not compile. They must identify and correct the missing quotation marks around the output text and insert a missing semicolon. The description for this lab shows students how to interpret the compile error messages, how to use the compile error message to find where the error is in the program, and to address each compile error one at a time.
- **Lab 3 (week 2) - Basic Math:** This lab adds basic math skills (addition, multiplication, division, and modulus) to the skills covered in previous labs. The example program uses an equation to calculate the “Dateable Age” for the user (the youngest age they “should” date based on the user’s age) using a formula that involves addition and integer division. The instructions point out that dividing two integers results in an integer, which is the correct result in this case. The students then complete a program that calculates a “magic number” using a formula that involves multiplication and modulus.
- **Lab 4 (week 2) - Console I/O and random numbers:** This is the first lab where we found games suitable for the content to be demonstrated. The example program simulates a coin toss by generating a random number between 0 and 1. The student’s program is the beginning of the development of the Pig dice game [6], a game they will continue to develop as the semester progresses. In this lab they ask the user to enter his or her name, roll the die once (generate a random number between 1 and 6), and print the value that was rolled. In this lab the students use a random number generation function that is provided in the lab skeleton code, and use the getline function from the string library. The use of pre-defined functions had also been discussed in class at this point of the semester.
- **Lab 6 (week 3) - if statements:** The example program for the if statements lab simulates a drive-thru restaurant where the customer chooses their menu item by number. Based on the number entered by the customer, the program uses if-else statements to determine the amount to charge for the order. The program that the students complete simulates the Magic 8-Ball toy (a fortune telling toy). The students must generate a random number then use if-else statements to pick the corresponding answer from the Magic 8-Ball. Note that nested if statements are covered in a separate lab.
- **Lab 9 (week 4) - switch structure:** The example program and student program are the same topic as the if statements lab, but now the selections are made using a switch structure. The instructions encourage the students to compare the switch solution with the solution from the if statements lab.
- **Lab 15 (week 7) - Functions:** The example program asks the user to input the price of an item in two consecutive

years and calculates the inflation rate for that item. It uses functions for user input, calculating the inflation rate, and printing a number with two decimal points followed by a percent sign. The students' program continues to develop the game of Pig [6] that we had started in earlier labs. The students are provided with a program that plays the Pig game for a single player. Their task is to create a two-player version of the game. The students must write a value returning function that gets user input (checking for correct input), a value returning function to play a single turn of the game, and a void function to print the output in a specified format. They must also complete the main function by calling the functions that they write.

C. Discussion of Original and New Labs

Both the original and new labs provide demonstration code then ask the students to complete a program. The new labs provide a more complete description of the task at hand, and generally focus solely on a single new skill. Some of the examples in the original labs contain code that the students had not yet learned in class, while the new labs restrict the code in both the example and student's program to code that has been covered in class. One benefit of the original labs is that they are very complete in covering the various skills and often directly identify these skills. The new labs do not cover the skills in such detail, but do discuss the skills that are covered in the comments in the example programs.

IV. COMPARISON OF STUDENT PERFORMANCE

We compared the performance of students in four semesters of CS1 that were taught by the same instructor. In Fall 2010 and Spring 2011, the students completed the original lab exercises. In Fall 2011 and Spring 2012 the students completed the new lab exercises.

A. Lab Completion Rate

The first metric examined was the total percent of labs that were completed in each semester. This number was derived by taking the sum of the number of labs that were completed and dividing that sum by the number of labs that were assigned. As shown in Fig.1, in Fall 2010, 71% of labs were completed, in Spring 2011, 66% of labs were completed, in Fall 2011, 82% of labs were completed, and in Spring 2012, students completed 81% of the labs.

There is a dramatic increase in the number of labs completed when the new lab exercises were used. We take this result as an encouraging sign that students might be more engaged by the new lab exercises and therefore decide to complete more of the exercises. Another possible reason for the increase in lab completion is that the instructor emphasized the impact of the labs on the course grade (labs contribute 30% to the course grade) more in Fall 2011 and Spring 2012 than she did in Fall 2010. However, she did also emphasize the importance of the labs to the students in the Spring 2011 class, which had the lowest lab completion rate.

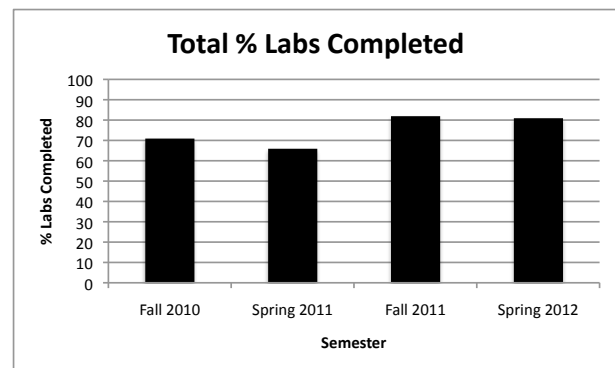


Fig. 1. Lab Completion Rate per Semester

B. Exam Grades

We are also interested in examining if the new labs had any impact on the students' exam grades. It is possible that by completing more of the lab exercises and, therefore, getting more programming practice, the students will perform better on the exams. Fig.2 shows the grades on the three exams for each of the four semesters. Each set of bars in this figure represents the grade on one of the exams for each of the four semesters. The average grades are presented both excluding and including zeros. As is especially evident in Spring 2011, there are students who stop participating in the course and decide to accept a grade of F instead of dropping the course. Because of changes in financial aid rules with regard to failing grades that were implemented in Fall 2011, we expect that fewer students will simply stop participating in the course in future semesters.

For this discussion, we focus on the average of exam grades excluding zeros because the students who received a grade of zero on the exam were most likely also not participating in lab. For all three exams, Fall 2010 has the lowest average (61, 67, and 65 for Exams 1, 2, and 3, respectively). Spring 2011 has the highest average score of 80 for Exam 1, but has the second lowest scores for Exams 2 and 3, of 71 and 75, respectively. The highest grades on Exams 2 and 3 were achieved in Spring 2012, with averages of 79 and 78, respectively. In Spring 2012, the average for Exam 1 was 75. In Fall 2011 had the average score was 77 for all three exams.

With the exception of Exam 1, the students in Spring 2012 performed better on the exams than students in the other three semesters, followed by the students in Fall 2011. This supports our hypothesis that getting more programming practice through completing more lab exercises leads the students to perform better on the exams. However, in the absence of a controlled study we are unable to confirm this hypothesis.

C. Course Grades

Completing more lab exercises has a direct impact on a student's grade in the course because the lab exercises contribute to 30% of the course grade. Most students receive a high grade on each lab exercise, with many receiving grades of 100% on each exercise. Therefore, we expect that by

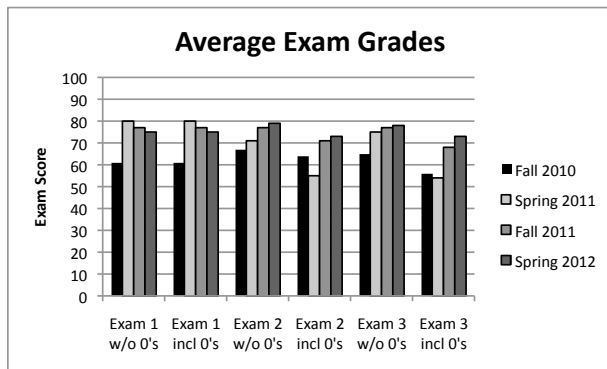


Fig. 2. Average Exam Grade per Semester

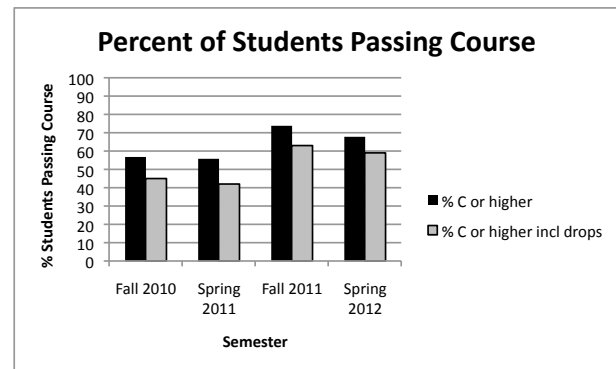


Fig. 4. Pass Rate per Semester

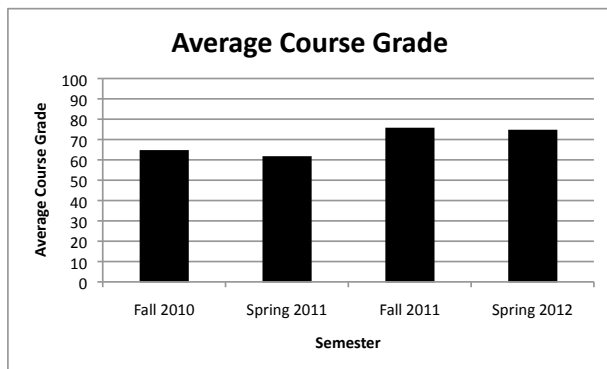


Fig. 3. Average Course Grade per Semester

completing more lab exercises, students will earn a higher grade in the course. This expectation is confirmed by our data, shown in Fig.3. Students in Fall 2011 had the highest average course grade of 76, followed by Spring 2012 with an average of 75. Fall 2010 and Spring 2011 had the lowest course grades of 65 and 62, respectively.

D. Pass Rate

We examined the proportion of students in each semester that passed the course. Students must receive a grade of C or higher in order for CS1 to count in the Computer Science or Computer Engineering curriculum. Fig.4 shows the pass rate of students in each semester, with the left side bar for each semester representing the percent of students who received passing grades at the end of the semester, and the right side bar including those students who dropped the course in the number of students who failed the course.

Our results show that the students in Fall 2011 and Spring 2012, when the new labs were assigned, had a higher pass rate than those in the previous two semesters. By completing more labs the students directly increase their course grade, as discussed above in Section IV-C, leading to more students passing the course when there are more students completing the labs.

V. CONCLUSIONS AND FUTURE WORK

Our conclusion is that the students perform better in the course when they complete the game/real world problem based lab exercises. However, we cannot draw a correlation between implementing the new lab exercises and the students' overall performance in the course. One reason for the higher course grade is that by completing more of the lab exercises, the students are directly increasing their grade. The fact that the students in Fall 2011 and Spring 2012 performed better on all but the first exam may indicate that more programming practice results in better retention of the material. Another factor that may affect the students' performance that the instructor did not have much teaching experience prior to Fall 2010. Despite the fact that we cannot draw a correlation between the new lab exercises and the students' course performance we are encouraged by the increased participation in the lab and by the large increase in the course grades.

As of the time this paper was written, we had not yet received the student comments from the student course evaluations for Fall 2011 or Spring 2012. Therefore we are unable to report on student opinions of the new lab exercises. Other sections of CS1 courses at UTPA, including the version for non-majors, utilized some or all of the new lab exercises. Feedback from the professors who taught these courses was very positive. We will continue to monitor student performance in CS1 when these new labs are used to determine if the improved student performance will be seen in future semesters.

We plan to continue refining the new lab exercises. In the future, we would like to explore the possibility of implementing exercises in C++ that involve a graphical user interface. We would also like to work on replacing the non-game topic exercises with game-based exercises.

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Work in Progress: Faculty Perceptions of Project-Enhanced Learning in Early Engineering Education: Barriers and Benefits

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Abstract—The application of problem-based learning (PBL) to undergraduate engineering education has emerged as an area of research interest over the past few decades, although it does not appear to be the dominant pedagogy for most engineering programs. A related form of active learning is project-enhanced learning (PEL), specifically designed to enhance but not replace traditional teaching methods in engineering science courses. The perceptions of instructors who attempt PEL were examined using extended-term mixed-method approaches, seeking to examine perceived benefits and barriers to PEL as an intervention for improved student learning. Instructors expressed satisfaction with improved student motivation, interaction, and socialization, which may help with student success and retention in engineering. Instructors also expressed concern about losing focus on the challenging analytical course topics, but were able to achieve appropriate balance by designing project tasks to align well with the topics and limiting non-aligned project activity.

Keywords - problem based learning; project-enhanced learning; engineering science; engineering education

I. INTRODUCTION

This paper represents the initial findings of the NSF-funded study “Implementation, Dissemination, Barrier Identification and Faculty Training for Project-Enhanced Learning in Gateway Engineering Courses” and highlights faculty perceptions of the use of Project-Enhanced Learning (PEL) strategies specifically in sophomore and junior-level engineering science courses. PEL is defined as an integrated project within a traditional lecture-based course that can be implemented in a gradual and transferable way and across multiple sections and instructors [1]. As many undergraduates perform poorly in early engineering science courses that are primarily lecture-based, attention to pedagogical innovation may present an opportunity for increased retention. Additionally, surveys, and classroom assessments indicate that many students completing these courses did not really understand the fundamentals, even if they could apply the ‘formulae’.

The guiding research approach for the project follows the Extended-Term Mixed-Method (ETMM) design [2]. This design includes five inter-related principles: (a) developing a long-term time-line, (b) using theory and data to inform decisions, (c) paying attention to formative and summative components of the study, (d) creating sharply focused causal questions regarding impact of the program, and (e) using a variety of quantitative and qualitative evidence to support claims. Workshop observation, qualitative interviews, and a constant-comparative analysis [3] were utilized in the research design.

The participants in this project have designed and implemented project experiences in three different ‘gateway’ engineering science courses, based on initial experiences in a course on *Thermodynamics*. We refer to the first courses in the engineering major as ‘gateway’ engineering courses, specifically courses in engineering sciences. In Fall 2011, PEL was introduced in two other courses: *Probabilistic Methods In Electrical And Computer Engineering*, and *Dynamics* in the mechanical engineering curriculum [4]. One or two major projects based on authentic systems, objects, or activities are designed and assigned to apply key course topics. The goals include increasing student motivation, provide realistic application of abstract concepts, and long-term learning retention. Teamwork, increased communication with Engineering faculty and professionalism were also emphasized. Significant findings include faculty perceptions of both the value of and barriers to implementing a PEL component in gateway engineering courses and an underlying understanding of the need for increased student engagement in the engineering curriculum.

II. LITERATURE REVIEW:

For most college majors, the first year is the most critical for persistence in college. Tinto [5] observed that almost one-half of students entering two-year colleges and more than one-fourth (28.5%) of students entering four-year collegiate institutions leave at the end of their first year. However, a significant fraction of students who decide at that point to persist in engineering, nonetheless leave engineering in the

middle years of college [6]. Practitioners and scholars seek explanations, whereas college and university administrators desire to manage their student enrollments by reducing such rates of departure. The findings [6] indicate that faculty classroom behaviors in general and active learning in particular (of which PEL may be considered a form) may constitute an empirically reliable source of influence on social integration, subsequent institutional commitment, and departure decisions.

A large body of research affirms that active learning enhances student knowledge and understanding of course content [7-10]. Moreover, students who frequently encounter active learning in their courses *perceive* themselves gaining knowledge and understanding from their course work. As a consequence of this self-efficacy, such students may be more likely to view their collegiate experience as personally rewarding [11]. Students who frequently experience active learning in their classes may also have more time available for participation in collegiate social communities because they feel that they are able to spend less time on course preparation and studying for examinations. Thus, active learning course practices may directly influence social integration and indirectly affect subsequent institutional commitment and student departure decisions. Tinto [5] presents findings on the role of active learning in influencing student persistence/departure decisions.

The research conducted by Southeastern University and College Coalition for Engineering Education (SUCCEED) provide a unique snapshot of engineering education at a transitional moment in its history [12]. The major component of this study is the design and implementation of a faculty development program. The objectives of this program were: (1) to promote faculty adoption of non-traditional instructional methods and materials that have been proven effective by classroom research studies and (2) to improve institutional support for teaching at each of the eight SUCCEED campuses. The study finds that the percentage of responders giving required team assignments vary from a low of 35% at one institution to a high of 72%. Assistant professors are more likely than associate or full professors and female professors are more likely than male professors to use in-class group activities and the internet in their teaching, and the assistant professors and female professors are more likely to believe that teaching is devalued in the faculty reward system. In short, there is general agreement that active learning approaches such as PEL have positive outcomes for students but there is great variance in faculty perceptions of non-traditional instructional strategies and the benefit/rewards for increased faculty implementation.

The application of problem-based learning (PBL) to undergraduate engineering education has emerged as an area of research interest over the past few decades, although it does not appear to be the dominant pedagogy for most engineering programs. Educational studies often use lecture as the default style to compare alternative methods to, such as PBL or active learning [13-15]. An evidence-based comparative study examining the effectiveness of PBL versus lecture-based learning in an introductory engineering course revealed that students retained more knowledge when instructors used a

PBL approach [13]. Research in engineering education has shown that building a sense of community and hands-on learning (which is often seen in PBL) contribute to increased student retention and motivation [16-17]. In many instances PBL is used as a partial strategy or in addition to traditional curriculum in engineering courses [18-21].

Conventional teaching methods for engineering courses are often lecture-based and emphasize deductive learning in the engineering science courses that students encounter early in their major. Projects are typically a component of engineering design courses, which are usually separate from engineering science and are more likely though not all at the upper level. Problem-based learning and project work share some similarities such as being multi-disciplinary, collaborative, and self-directed, but the two approaches differ slightly in their focus and method of implementation [21]. In problem-based learning, students are given a real-life problem to solve as a team and the teacher is seen as a facilitator in the process, rather than a lecturer. The process is self-directed and the students' goal is to refine the problems [22]. Problem-based learning is geared toward acquiring knowledge, whereas project-based learning is directed toward applying knowledge. Project-based learning tends to be more focused on real-world applications and attempts to mimic professional work. Project work tends to take a longer period of time than the tasks in problem-based learning because the projects are more complex and closer to professional reality. Students also tend to produce a concrete product in project work (Table 1).

The suitability of problem-based versus project-based learning for engineering education was compared in [23]. In their review of university engineering programs, they concluded that a mixed-mode approach in which students took more traditionally lecture-based courses covering the fundamentals of engineering combined with project-based components was best for preparing students for the workforce and would be more familiar to instructors than problem-based methods. Perrenet et al. [21] concluded in their review of the literature and in comparing programs that implemented PBL as a partial strategy, that some direct instruction of core concepts is necessary and PBL and project work have some advantageous aspects, such as motivating students as well as being more cognitively engaging than conventional instruction.

The trend of combining or mixing elements of PBL and traditional "topic" focused instruction is also seen with project enhanced learning, as described in [24]. The authors make distinctions between project-enhanced versus project-added implementations. Barroso and Morgan [24] describe project enhanced learning as the implementation of projects in engineering courses that utilize open-ended problems and allow abundant opportunities for students to make decisions in the design and assessment of their work. This is in contrast to a project-added implementation, in which projects are often viewed as an additional lengthy homework assignment and have well-structured problems with clearly defined solutions and outcomes (Table 1).

TABLE I. FOCUS AND COMPONENTS OF SELECTED TEACHING METHODS [24]

| Problem-based learning (PBL) | Project-based learning | Project-enhanced learning (PEL) | Project-added implementation |
|--|--|---|--|
| <ul style="list-style-type: none"> Acquisition of knowledge Students solve real-life problems as a team Teacher is seen as a facilitator in the process Students' goal is to refine the problems | <ul style="list-style-type: none"> Application of knowledge Students create projects with real-world applications Mimics professional work Projects take an extended period of time (up to several months) | <ul style="list-style-type: none"> A project is integrated with a traditional lecture-based course Can be implemented in a gradual and transferable way over time and among multiple sections and instructors | <ul style="list-style-type: none"> Projects are an added course component that can be seen as a larger and more complex homework problem Well-structured problems with clear instructions for completion Well-defined project outcome |

Krishnan and Nalim [1], offer their own unique approach of project-enhanced learning (PEL), which integrates a major project with a traditional lecture series. In their conceptualization of PEL, core topics are introduced early in a course in relation to a project so that students anticipate what they will learn in lecture. This model is designed for implementation at the early stages of an engineering student's coursework, such as the sophomore year when students take many gateway courses, rather than waiting until content is mastered to begin project work. PEL introduces core concepts early in an engineering program with the integration of a term-long project, and the learning is thought to be transferred over time with this method. The current study adopts this interpretation, contrasting PEL with the more student-created project-based learning, but not making it sharply distinct from project-added implementation. The accommodation of PEL within a traditional lecture-based setting is deliberately intended to ease this intervention into courses where traditional methods are most entrenched. Some benefits of this model have been identified, such as increasing the motivation of students, but more research is needed on PEL. Krishnan and Nalim recommend future studies looking at the longitudinal impact of PEL on student retention in engineering programs, student performance, and students' professional outcomes.

III. RESEARCH DESIGN

The research project follows a formative case study design to explore the implementation of PEL in gateway engineering courses. The research team has been conducting the evaluation, consisting of process observations, qualitative data collection, and a satisfaction survey. The evaluation results, considered existing data that the research team then used to inform the ongoing design of the proposed research project.

One group of participants in the case study includes instructors who teach gateway engineering courses at Indiana University – Purdue University Indianapolis (IUPUI), University of Illinois Chicago (UIC), and Virginia Commonwealth University (VCU). The participants all agreed to attempt PEL, and some had begun implementation of PEL in their courses. The current study does not include instructors

who declined to attempt PEL. The team conducted interviews focused on instructional planning and reflections on PEL as a pedagogical strategy. In addition, instructors were recruited to participate in a series of professional development activities and focus group discussions occurring at various points throughout the ongoing project.

All individual participants were contacted initially by a member of the research team via email or a phone call, and face-to-face during the interview phase. Consent statements were collected for participation in the research and evaluation following all appropriate requirements of Human Subjects Research via Indiana University.

A. Research Team

The research team, led by Robert Helfenbein, professor in the School of Education at Indiana University - Indianapolis, includes two graduate assistants from the Center for Urban & Multicultural Education (CUME) involved in literature review, data collection, and preliminary data analysis. The guiding approach for the processes and products of the project follows the Extended-Term Mixed-Method (ETMM) design [2]. This design includes five inter-related principles: (a) developing a long-term time-line, (b) using theory and data to inform decisions, (c) paying attention to formative and summative components of the study, (d) creating sharply focused causal questions regarding impact of the program, and (e) using a variety of quantitative and qualitative evidence to support claims.

B. Research Questions

1. How are instructors implementing (or not) PEL in their classrooms?
2. How does the implementation of PEL in gateway engineering classrooms follow "best practice" as identified by the research?
3. How supported (by all stakeholders) do instructors feel during the PEL implementation process?
4. What are the challenges to implementing PEL in engineering classrooms?

C. Methods and Instruments

1) *Observations.* Using qualitative inquiry and ethnographic methods [25-26], team members have conducted a series of observations of PEL instruction, professional development, and coaching. An ethnographic approach is appropriate for building a detailed account of how the implementation process unfolds within the context of a classroom and school, and illuminate some of the strengths and challenges of individual instructors as they move through the implementation process.

2) *Focus group discussions.* Team members conducted focus group discussions with the gateway engineering faculty. These were used to check the data collected through the surveys. Sample focus group probes are: "What kinds of support have you been given during the implementation process?"; "How have colleagues helped or hindered your

implementation of PEL?” and “How has PEL affected student learning?”

3) *Interviews.* Team members have interviewed faculty members (n=5) about support structures within the School of Engineering & Technology and about their perceptions of how the implementation process is going overall. Sample interview probes are: “What kinds of support have been provided during the implementation process?”; “How have students responded to PEL?”; and “How has PEL affected student learning?”

4) *Document review.* The research team is collecting lesson and unit plans including entry documents and other PEL-related planning materials, assessment rubrics, samples of student work, and teacher reflections in order to understand PEL implementation processes and evaluate the objectives. These data were analyzed using content analysis [27].

5) *Survey.* Implementation surveys were disseminated to all participants at the end of the relevant semester. These asked participants a series of questions about their implementation of PEL in their classrooms as well as some of the challenges they have experienced in implementation. Results were compared to the existing data from the PEL evaluation to see how and in what ways teachers have followed through with their plans to implement PEL in their classrooms.

D. Qualitative Analysis

The constant-comparative method [28] was employed to allow researchers to use the initial results of one method to extend or clarify the results from another method. As data sets from each of the various sources are obtained, they were initially coded to determine common patterns within the data and develop overarching themes. Throughout subsequent data collection activities, researchers built upon existing data to inform the collection process. Additionally, data previously collected and analyzed was shared with stakeholders including participants for member checking in order to solicit feedback on analyses to date.

IV. FINDINGS

A. How are instructors implementing (or not) PEL in their classrooms?

Implementation of PEL and other active learning strategies varies among the engineering faculty participating in this study. Differences in approach relate to the educational experiences of the faculty themselves as frequent responses related their teaching approach to the ways in which they experienced engineering education at various points in their career. Typically, the PEL projects followed the model suggested by [1] and included a semester-long supplemental assignment that attempted to provide an authentic application of course concepts.

Faculty report that “best practices” of implementing PEL projects include providing time for project development, advance notice for students to ensure clear expectations, and

projects that are designed to be semester long to include a variety of course concepts. One faculty member suggests that it is best to assign the project early in the semester “so that they can get thinking on a concrete example[s].” This additional time allows groups to review the project concept several times as a group and turn to instructors throughout the semester for clarity. Due to the weight and length of the project groups are often strategically composed to provide an intellectual balance in the hopes of peer-to-peer instruction and added camaraderie. However one instructor commented that his approach to assigning teams varies. Commenting on issues that face PEL he states: “some of the issues of course have to do whenever you have a team project as to how you form the teams and whether a student likes their partner...I let them choose their own partner, but [I] put some constraints on that because I wanted to make sure that the teams would not [be] very unbalanced in the [intellectual] composition...”

B. How does the implementation of PEL in gateway engineering classrooms follow “best practice” as identified by the research?

Faculty who attempted PEL perceives significant benefit to implementing PEL in engineering education and cites increased student motivation as the most significant outcome. One participant noted the dual nature of benefit to students “the benefit is that students will have an immediate application of the theory that they are learning-something that is quantifiable [and] something that is physical and that they can relate to.” Succinctly put, one faculty member states that PEL provides “an immediate application of the theory that they are learning.”

Interestingly, faculty reported that increased contact between instructor and student as an unanticipated positive outcome as an increased number of students attended office hours and engaged faculty outside of class. One subject recalled that time spent processing the project prompted students to “come and discuss the project with me when they’re having difficulties [or] when they have questions and I have office hours outside the classroom, but I always make sure that if they [can’t] come at that time that I was available to discuss any questions they had on the project.” Faculty reported that these interactions expanded beyond the assignment and provided an opportunity for professional mentoring and socialization to the life of an engineer. This increased sense of community follows the research that suggests a positive relationship with retention and degree completion efforts.

C. How supported (by all stakeholders) do instructors feel during the PEL implementation process?

Faculty report that the support for active learning approaches including PEL is beginning at IUPUI. The time provided through the NSF grant to work together on the generation of projects and sharing of tips and techniques is seen as beneficial for faculty to adopt these practices. It would seem that creating further opportunities for faculty to collaborate would have positive impact on the level of implementation and the possibility of compiling a collection of projects across curricula could be advantageous.

D. What are the challenges to implementing PEL in engineering classrooms?

Faculty had strong feelings regarding the barriers to implementing PEL and other active learning strategies in engineering instruction. While it is clear there is an intention on the part of engineering instructors to use PEL to advance the curriculum, there is significant concern that its adoption not be used to the detriment of the content instruction or student growth. PEL, as one instructor states, can be used to fool students into thinking that engineering is "fun" or likened to a science fair that ultimately waters down foundational concepts. Conversely, one participant noted that "the project should not be burdened with a lot of additional busy work that might actually be realistic in terms of what an engineer has to do in a real project, but is not helpful in the learning process." Here the point is made that there needs to be a balance between the authentic tasks of engineers and the larger conceptual goals of the course. Faculty members see the projects as helping students bridge concepts built around mathematical equations to real life applications in the field. It was also suggested that projects can also be used after the course as a way to enhance a student's resume or demonstrate knowledge during job interviews.

Obstacles to implementation can include an instructors level of comfort with the project's purpose in the course (i.e. they will not have a project just to have a project or for the sake of saying they are practicing PEL) and the time required for faculty to create and assess projects in a research-intensive university. Faculty reported some concern with the level of student comfort or prior experience with PEL or active learning approaches as it is possible that some students prefer a more traditional instructional approach. As some courses are shared enrollment with other subfields in science education (i.e. students from various fields outside of engineering), one instructor reported sacrificing or adjusting a project in order to meet the needs of class as a whole, rather than just a portion.

Although instructors who declined to attempt PEL were not interviewed formally, some reasons given for declining are noted: (a) The class size is too large, and the burden of grading a large number of projects is unacceptable; (b) The effort to create a meaningful project is beyond what a tenure-track instructor can accomplish, given pressing research goals; and (c) The best way for students to learn difficult engineering science fundamentals is to work hard on more homework problems. There also appear to be interesting differences between the concerns of experienced, perhaps more conservative, instructors, and younger, novice faculty members. We may generalize from these observations that an incremental approach to introduce PEL that also anticipates these perceived barriers may in the long term lead to more successful transformation of the student's learning success in gateway courses in the engineering curriculum.

V. CONCLUDING THOUGHTS

An on-going study of faculty perceptions of project-enhanced learning in early engineering education is reported in this paper. There are well-researched and demonstrated benefits of active learning strategies in engineering education,

including the use of projects. PEL is a carefully calibrated approach to active learning using projects that seeks to retain and enhance traditional lecture-based instruction.

Instructors who agreed to attempt PEL expressed satisfaction with student learning outcomes, despite reservations about workload and potential dilution of academic rigor. They were particularly impressed with increased student motivation and with the immediacy of application provided by the project, as well as the socialization of students into the community and culture of engineering. They also noted the increased interaction of students with each other and with instructors.

Instructors expressed concern about misleading students about the challenges and rigor of engineering education by focusing on the project perhaps at the expense of more analytical tasks essential to the course topics. They achieved a balance between project benefits and course goals by designing project tasks to closely align with specific learning outcomes of the course, and whittling down less relevant activity.

Support from an NSF grant allowed instructors some time for creation of projects and preparation for teaching. For some instructors, PEL materials were already available and had been used in their course previously. Using ETMM to study PEL perceptions, utilizing multiple scholarly sources and research approaches over a long-term time-line, allowed the research team to delve deeply into multiple facets of PEL. Insight provided in this research embarks on a discovery on not only how pedagogical practices in engineering influences student learning, but how administering it impacts the professoriate. This study does not investigate whether instructors would attempt PEL without such assistance. This study has also not examined the thinking of instructors who either ignored the PEL activity or specifically declined to attempt PEL. These questions would be fruitful areas for future research.

This paper points to several conclusions about PEL and faculty implementation. As an active learning approach, PEL provides increased opportunity for faculty/student interaction and enhances traditional lecture-based instruction with authentic application of engineering concepts. Faculty report positive increases in student motivation, socialization to the field, and learning outcomes as a result of implementation. Faculty satisfaction was a direct result from intentional project design that incorporated specific learning outcomes within courses and minimized "busy work." While the need for more research is clear, this project suggests that the positive impacts of PEL may go well beyond course enrollment numbers by increasing engineering faculty and student satisfaction and broadening instruction experiences in engaging ways.

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Unveiling Fieldbus Network Technology through Project-based Learning

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Abstract—Fieldbus communications networks are a fundamental part of modern industrial automation technique. This paperwork presents an application of project-based learning (PBL) paradigm to help electrical engineering students grasp the major concepts of fieldbus networks, while attending a one-term long, elective microcontroller course.

Keywords - Hands-on education; projec-based learning; automation; networks; fieldbuses; microcontrollers.

I. INTRODUCTION

Modern industrial automation systems rely heavily on field control systems (FCS), such as temperatures controllers, pressure controllers, and level controllers, to name but a few systems, that are distributed over the plant area and interact and communicate with each other by means of industrial communications protocols [1]. FCS evolved from discrete control systems (DCS) over the last decade to bring the control of the process the nearest possible to the locus of sensors and actuators, thus reducing wiring, easing troubleshooting and lowering maintenance cost of the industrial control network [2].

Controllers, sensors and actuators are networked on the factory floor by means of a fieldbus, which is a local area network (LAN) featuring digital, serial, bidirectional and multidrop communications technology. Despite the enormous importance of fieldbus communications networks, researchers

have shown that there is still a great need to integrate fieldbus topic with hands-on experiments into undergraduate engineering and technology curriculum [3].

Whilst engineering education research has shown that traditional lecturing is far from being an efficient instructional pedagogy [4], project-based learning (PBL) has proved a powerful learning strategy, capable of engaging students and fostering their learning enthusiasm [5].

This paper presents the design, development and test of a fieldbus communications network by senior year students of electrical engineering of our university. PBL was chosen as the learning paradigm.

II. PROPOSED APPROACH

A. Project Specifications

Fig. 1 shows the general block diagram for three controllers assigned to the students for networking. The controllers are based on an 8-bit microcontroller manufactured by Microchip Inc. (PIC18F4550). As Fig.1 makes it clear, though the controllers feature basically the same hardware, each unit has received a special function, namely: controller 1 incorporates a real-time clock (RTC); controller two encompasses a temperature sensor; and controller three includes a 110-V ac motor and its relay-based driving circuit.

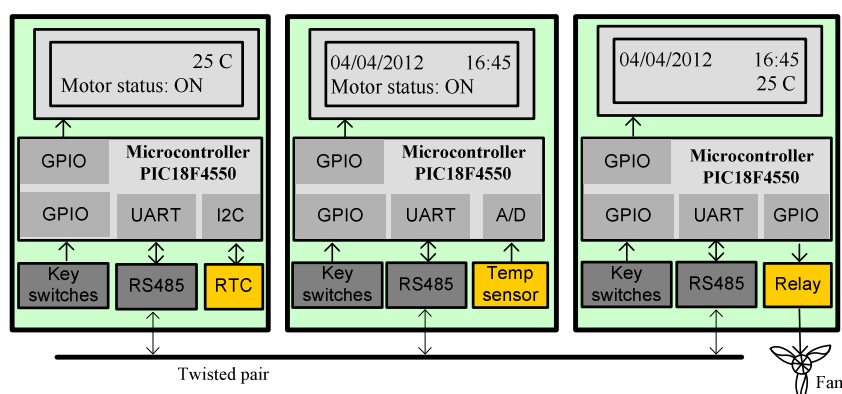


Figure 1. Three controllers networked by students.

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At our campus, microcontrollers is a 45-hour long elective course offered to the senior-year students of electrical engineering. A 150-hour long microprocessors systems course is the prerequisite. This is a comprehensive course on the design of microprocessor-based systems and their programming in assembly language. Theoretical and practical topics include CPU interfacing with ROM and RAM memories, memory map and address decoding techniques and circuits, interfacing of digital and analog input and output ports, synchronization techniques (polled i/o and interrupt driven techniques), and serial communication techniques (UART). Additionally, students have taken a 150-hour long course on C language during their freshman year. At the edition this project refers to, a group of 10 students enrolled in this discipline. The lecturer used the first two weeks to swiftly introduce students to the microcontrollers' world, in especial to the brand they were about to begin working with and to a corresponding professional integrated development environment (IDE). Eventually, the lecturer addressed more topics as students demanded or needed. Students were grouped into three different teams. Each team developed the needed programs for the specific controller, while all groups collaborated to develop the fieldbus (LAN) protocol. All programs were developed in C language. The students were assigned as major task networking the three node controllers so that every individual node controller could obtain information from any of the other controllers on the bus at any time and under request. Therefore, daytime, room temperature and the motor status (turned-on or turned-off) are available to all controllers at any time. Moreover, simple messages can be edited in any controller and sent to any other on the bus. In this case, the targeted controller must display on the LCD the received message.

B. Network Topology

Fig. 2 shows six types of network topologies that are commonly used in industrial data communications systems [6]. There are advantages and disadvantages to each type of topology. The bus topology is one of the most common on industry floor due to its simplicity and the fact that a failure of any node (controller) to operate should not prevent other nodes (controllers) from communicating, a feature that is crucial to industrial automation. As can be seen in Fig. 1, the controllers of this project were connected to form a bus.

C. International Standard Organization's Open System Interconnect (ISO's OSI) Reference Model

ISO's OSI is perhaps the most robust and generic standard and model that has been proposed for data networking. And though OSI is a seven-layer reference model for computer networking, it is applicable to any type of network wherein the processing elements communicate over a common path. Most fieldbus networks specify only the first three or four initial layers, which are the most basic ones [6], [7]. As illustrated in Fig. 3, in this project, only the first three layers have been implemented.

- Unshielded twisted pair (UTP) and ubiquitous RS485 were used to implement the physical layer of the network. The RS485 transceivers (DS75176B) enable

up to 32 devices to communicate over UTP whereas controllers may spread over a distance of up to 1200 m. This formidable performance is a result of the high noise immunity of the differential voltage signaling provided by RS485 transceivers.

- Universal asynchronous receiver/transmitter (UART) has been adopted to implement the data link layer. Fig. 4 depicts the serialization of one data byte by the UART. Every data byte is preceded by a start bit and followed by a stop bit. A bit rate of 9600 bits per second (bps) has been selected. Parity bit has not been used.

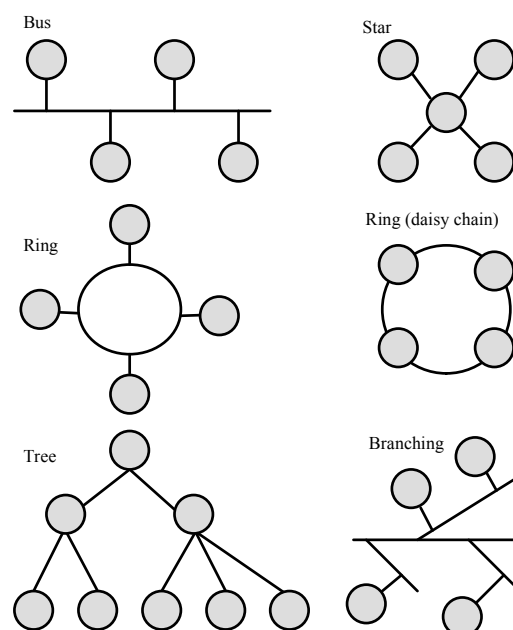


Figure 2. Network topologies.

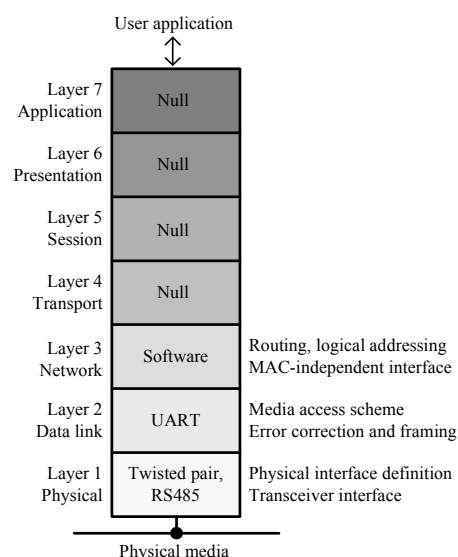


Figure 3. The OSI seven-layer reference model as used in this project.

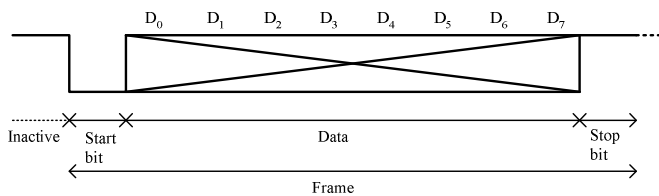


Figure 4. Data frame standard used by UART.

- The network layer has been implemented in software. The LAN protocol includes a medium access control (MAC) which uses the “listen before transmit” principle to access the medium, detect and avoid collisions. LAN frame structure employed (Fig. 5) resembles that of Ethernet and contains several fields as preamble, destination address, source address, message type, data length, payload (application data), and a frame check sequence. This last field allows for error detection and correction.

III. RESULTS AND DISCUSSION

The two upmost pictures of Fig. 6 offer a view of the three implemented controllers and a close-up of the third controller and its fan load, respectively. Though much of the hardware was designed and mounted by the professor (one of the authors) who was in charge of the course, students had the opportunity to deal with (and explore) the controllers’ hardware during the whole semester. They used oscilloscopes to measure signals and to make sure that the hardware was operating appropriately. Then they dedicated their course time to write and test software to the controllers. Weekly, the teams discussed their progresses and drawbacks and planned common actions. Needless to say, they shared all conquests that could interest any specific team.

Student teams were provided with a couple of basic functions to deal with the LCD and key-switches. The functions to work with the RTC were handed only to the team who needed it. One of the authors had developed these functions earlier. This “helping hand” aimed at getting the teams tackling the main problem as soon as possible. In other words, they had to discuss, plan, write and test software to put the controllers up and running on the bus. This is far from being a trivial task and many work hours were spent before the controllers could change the first messages through the bus. It is noteworthy that a seemingly humble twisted pair cable problem fooled the teams with an intermittent flaw that lasted for weeks. Owing to the nature of mixed hardware and software-made functions, it is quite challenging to pin point fast the problem source and nature in an intermittent malfunctioning system. This, however, may turn out to be an extraordinary opportunity to educate future engineers on the challenges they will face during their careers while dealing with real-world application. As a matter of fact, this kind of environment is what makes PBL so powerful an instructional methodology.

The three lower picture of Fig. 6 are snapshots of the three controllers’ LCDs. Controller 1’s LCD is showing the room temperature which was measured by controller 2 and sent to

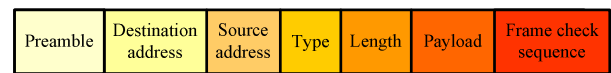
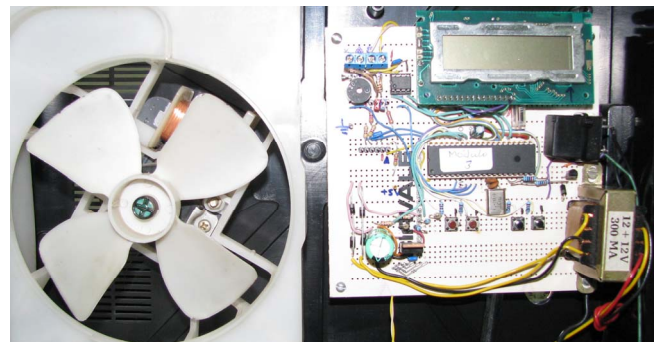
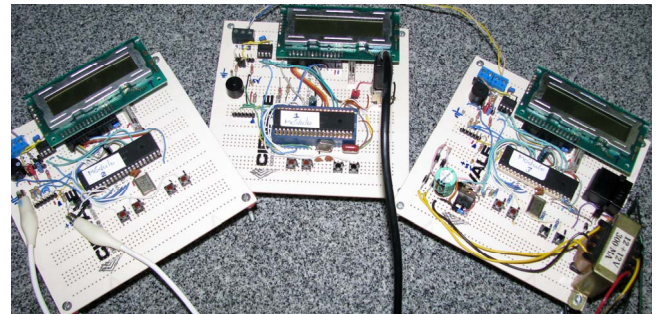


Figure 5. Frame format used by the network layer.



Controller 1
(RTC)



Controller 2
(Temp)



Controller 3
(Motor)



Figure 6. From top to bottom: picture of the three controllers used by student teams; a close-up of controller 3 and its fan; LCDs’ screens of the three controllers at a given time.

controller 1 over the fieldbus upon request from the latter. Additionally, controller 1’s LCD shows the motor status (on, at the time of the snapshot) which is ultimately governed by controller 3. This information was transmitted by controller 3 to controller 1 over the fieldbus, following a request for this information from controller 1 to controller 3. Likewise, controller 2’s LCD presents a message sent to it by controller 3. Finally, controller 3’s LCD is populated with the message it sent to controller 2 and with date and time information the former received via the fieldbus from controller 1.

This is to illustrate that controllers networked via a fieldbus can exchange information easily and conveniently. For instance, controller 3 can turn the motor on or off, based on

temperature information that it gathers via the fieldbus. The temperature sensor and the corresponding controller may be located in far apart plant locations.

Shown in Fig. 7 is a collection of oscilloscope records for the differential signal on the fieldbus network as registered at different points and during active and inactive bus state. Two oscilloscope channels have been employed, for the bus uses a differential signal. The bottom signal was recorded when no information was propagating over the bus. This is easily noticed by the absence of relative inversion between the two signals. Signal wanders owing to bus wire fluctuations, i.e., all controllers are in the “hearing” mode and this effectively fluctuates the bus until a transmitter puts some information on it. The second oscilloscope screen shows a beautiful differential signal captured on the bus at a point near a transmitting controller. The not-so-beautiful signal of the third record illustrates how the signal is degraded as it propagates over the bus, as the record was taken at a point away from the transmitting controller. Nevertheless, from a differential receiver viewpoint, this is a very good signal, given that the signal-to-noise ratio is very high. In other words, subtracting one signal (channel 1) from the other signal (channel 2) would surely result in a quite clean single-ended signal. The top screen is just to illustrate the fast settling of the differential signal on the bus, as can be noted by the horizontal settings of the oscilloscope.

Not surprisingly, students were observed to feel significantly more enthusiastic about the course than those who took the same course the year before but under traditional lecturing scheme. Likewise, professor dedication to students was quite bigger as was the students’ dedication to the project.

Weak points noticed include asymmetries in task planning and execution inside teams. It was crystal clear that in each group a leading student assumed the team’s task as his (her) sole task. Maybe this stems from the fact that almost all students were quite involved in their internships in industrial plants and with an eye in their first jobs as engineers (of course, in occupations not related directly to either microcontroller applications or industrial networks area). Assessing students in PBL-based courses in quite challenging, given that team work and peer-to-peer instruction are pillars of this strategy that would be broken if projects were assigned to students individually. Moreover, this could be impractical whenever a great number of students got enrolled (not the case in this course edition).

IV. CONCLUSION

Traditional lecturing fails to motivate engineering students. The result is that retention and engagement of students are jeopardized. The lack of engagement leads to graduates with “less-than-expected” understanding of engineering basics. This, in turn, can compromise career and hiring, on the individual side, and innovation rate and industrial competitiveness, on the social side. The solution to this crucial problem is neither easy nor cheap. Research on engineering education (and on learning overall) over the last four decades has led to a much better understanding of learning mechanisms. This has open a door leading to different teaching strategies

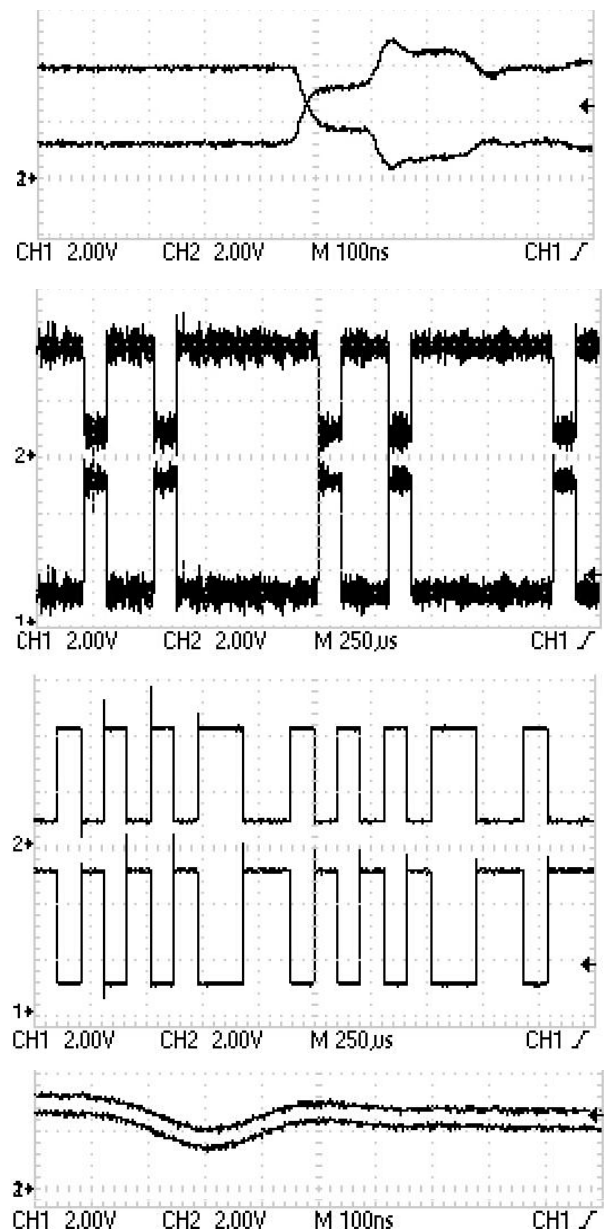


Figure 7. A and B (differential) signals recorded on the bus, from bottom to top: when no transmission is occurring through the bus; near an active transmitter; near a receiver; fast trace near an active transmitter.

that have been shown far superior to traditional teaching methods. The different approaches of “active learning” (e. g., problem-based learning, project-based learning, service learning, scaffolding, peer-to-peer mentoring, hands-on training, etc), as opposed to traditional lecture-based “passive learning”, put the focus on the students (the learners) rather than on the subject-matter itself. As students play an active role in the learning environment, they naturally work with the superior mental structures required by goal planning, decision making and prediction. These activities are crucial to definitive knowledge acquisition, and contrast with “knowledge” apparently gathered through simple memorization. The latter vanishes fast as experience has shown.

In traditional lectures, students do not see a connection between the subjects they are required to learn and the real world experience, notably the world of their daily lives. Students are passive “learners” (listeners) during the lectures and passivity does not leverage learning. Additionally, in traditional instructional methods students-faculty interaction is admittedly weak, though this relationship be recognized as an important student engagement, retention and motivational tool.

This paper presented an application of the project-based learning paradigm to the difficult task of teaching electrical engineering students the fundamental concepts of industrial network technology. There are a myriad of details embedded in this theme and, worse, abstraction is almost inevitable, what renders it a highly tough subject to tackle with traditional classes.

Our approach was to use a couple of homemade controllers and assign students the global task of networking them. While pursuing the global objective, students had to deal with some mundane, but “must-know”, microcontroller-based human-machine interfacing techniques, such as key-switch monitoring and decoding and writing messages to an LCD. Some basic and minimum knowledge about fieldbus network were presented and incorporated by students into their projects over the semester.

Developing and testing the software to implement the data communications protocol for the network layer of ISO’s OSI reference model was a much challenging design goal that required the students to use the most their creativity and theoretical understanding of the topic. This is a premium example where theory and practice must walk hand in hand to meet a design specification.

It was felt that student assessment is much complicated than in traditional lecturing, as expected. Also, instructor and students’ dedication to course is far higher than in conventional methodology. Despite these difficulties, the power of PBL to promote student mastering of fieldbus network technology is undeniable, as results of the projects carried out by the student

teams made it clear. By the end of the course, students demonstrated proficiency in navigating through the IDE and in developing and testing programs in C to the target microcontroller. To achieve the project goals, they utilized several microcontroller resources (e.g. timers, interrupts, serial ports, and general purpose input/output pins), and used programming techniques as modularization and top-down design approach, thus fulfilling the main course requirements. The students’ enthusiasm and engagement observed during this experience, besides effective mastering of key subjects by students, have definitely changed our minds, leading us to decide to adopt PBL methodology in all future editions of this course. Nevertheless, some improvements should be implemented, as closer follow-up of groups, through for instance a quarterly presentation of achievements, and assignment of rotating roles such as team leader and spokesperson for every team.

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Work in Progress: Hands-on Biomechanics Lab for Undergraduate Universities

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Abstract—This paper discusses the development of a biomechanics lab course suitable for use at undergraduate engineering institutions who wish to expand their elective offerings or move towards developing a bioengineering degree program. The labs are designed to be low cost and feasible in a teaching environment with groups of students rotating through stationary lab setups. The biomechanics course at the University of Portland has nine labs. The six stationary labs are 1) Gait Force Profile Analysis, 2) Basketball Freethrow Arm Angle Analysis, 3) Biomechanical Arm Muscle Analysis, 4) Muscle Fatigue Analysis, 5) Occupational Biomechanics Glove Fatigue Analysis, and 6) Breathing, Heart Rate, and Knee Motion Analysis. The three labs performed as a class are 7) Sprint Acceleration and Terminal Velocity Analysis, 8) Auto Collision Analysis, and 9) Orthopaedic Implant Mechanical Testing. The remainder of this paper is a detailed description of each lab, its learning objectives, and how it was implemented. Other aspects, such as final projects, research reports, and student opinions of the course will also be discussed.

Keywords- *biomechanics, hands-on laboratory experiments, undergraduate engineering, bioengineering*

I. INTRODUCTION

In recent years, undergraduate engineering programs across the country have seen marked increases in enrollment, with the enrollment increasing 15% between 2006 and 2009, bringing enrollments to the highest level since 1982 [1]. Mechanical engineering has seen the greatest increases, but bioengineering is rapidly growing in popularity, and it's no wonder, as the US Department of Labor and Statistics predicts a 72% growth in jobs between 2008 and 2018 in bioengineering fields [2]. Traditionally, bioengineering was only taught at the graduate degree level, but the last ten years has seen a tremendous increase in the number of undergraduate institutions offering bioengineering degrees. Developing a full-fledged bioengineering program is a long, involved process with multiple considerations that the institution must take into account, and yet students want to learn about bioengineering now, during their brief four year tenure. As educators, we have the opportunity to introduce students to the field of bioengineering through special courses and electives that will give them the exposure they need to pursue careers in this field. One such course is Biomechanics, which has been developed in the Mechanical

Engineering program at the University of Portland (UP). This combination lecture and lab course is designed to expose students to the very broad field of biomechanics. The purpose of this article is to clearly outline the lab component of a course developed at UP and to provide enough detail that other undergraduate engineering programs could implement a biomechanics course in their curriculum at low cost.

The target audience for Biomechanics is engineering students who have taken Physics, Statics, and Dynamics. It is helpful if they have also taken Strength of Materials and some kind of lab in signal measurement, but not required. Most engineering students will not have taken any biological sciences, such as Biology, Physiology, or Anatomy. Students interested in the bioengineering field should be encouraged to take such courses to fulfill science requirements or as electives, as this will only improve their understanding of the field. Students will also not have had exposure to testing with human subjects and how to analyze data gathered from human subjects. Knowing these restrictions, the build-up of the course requires some foundational knowledge.

The course at UP is offered three days a week, with two hours of traditional lecture and one hour of lab. The syllabus covers several broad topics: Anatomy & Physiology, Biomechanics: Statics, Biomechanics: Kinematics (Dynamics), Lower Body Performance (Hips, Legs, & Knees), Muscle Tissue Mechanics, Bone Tissue Mechanics, Fatigue, Occupational Biomechanics, Sports Biomechanics, Accidents and Injuries (Vehicles, Consumer Product Failure, Slip & Fall), and Orthopaedics. These topics are all subjective, and any of them could be eliminated, replaced, or emphasized depending on the instructor. Also, some of the topics are covered through a combination of guest speakers from local industry and field trips. UP is located near a biomechanics research lab, a prosthetic upper limb manufacturer, an athletic shoe company, and an orthopaedic implant company. However, any local industry could be substituted that has some relativity to the field of biomechanics.

Laboratory experimentation is an important component of this course in biomechanics. Dealing with human subjects and the ability to gather meaningful data for analysis is one of the key challenges in biomechanics. Unlike other

engineering disciplines, bioengineering is extremely dependent on test setup conditions. Thus, graduates need hands-on experience with research techniques in biomechanics, and how to present those results to an audience of their peers. Human performance is influenced by fitness, age, gender, diet, fatigue, prior activities, time of day, and countless other variables that cannot be controlled. Generated data is noisy and can be altered by placement of electrodes, movement of the body, clothes worn, stance, temperature of the room, air flow, etc., so it is very difficult to compare results from laboratory experimentation to published literature, as it is virtually impossible to recreate the same conditions. In order for students to be successful performing biomechanical research in their field, they need to have firsthand knowledge of the challenges and limitations so that they can properly interpret their results. The course at UP has eight to nine laboratory experiments. This number can be increased or decreased at other institutions as needed to fit the curriculum, and the exact types of experiments can also be adjusted as needed to give students the exposure desired. At UP, six of the labs are stationary, and the student groups rotate through them every two weeks. The first week is used to read about the lab and learning objectives and to practice with the data collection equipment. Technical journal articles on the subject of the lab station are posted online, and those are also read by the students prior to performing the lab. Many of the labs also require the student volunteer to wear particular clothing or shoes, so this gives the groups time to prepare for data gathering the second week. Three additional labs are performed outside of the classroom, and all groups participate in the lab at the same time. The six stationary labs are 1) Gait Force Profile Analysis, 2) Basketball Freethrow Arm Angle Analysis, 3) Biomechanical Arm Muscle Analysis, 4) Muscle Fatigue Analysis, 5) Occupational Biomechanics Glove Fatigue Analysis, and 6) Breathing, Heart Rate, and Knee Motion Analysis. The three labs performed as a class are 7) Sprint Acceleration and Terminal Velocity Analysis, 8) Auto Collision Analysis, and 9) Orthopaedic Implant Mechanical Testing.

First, it is important to emphasize that this is an introductory, broad overview biomechanics course developed for undergraduate mechanical engineering students. Since UP is a teaching institution, funding for the development of this course came from the School of Engineering and from an internally awarded Butine Grant. Funds were thus very limited, and state-of-the-art data gathering equipment was not the objective. Instead, low cost ways of gathering the type of data desired was purchased, and much of the instrumentation came from Vernier Software & Technology, a company that specializes in science education instrumentation [3]. Many other pieces of equipment are standard, commercial sports equipment, tools, and electronics. Concepts learned in this course, however, are easily transferrable to more sophisticated tools the students may encounter in the future. The total cost for all equipment used in this course was about \$4000, purchased over a period of three years.

In this senior level course, students have already been exposed to numerous writing and presentation experiences, but they have not learned how to present their work in a format suitable for journal publication. As such, these laboratories are designed to give students skills in experimental design, hypothesis testing, and journal publication writing. At the beginning of the semester, each student performs a clinical literature review on a biomechanics topic of their choice, which they then submit in typical journal format, with Abstract, Introduction, Methods, Results, Conclusions, Discussion, and Works Cited. They must cite a minimum of five peer-reviewed references, using library resources to obtain the full articles. They summarize the articles and then analyze the similarities and differences between opinions and draw their own conclusions. This journal format is then used for all group laboratory reports.

At the end of this course, student teams conduct student-designed experiments on any area of biomechanics. Topics have ranged from baseball swing analyses to vehicle-pedestrian accident reconstruction analyses. Again, these reports are written as journal articles, and each team must present their findings to the class. This has led to lively discussions, and students really enjoy the opportunities to define their own experiments.

The remainder of this paper is a detailed description of each lab, its learning objectives, and how it was implemented at UP. As the goal was to provide a forum for students to become better experimental researchers, outcomes for the laboratories were not defined. Each lab station had a set of equipment and a handout. The handout gave an overview of how to use the equipment and the learning objectives of the lab. It then provided a series of open-ended questions to answer. Students could choose to answer one or more of the provided questions or create a hypothesis of their own. As each lab was conducted over a period of two weeks, the first week the students familiarized themselves with the provided equipment and decided as a group what their hypothesis would be. The second week, a student volunteer would arrive appropriately attired, bringing any necessary props or equipment, and the team would collect the data during the lab period. They then had one week to analyze their results and submit their journal-formatted report.

II. LAB EXPERIMENT DETAILS

A. *Gait Force Profile Analysis*

In this lab station, students gained an understanding of how shoes affect the motion of the foot. They were directed to walk and jog across a force platform in athletic shoes, rigid sole boots, and barefoot. They had a choice of collecting all the data for one foot or alternating feet. They were equipped with two force plates by Vernier Software & Technology. The force plates were connected to a Vernier LabPro interface. The LabPro was connected via a USB cord to a Windows XP computer. The software used to read the input was Vernier's LoggerPro for real time graphing and analysis. The two force plates were summed within LoggerPro and the output was exported for later spreadsheet analysis, using Microsoft Office Excel 2010. Like much of

the equipment used in this course, the force plate has limitations. It can only gather force in the z-direction, perpendicular to the floor. This is a significant limitation, but a lot of good data can still be collected with this device. Three axis force platforms are very expensive and must be installed flush with the floor, which was not an option in the lab at UP. The Vernier force plate looks similar to a bathroom scale, and since it is not flush with the floor, early attempts to use it for walking force profiles were unsuccessful. First, the student volunteer had to step up onto the force plate and then back down. The step up motion altered their gait and made it difficult to compare changes in walking profile. Second, the force plate was small, and students had a hard time adjusting their stride to land their foot squarely on the force plate. To overcome these challenges, a ramp was built to allow a gradual change in inclination. The ramp was built wide enough for both feet, and two force plates were placed under a wood cover to give an extra long striking surface for running. This new ramp was student-built from plywood and was designed to be modular for easy storage when not in use.

Recently, barefoot running has become popular. Biomechanically, there are several advantages to barefoot running, especially the more natural gait. In an athletic shoe, a runner will stride out and strike heel first. This leads to larger forces in the knee joint and thus a higher probability of injuries. However, barefoot running is not necessarily the answer, as most runners now run on paved surfaces that are much harder than natural surfaces, and these surfaces are often strewn with sharp objects and fluids that could infect the foot. Thus, shoe manufacturers are now marketing so-called barefoot running shoes. The goal of the lab is to compare the walking and running force profiles with different footwear. Like all of the labs, the data gathered depends upon what the student group decides they want to analyze. For each lab station, a series of open-ended questions were asked to promote the students to think about what they should observe. These questions are based around the learning objectives of each lab. For this lab, the questions were: 1. How does the shape of the force profile change for shoe type? 2. How does the magnitude of the impact force change for shoe type? 3. How does the force profile change for running versus walking?

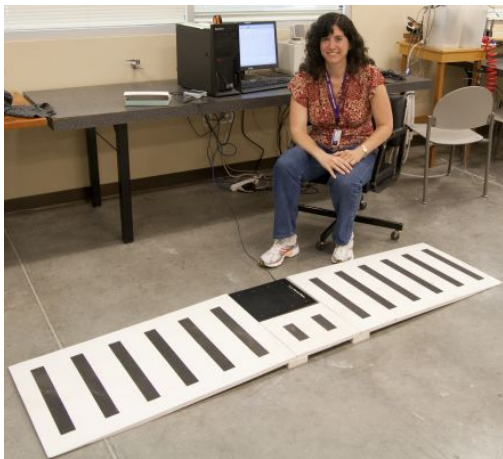


Figure 1: Wooden ramp for force plate

B. Basketball Freethrow Arm Angle Analysis

In this lab, students made a video recording of a volunteer shooting basketball freethrows. They were directed to capture the angle of the arm at ball release and to correlate this with the success or failure of the shot. The lab station was equipped with a Panasonic video camera with 40 gigabyte hard disk drive and a tripod. Within the lab, a standard basketball stand with a reduced rim height of seven feet is set up on its rolling base. The base is filled with water to counterbalance the weight of the stand. Part of the safety training for the lab explains the dangers of having a water-filled base. If a student were to hang from the rim, the stand would come over, and the mass of the water flowing towards the front of the base would accelerate that motion. The lab station also has a regulation size basketball and a ball pump. To facilitate finding the arm angle, the volunteer's shoulder, elbow and wrist are marked with black permanent marker. Within LoggerPro, video input can be analyzed. LoggerPro has a video utility that advances the movie file frame by frame. Marks can be added at each frame and plotted as desired in real time. The students advance to the frame of ball release and mark each joint with X-Y coordinates and determine the vector between elbow and shoulder and elbow and wrist. Using the dot product, they can then calculate the included angle. The angle can be correlated with the success or failure of the shot, with most student groups recording "swish", "backboard make", "rim make", or "miss" for a total of 30 shots. Questions for this lab were: 1. How far off from ideal does this angle have to be to miss the basket? 2. What does the shot look like if the arm angle is oblique versus acute? 3. Is there a significant difference between a "swish" and a backboard shot in terms of arm or body profile? 4. Besides arm angle, what other factors influence the success of a basketball shot?

C. Biomechanical Arm Muscle Analysis

For this lab station, the students investigate mechanical advantage of muscle attachments using either a biomechanical arm or leg developed by Denoyer-Geppert [4] and a dual force sensor and low G accelerometer from Vernier Software & Technology. The biomechanical arm apparatus has attachment points that allow the biceps muscle to be simulated with the dual force sensor. Weights are placed in the hand of the biomechanical arm, which causes the arm to rotate downwards about the elbow joint. The tension in the biceps is adjusted until the forearm is once again horizontal. This is repeated for multiple weights in the hand and two different biceps muscle attachment points on the forearm. The sensors are attached to a Vernier LabQuest Mini unit, which is a simplified version of the LabPro, with four input/output ports. The LabQuest Mini is connected to a Lenovo Windows XP computer and the sensor input is analyzed using LoggerPro.

The goal of the lab is to demonstrate how human muscles act at a mechanical disadvantage in favor of increased range of motion. The LoggerPro software has many built-in mathematical functions, so the low G accelerometer signal can be integrated twice to get position, and this can be used to make the arm horizontal. Most student groups, however, simply use the protractor scale on the elbow joint to

determine horizontal. The output result should show that at the nearer attachment point for the biceps muscle, the muscle is producing about eight times the force in the hand; whereas, at the further attachment point, the muscle is only producing about three times the force in the hand. The questions for this lab were: 1. What is the mechanical advantage (multiplying factor) for the far muscle attachment point versus the near muscle attachment point? 2. Why are muscles attached so closely to the joint? How does this influence the design of muscles and bones? 3. How could biomechanics of the arm be improved externally (with tools and sports equipment)?

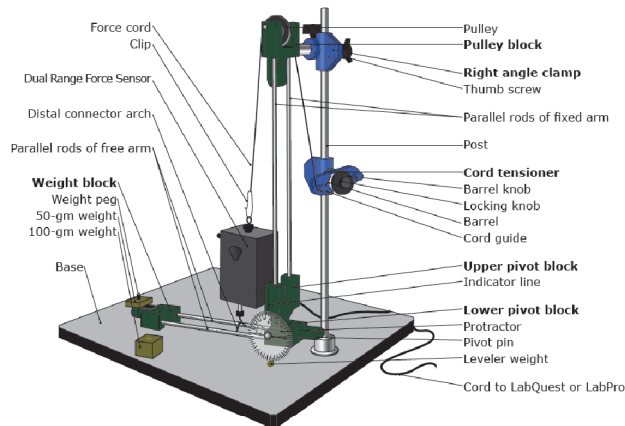


Figure 2: Denoyer-Geppert biomechanical arm [4]

D. Muscle Fatigue Analysis

This lab introduces the use of electromyographic signals (EMG) to capture electrical signal from muscles. EMG signal is extremely noisy and highly dependent on electrode placement, so the students get to learn what EMG signal can be used for and what it cannot. The volunteer performs three exercises, first wrist extensions with a light weight with electrodes on the forearm extensor muscles, then they flip their arm over and perform wrist flexions. The extensor muscles have baseline potential voltage noise, but they only "fire" when the wrist is extended. After gathering this data, the volunteer moves the electrodes to the biceps muscle and does biceps curls with the maximum amount of weight they can lift. These are repeated until the volunteer cannot produce any more repetitions, at which point their team begins cheering for them forcefully. With cheering, the volunteer finds they can do multiple additional repetitions. Throughout the exercise, the EMG signal changes, first decreasing in overall amplitude, then increasing in firing frequency. When cheered, the muscle EMG signal does not improve, allowing students to consider what is happening, such as other muscle recruitment. The questions for this lab were: 1. When the muscle is being activated versus not activated, how does the EMG signal differ? 2. How does placement of the electrode affect the EMG signal? In other words, what can you infer and not infer about the muscle based on the signal amplitude? 3. How does EMG amplitude change with fatigue? 4. How does cheering (brain stimulus) affect performance? 5. What is happening to the EMG amplitude when the volunteer is fatigued yet being cheered on to perform more reps? What is happening biomechanically in the muscles?

E. Occupational Biomechanics Glove Fatigue Analysis

Many professions require the use of gloves, which protect hands from the elements and harsh conditions, but also decrease feedback on grip force. Thus, workers must increase their grip force when wearing gloves, and this accelerates fatigue. For this lab station, the students are provided a Vernier hand dynamometer, a LabQuest Mini unit, a Windows XP computer, and a variety of work gloves. They first grip the dynamometer barehanded and record their maximum voluntary contraction (MVC). Then they record the amount of time they can hold within 75-80% of their MVC barehanded. Then, they don a glove and try to hold 75-80% of their MVC for as long as possible. This is repeated for both hands for all gloves, as well as for pinch force. The students are surprised to see the effect of gloves on their performance. They are also surprised that pinch force is improved by wearing gloves. The questions for this lab were: 1. How do gloves affect grip and pinch forces? 2. From an occupational biomechanics viewpoint, what are the advantages and/or disadvantages of using gloves for various tasks? 3. How could the effects of gloves be minimized? In other words, for a particular task that requires a certain type of glove, how should the glove be designed to minimize fatigue?

F. Breathing, Heart Rate, and Knee Motion Analysis

For this lab, a student volunteer rides a stationary bike for 30 minutes then stopping for 5 minutes while breathing into a Vernier spirometer and wearing a heart rate chest strap or wristwatch. The respiration rate and heart rate are recorded frequently for the first few minutes, then every minute for the remaining time, then frequently again during the rest period at the end. The goal is to determine whether heart rate or respiration increases first and which one decreases first. In the future, the hope is add a carbon dioxide sensor to the spirometer to see the oxygen flow rate.

Also for this lab, the students video record a few pedal rotations of the knee and import the motion into LoggerPro for analysis. Both the angular velocity versus time and the angular velocity versus angular position are analyzed to show the interesting kinematics of the knee. The questions for this lab were: 1. What do the knee path profiles look like during cycling? Why is this significant? 2. How do heart rate and respiration rate change during exercise? Which increases first? Do they reach steady state over time? Which decreases first? 3. How do revolutions per minute and "aerobic threshold" affect heart rate and respiration? 4. How do seat position and body posture appear to affect the biomechanics of motion, heart rate and position?

G. Sprint Acceleration and Terminal Velocity Analysis

For this lab, an indoor or outdoor running space is needed where the student volunteers can safely run 100m without having to slow down at the end of their sprint. Timers with stopwatches are located at each 10m interval, and everyone starts their stopwatch at the same moment. Using an inexpensive high speed camera from Casio, video of the start is captured at frame rates up to 1000 frames per second, although 30 frames per second is sufficient. Each volunteer runs two trials, and the results are averaged. The goal is to

demonstrate that terminal velocity is not as significant as acceleration rate and time in determining a person's finishing sprint time. Thus, a "fast" runner is one that accelerates to full speed in the shortest period of time. No questions were provided for this lab.

H. Auto Collision Analysis

For this lab, UP has constructed two buggies that ride on rails. The buggies were built from garden wagons and modified to have windshields and rail wheels. They have child booster seats on them and shoulder harness seatbelts from a salvage yard. In the seats are two large teddy bears. Students push the two vehicles toward each other over a distance of 30 feet, then release them just prior to impact. A high speed video camera is used to capture the release and impact for analysis of deceleration of the passengers. The vehicles are inspected for damage, and sheared bolts are located and dent depths are measured. The experiment is then repeated without the seatbelts. This experiment has evolved over the years to something that can be done precisely and indoors. In a lecture on accident reconstruction, forces on the body due to automobile collisions is discussed and physics is used to determine impact forces. In the future, it is hoped that the teddy bears and vehicle could be outfitted with accelerometers to capture additional data, but the G forces are too high for the sensors currently owned. No questions were provided for this lab, as it was intended that all groups would determine the speed of the two buggies, their impact force, and anecdotally discuss the effects of the seatbelts. Due to delays in the fabrication of the rails for the buggies, there was not enough time to write reports before the end of the semester, so this lab was discussed by the class as a group. Slow motion videos were played on the digital projector, and students discussed the pros and cons of how the data could be analyzed.

I. Orthopaedic Implant Mechanical Testing

One major field in biomechanics in orthopaedic implants. These implants must survive at least ten million cycles of wear testing, at physiologic worst case loads. There are dozens of standards for how the tests must be performed. One test that can be performed is on the spine. Spinal fusion surgeries are performed hundreds of thousands of times per year in the United States. On the posterior spine, four pedicle screws are fastened to adjacent vertebrae, and then rods or plates are positioned over two screws on adjacent vertebrae and anchored in place. This constructed can then be mechanically tested using a fatigue test machine, or more simply with strain gages on the hardware in a standard tensile test machine. For this lab, a sheep spine double loin is purchased from a local butcher. Using scalpel blades, all the excess tissue is removed and disposed of in a compost bin. Using a standard cordless drill, hardware donated by an orthopaedic spine company is installed on the sheep spine, and it is mounted in the test stand to gather some data. This is an easy lab to do, especially if no testing is performed. Much biomechanical testing is done on animals and cadavers, so exposure to the process of dissection is a valuable skill. Performing "surgery" on the spine also helps the students learn, as many will end up being present during surgical procedures, either to learn more about the challenges

of current devices or to test a device they have designed. This year's class did not get to prepare the spines themselves, and testing was only discussed with the class as a whole, as it was conducted late one evening in order to finish it by the end of the semester. New dynamic fatigue test equipment and better planning will allow this lab to be more hands-on in future years.

III. CONCLUSIONS

Implementing a biomechanics course at an undergraduate university is a feasible option for engineering programs that would like to offer electives, tracks, or majors in the bioengineering field. This paper has outlined how such a course with a full laboratory experience was developed at the University of Portland at very low cost. Other educators have discussed the importance of teaching experimental design at the undergraduate level, specifically in the area of biomechanics [5-9]. Gefen provides a list of equipment available to students in his undergraduate course, along with guidelines for using the equipment. Like the course at UP, he avoids providing "recipes" for the students to follow. He also places students in groups of three to four and has them conduct literature reviews prior to each laboratory. They are required to prepare a protocol in advance of the lab, which is then approved. For his course, there are six lab topics: tissue mechanics, biomaterials, posture, gait, heart valve, and exercise biomechanics. UP offers a separate course in biomaterials, so only four of the six labs are similar. Gonzalez works at a university that built a laboratory equipped with modern research equipment, specifically for the use of undergraduates for education and research [6]. Again, the equipment is meant as "tools" for students to answer their own research hypotheses. The goal of Gonzalez is to teach students to observe phenomena, formulate a hypothesis, develop an experimental methodology, and gather data for analysis. Results are presented as a poster or conference proceeding paper. He states that experimental methods are as important as analysis and design in the engineering curriculum, and agrees that biomechanical labs should be the focus of the course, not a supplement to lectures, if we hope students to develop skills in independent scientific inquiry. His laboratory is equipped with very high quality equipment, such as a 5 camera motion analysis system and a six degree of freedom force plate. His setup requires extensive software as well, which makes the cost of such a laboratory well beyond the means of smaller, teaching universities. His course has three defined topics and two independent design experiences. The three topics are maximum vertical jump analysis, hand dynamometer output with EMG, and arm stiffness measurements. The independent experiments are designed by the students, conducted in the laboratory, and then presented. He notes that several of these independent experiments have led to undergraduate research investigations. Cluss describes a low-cost method to measure the biomechanical forces in a moving human body [7]. She uses a 2D video analysis and software from Vernier, Inc. called VIDEOPOINT to evaluate the vertical jump of ballet dancers. With the software, students calculate the center of mass of the various body parts and deduce the accelerations and thus forces in the

joints. She states that many state-of-the-art video analysis systems cost upwards of \$250,000, but with a simple video camera, or even a cell phone with video function, and some low-cost 2D software, meaningful results can be obtained. This compares well with the experiences at UP. Using regular and high speed cameras (purchased for less than \$300), we are able to analyze many complex motions, including basketball freethrows, sprinting acceleration, golf swings, baseball swings, and simulated auto collisions. With software, it is simple to determine the acceleration and velocity, from which many parameters can be calculated, depending upon the hypothesized question. Zapanta also discusses the importance of laboratory courses in bioengineering and how his university has developed an introductory course to cover the five areas of biomedical engineering offered at his institution: cellular and molecular biotechnology, bioinstrumentation, bioimaging, biomaterials, and biomechanics. He uses EKG to study the heart and EMG to study force generation by limbs for movement. For the EMG labs, he has two experiments. The first is fatigue of the bicep muscles, using a weight held stationary in the hand for 60 seconds. The Fast Fourier Transform is analyzed. The second EMG lab is done in conjunction with a force plate to study the phases of jumping. This is analyzed using MatLab. His course also includes a research project, which culminates in a poster presentation with a written report. Student feedback is very positive for his course, and students liked the breadth of coverage. Some complained that the MatLab was too hard, and some students wanted more depth. At UP, MatLab is covered in a one credit hour computer science course, so all students have excellent MatLab skills, but the Vernier LoggerPro software is quite comprehensive, so no students have used MatLab to complete their analyses. Barr discusses a series of virtual labs developed by VaNTH that evaluate student outcomes based on pre and post tests and surveys administered to the students [9-10]. These biomechanics lab modules cover a variety of topics, including Iron Cross muscle strength, various gait analysis exercises (center of gravity, force generation, and EMG of quadriceps muscles), jump height experiments, and the performance of the ACL during knee extensions. Although the data is provided to the students, the modules are quite thorough and provide a series of videos, relevant literature, and analysis tools to the students. If implementing a physical lab experience is not feasible, this may be another low-cost option for some universities. The course is broad enough to cover a wide variety of biomechanics topics, while still having plenty of depth for students to understand how and where these concepts could be applied.

For the course at UP, student evaluations have been overwhelmingly positive. The overall score was 4.73 out of 5. When asked what students liked best about the course, comments included, "The labs were really interesting and fun.... It is nice that we can infer what we find most interesting from the labs and have some freedom to do them as we want. I learned about new programs and ways of analyzing which I liked as well." Also, "This course is a great opportunity for those looking to go into biomedical engineering. It really gives a well-rounded opportunity to learn about every aspect of biomechanics. The material

learned could be used in many different ways. The labs were also a great experience.... The reports helped the students really look into the background of what they were doing and then really how to evaluate the data they just collected."

Based on this feedback, the open format of the course and lab exercises will not be changed, but students were disappointed that we did not get to do the orthopaedic dissection and testing as planned. This summer, UP is receiving a dynamic fatigue test machine, which will provide a much-needed testing resource for biomechanical experimentation. Labs based around this new test machine are planned for the upcoming year. Also, Gefen's requirement of a test protocol in advance of data collection is intriguing and will be tried [5]. Gonzalez's formal approach to scientific inquiry was similarly intriguing, and I intend to add a stronger emphasis on development of the experimental method [6]. And Zapanta's use of Fast Fourier Transfer and MatLab to further analyze results are excellent low-cost options for UP that I intend to incorporate into the set of skills I provide to the students [8].

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IT Experiential Learning: The Living Lab

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Abstract - In today's competitive job market, businesses will hire people with the relevant work experience, which creates quite a challenge for graduating students. Thus, graduating students also need experience to go with their degrees in order to be competitive in current job market. To better prepare our students, the Computer Information Technology program developed an experiential learning program called the "Living Lab". The Living Lab provides real world experience in all aspects of information technology to students by assigning various projects in a real work environment. This allows students to apply their classroom learning and develop the skills and experience needed to prepare them for today's competitive job market, which is the mission of the Living Lab. Just like the name, the Living Lab experiences remain ever evolving and complicated; thus, finding ways to effectively assess learning persists as a challenge. In this paper, we will show how the Living Lab evolved and the organization, management, and assessment tools used in order to provide students the best experience to assist in their obtaining jobs. Further discussions will show our findings and the innovative ways the lab evolved to take into account the blending of processes, business practices, and academic rigor.

Keywords - *experiential learning; IT; living lab; service*

I. INTRODUCTION

According to Ferrara's research [6], the unemployment rate at 9.9% makes the current marketplace even more competitive, which adds more pressure for college graduates. Furthermore, the CareerBuilder survey concludes that less than half of employers prefer to hire recent college graduates in 2010 [6]. Therefore, without work experience, students will have a lower chance of getting a job. In order to help students overcome this difficulty, the Computer Information Technology (CIT) program in the Purdue School of Engineering and Technology at Indiana University Purdue University Indianapolis (IUPUI) developed an experiential learning program called the "Living Lab" (<http://cit.iupui.edu/citnet>). The Living Lab's mission is to provide experiential learning for students in the Information Technology and Security discipline. It immerses students in a real technology business environment and expands their knowledge and experience beyond the typical classroom environment. The goal of the Living Lab is to promote learning through challenging real-life hands-on experiences that are supervised by faculty, students and staff. Not only do the students improve their hard skills, but they are also taught soft skills.

Just like the name, the Living Lab experience remains ever evolving and complicated; thus, finding ways to effectively assess learning persists as a challenge. Furthermore, because the Living Lab is still so new, being able to organize and

manage it won't be an easy task. With the efficient organization and management tools, the Living Lab's foundation will be greatly enhanced. It is necessary to assess student's learning, and to find the way to improve the organization and management of the Living Lab in order to ensure the validity of the course and provide students with the best experience to assist in the process of life-long learning and the ability to gain employment.

II. BACKGROUND

A. Literature Review

Experiential learning – or learning by doing – is an important factor in education improvement. The purpose of experiential learning is to fill the gap between theory and practice. Consequently, many researchers such as Walker [7], Krane [3], and McCarthy [4] have shown interest in experiential learning, which was proven to be a valuable asset in education. All of these authors believe that it is important to bring theory which was studied in class into a real-life situation where the students can apply what they have learned to solve problems. They agree that experiential learning plays a significant role in education improvement. In their research, they explained the link between theory and application as well as the necessity of experiential learning. However, each of them expressed their ideas in a unique way.

Walker [7] described the process of experiential learning, and how students adapted to this process. Unlike Walker [7], Krane [3] implemented a self-directed learning course and showed its result. McCarthy [4] took a different path and focused on comparing an example of experiential learning and traditional learning. According to Walker [7], the process of experiential learning moved students from passive recipients of information to learners who observed and experienced phenomena in the workplace; as a result, the students were better equipped to implement the principles they learned from class in the marketplace. While Walker [7] showed a general process of experiential learning, Krane [3] applied it to a specific area such as physiology. He realized that there was a disconnection between what information was retained in the laboratory exercise and its application in a practical setting. According to Krane [3], students tended to memorize information in a static pattern rather than process information and formulate strategies for truly understanding the dynamism. Krane [3] created a course which was designed to extend the individual lessons performed in the laboratory course with self-directed learning through the contextual application of information. He also showed that the students' responses were overwhelmingly positive despite a small number of students expressing disappointment due to schedule conflict or an

unexpected event. On the other hand, McCarthy [4] didn't apply experiential learning to any specific area, but compared between case study method which was popularly used in a class and job shadowing method which was integrated into a business course. McCarthy [4] said that direct learning forced students to make their own decisions when facing a real-life problem. When students engaged in tasks, it fostered the development of their skills. McCarthy [4] incorporated job shadowing in a junior-level business communication course. Students who took this course would need to write a research paper, orally share experience with each other and complete a survey. After that, she evaluated all activities, and used paired-samples t test for job shadowing and cases. With the t test in 95% confidence level, she concluded that experiential learning was preferred over traditional learning.

In the same way, Massachusetts Institute of Technology (MIT) developed a similar program called "Action Learning" (<http://actionlearning.mit.edu>). MIT Action Lab said "Our approach integrates theory, real world practice, and personal reflection to develop principled, innovative leaders who solve complex problems and produce systemic changes" [5]. For this reason, Action Learning offers many opportunities for students such as China and India Lab, E-Lab, Global Health Delivery Lab, Global Entrepreneurship Lab, i-Teams, L-Lab, P-Lab, and S-Lab. Each of these labs encloses a different segment of learning perspective. China and India Lab focus on international cooperation while E-Lab focuses on local internship. Global Health Delivery Lab helps students learn about healthcare perspective. The i-Teams (short for "Innovation Teams") lab teaches students the process of science and technology's commercial potential. And Global Entrepreneurship Lab, L-Lab, P-Lab, and S-Lab focus on business perspective.

In short, all of these researchers have proven the important role of experiential learning. Walker [7] showed a general process of experiential learning which consisted of four stages, whereas Krane [3] actually implemented experiential learning to a specific area such as physiology. On the other hand, McCarthy [4] compared between case study method and experiential learning method. Furthermore, MIT University realized the advantage of experiential learning and developed the "Action Learning" program [5]. In other words, experiential learning was an excellent supplement to the classroom environment, which allows student's learning to extend past classroom walls and into the real world environment. Experiential learning presents students the opportunities and problem solving skills which are usually encountered in the workplace so that it required them to think and apply theories to solve problems. It also helps them experience teamwork and expand their learning. Walker said: "This process is indeed a necessary tool in which students expand their abilities to analyze, reflect, and make adjustments" [7]. However, Walker [7] showed a general process of experiential learning but didn't show the application of the process. Krane [3] applied experiential learning to a specific area such as physiology, but didn't actually assess student's learning in depth. McCarthy [4] analyzed and compared experiential learning with traditional learning, but she didn't analyze for the actual improvement of student's learning. Moreover, MIT "Action Learning" program

[5] is too general and doesn't focus specifically on Information Technology. Most of their labs are on external sites and are optional for students whereas "Living Lab" is an in-class and required course which students have to take before graduation. The "Living Lab" is a true experiential program and focuses on a student's true immersion into the business environment.

B. Living Lab Genesis and Organization

It is all started back in 2001 when the CIT faculty needed a server that ran Microsoft's IIS 4.0 for their courses. However, due to security risk, University Information Technology Services (UITS) would not install it in any of their labs. Therefore, the CIT program acquired their own servers starting with two machines. The servers continued to grow, not only to be used for courses, but also to support faculty for their testing space. The first recruited CIT student was able to maintain, monitor and administrate the servers. Meanwhile, the program coordinator was also trying to design hands-on laboratory for networking courses. From there, the idea grew and the Living Lab was born.

The course requires no previous work experience and students that have completed the introductory networking courses are eligible for the Living Lab. The students work under the supervision of faculty and/or staff, supporting CIT's web site, database, security, and networking labs. The internal projects vary from being simple to being complex such as server management. When their level of experience and expertise grows, students are ready to work on external projects in other companies who cooperate with the Living Lab such as Simon Properties Group, Inc.

The first Living Lab roster started with 6 students and grew to 24 students in the fall of 2010. Currently, there is an average of 14 students attending the Living Lab each semester. The CIT program utilizes two student classrooms (ET005 and ET007) to support the lab work for networking and security classes. Today, the Living Lab has expanded to include support for other departments at IUPUI. There are 15 workstations in the room ET005, 30 workstations in the room ET007, and 32 servers in the server room (ET005A). These labs are isolated from the campus network, and give the students administrator access to the workstations, which provides a realistic working environment without a risk of security breach on the campus network. As a result, it offers instructors in the security courses a chance to introduce vulnerability and risk assessment tools for the students. Moreover, the Living Lab provides firewalls, switches, routers, etc. as class materials to students. Therefore, the students get some hands-on experience using equipment and software as part of their class work. Students who complete the Living Lab gain even more experience by maintaining the labs and completing assigned projects. Furthermore, all of the classes taught by the CIT program have the ability to host applications and websites on the Living Lab servers. These servers are also built, administered and maintained by students in the Living Lab. Fig. 1 shows an overview of the Living Lab organization.

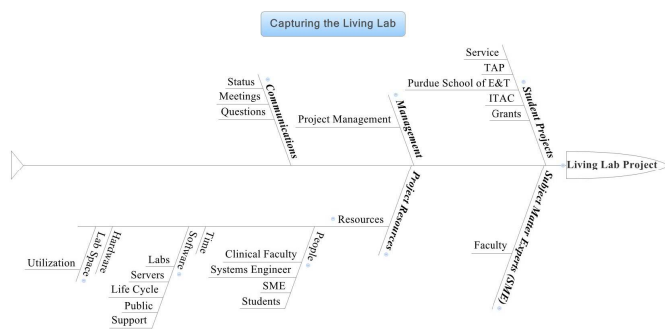


Figure 1. Living Lab overview.

III. MANAGEMENT

To qualify for the Living Lab, students must have successfully completed the first two semesters of courses in the curriculum. It is a required course before the students graduate.

All members are required to attend weekly meetings, including supervising faculty. In the weekly meeting, each student must report on their project work. These meetings are conducted similarly to status meetings in a corporate environment, which provides each student with real world experience. In addition, students are present in the Living Lab on Fridays and Saturdays from 9am to 5pm during the semester (supervised by systems engineer). Supervising faculty and staff have weekly planning meetings as well. Project management tools are used to track the progress and document milestones for each project. The project management tools provide a roadmap for the students to make sure deadlines are met. Projects being assigned to students include technology projects for the department, external service learning projects, university-wide projects. Recognizing the role of reflection in extracting learning from experience, each student in the Living Lab is required. Students keep track of their projects during the semester by writing status reports and journals. Status reports document all the project milestones. Journals document project activity as well as any processes helping to accomplish a particular task in the project with personal reflection. As a result, journals offer students a chance to reflect on what they have been learning and how it relates to the theory they memorized from courses taken before. Likewise, students also need to create documentation (how-to) by recording their processes, procedures and fixes. This is extremely important. Not only does it help students to have a best practice, but also makes the process easier. If a similar situation arises, other students can look at the documentation for help. As the students reflect and document on their project work, they gain confidence in their ability to accomplish any IT project or task that they are given. It is amazing to see students without experience come into the Living Lab as uncertain neophytes and leave with confidence in themselves and their abilities. Fig. 2 illustrates the Living Lab methodology.



Figure 2. Living Lab methodology.

The project opportunities for students are wide-ranging. Projects can come from the CIT program itself, other university-wide departments, or even externally from other companies, and nonprofit companies. Here is a list of some projects, which were assigned to students in the Living Lab. More information about Living Lab projects can be found via our website at <http://cit.iupui.edu/citnet>.

- Living Lab web site development
- SharePoint server / Oracle server setup
- Secure media sanitization
- Bacula Backup Project
- Dell OpenManage Server Admin
- Symantec Ghost implementation
- Encryption protocols implementation
- Nagios setup and configuration
- Forensic projects: Encase, FTK
- External projects: Simon Property Group, Inc., Avon Church

At the end of semester, students are required to submit all deliverables for grading: project report, presentation, poster, weekly status, and journal. The project report is an overall summary of all the project work, including what students have accomplished over the semester and, more importantly, what the Living Lab experience has meant to them. They are expected to clearly state what kind of projects they did, the purpose of each project, how this experience related to their course work, and how it may help them with future employment. To summarize, Fig. 3 shows the flowchart of Living Lab processes.

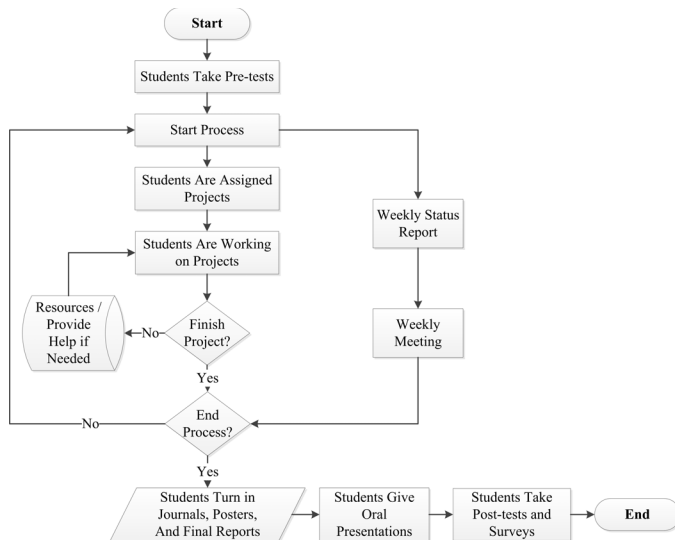


Figure 3. Flowchart of Living Lab processes.

IV. ASSESSMENT OF STUDENT'S LEARNING

Many researchers such as Brinke & Jochems [1], Koriati & Bjork [2] think that student's learning needs to be evaluated. Not only does it help to know whether the student's learning improves during the course but also helps to identify any problem and find a solution for it. Therefore, learning assessment was also an important factor in this picture. It helped to evaluate the student's learning outcomes. Without student's learning assessment, we would not know if students are learning or meeting the course expectations. And the main question is: "Will student's learning increase or remain unchanged after they complete the Living Lab?"

A. Participants

Since this study was intended for the Living Lab, the population of this study was all students participating in Living Lab. Students in the Living Lab between Spring 2010 to Spring 2011 served as the sampling frame (see Table I). That was small enough so that all students in the sampling frame would be included. The advantage of this is the ability to test all the individuals in the segment of the population in order to obtain reliable, valid and accurate results.

TABLE I. SAMPLING FRAME

| Semester | Number of students |
|-------------|--------------------|
| Spring 2010 | 13 |
| Fall 2010 | 16 |
| Spring 2011 | 7 |
| TOTAL | 36 |

B. Materials

In this study, the quasi-experimental approach was utilized to obtain a general overview of the student's learning performance. Single-Group Pretest/Posttest design was used. A skill assessment test was developed and designed based on general knowledge about Computer Information Technology. It

was divided into 9 different areas of knowledge, all of which were necessary for students to know in order to be able to get a job. Also, a course evaluation survey was used to ask for students' opinions and suggestions about the course and the skill assessment test.

C. Procedures

The students took the skill assessment test at the beginning and the end of the Living Lab through an electronic testing tool in the university learning management system. These tests were graded based on a grading checklist with a total of 100 points. The two measures of the pretest and posttest could then be compared, and any differences in the measure were assumed to be the result of the course. Furthermore, at the end of the Living Lab, the students took a course evaluation survey. The surveys were also collected for future reference.

V. RESULTS

By completing the Living Lab, students learn to develop self-directed learning ability in a real-world environment as well as to integrate knowledge studied in the classroom with practical application. They learn to manage projects effectively, work in a team, and communicate their synthesis and interpretation of the experience in both written and oral presentations.

To test for whether student's learning increases or remains unchanged after they complete the Living Lab, pretest and posttest scores were examined. Pretest and posttest scores were collected from 36 students in 3 semesters. Table II shows the mean test scores of pretest and posttest by semester.

Before doing any analysis, the null and alternative hypotheses were defined. The null hypothesis was that student's learning remained unchanged after they completed the Living Lab; and the alternative hypothesis was that student's learning increased after they completed the Living Lab. A paired-samples t test was conducted to determine if there were any significant differences among the pretest and posttest scores. In addition, the result in Table III indicates a significant difference at the 0.05 level of significance among the means of the pretest and posttest scores.

A paired-samples t test was calculated to compare the mean pretest score to the mean posttest score. The mean on the pretest was 22.7597 (sd = 12.35004), and the mean on the posttest was 36.8872 (sd = 21.72411). A significant increase from pretest to posttest was found ($t(35) = -3.675, p < 0.001$).

TABLE II. MEAN TEST SCORES

| Semester | N | Pretest Mean | Pretest Std. Dev. | Posttest Mean | Posttest Std. Dev. |
|-------------|----|--------------|-------------------|---------------|--------------------|
| Spring 2010 | 13 | 19.66 | 0.11 | 37.65 | 0.212 |
| Fall 2010 | 16 | 27.22 | 0.137 | 40.59 | 0.186 |
| Spring 2011 | 7 | 18.34 | 0.091 | 27.00 | 0.289 |

TABLE III. PAIRED-SAMPLES T TEST

| Paired Difference (Pretest – Posttest) | t | df | Sig. |
|--|---|----|------|
|--|---|----|------|

| Paired Difference (Pretest – Posttest) | | | | t | df | Sig. |
|--|--------------------|---|--------|--------|----|------|
| Mean | Standard Deviation | 95% Confidence Interval of the Difference | | | | |
| | | Lower | Upper | | | |
| -14.128 | 23.062 | -21.93 | -6.324 | -3.675 | 35 | .001 |

As a result of the paired-samples t test, we rejected the null hypothesis. Student's learning did increase significantly after they completed the Living Lab. Fig. 4 illustrates the pretest and posttest scores per students.

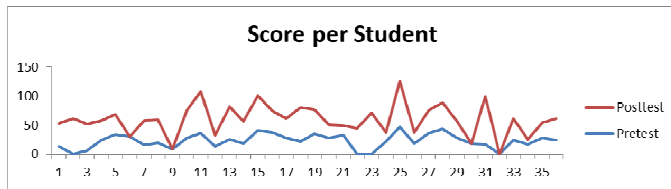


Figure 4. Pretest and posttest score difference among the students.

On the other hand, Fig. 5 illustrates the pretest and posttest score per semester.

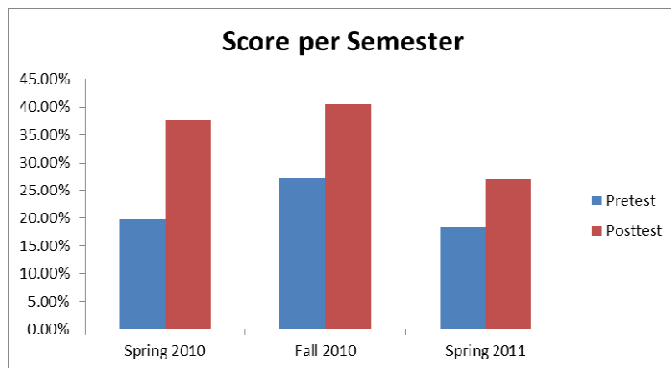


Figure 5. The pretest and posttest scores per semester.

VI. DISCUSSION

The Living Lab aligns with the mission of the CIT program by helping students to develop modern technological skills, effective oral and written communication skills, and the ability to perform well in teams. The program has produced experienced students who can function in the IT space with confidence. Buoyed by its success, and to continue to help prepare our networking students to meet the needs of today's employers, we have recently added a mandatory IT experience for all students in the entire CIT curricula. The Living Lab is one way to meet this requirement. Furthermore, we try to expose students as many different projects possible so that they can experience a variety of skills. Besides receiving many projects from other department or external organizations, we also focus on experiential services such as volunteering projects for churches, charities, etc. Along with the process, there are some challenges that we has faced.

A. Challenges

The Living Lab has faced several challenges over the years, primarily how to accommodate the numbers of interested students, and projects to work on, processes of taking project from initial to final stages, and assessing student work. To be effective, each student or student team must have at least one project that he or she can research, implement, and maintain each semester. Furthermore, Living Lab business hour in the lab for the students to do their work was also a problem. Since the labs and servers supported by the Living Lab are used almost nonstop during the week for CIT courses, business hours for the Living Lab had to be on Friday and Saturday from 9am to 5pm. However, this schedule is not always conducive for those students who work weekdays. In order to solve that problem, students work any other weekday or offsite in the evenings to complete their projects.

B. Assessment Evaluation

Living Lab successfully integrated the work environment into the academic environment. Rapid project completion inside of the Living Lab raises the need of student's learning assessment. It is necessary to perform an assessment on student's learning in order to determine whether students actually learn after completing the Living Lab. Using comparative means analyses, we found that there was a significant difference among the pretest and posttest scores. This can suggest that student's learning did increase after they completed the Living Lab. Surprisingly, as showed in Fig. 5, we could see a slight increase from Spring 2010 semester to Fall 2010 semester, and a significant decrease from Fall 2010 semester to Spring 2011 semester. This change is due to the number of students completing the Living Lab (see Table I). This result suggests that the more data collected, the more accurate the hypothesis test would be.

Because the pretest/posttest design includes only one group, there is a limitation in this study. Testing effect confound might affect the results since experience with previous test may change performance. It occurs when taking a pretest influences students' behavior on a posttest; for example, students would be more relaxed on the posttest because it is now a more familiar testing situation, or taking the pretest allows them to have practice with the particular types of items on the test. The design does not control for potentially confounding extraneous variables such as testing effect; so it is still difficult to identify the effect of the "Living Lab treatment" condition. Furthermore, this study lacks a comparison group. With no comparison group, we do not know whether any observed change in student's learning is due to the "Living Lab treatment" or to something else that may have happened during the time of the study. For example, maybe the students got a job while taking the course. Therefore, the students might have scored higher on the posttest regardless of whether they completed the Living Lab or not.

Further research requires a control group, thus minimizing confounds and ensuring the validity of this study. In addition, the skill assessment test can be re-edited in order to keep the

testing questions updated. A feedback system will be developed to collect the future success of students who took the Living Lab. With this information, we can evaluate how effective the Living Lab is in helping students acquire work. Despite the limitation, the data analysis revealed that student's learning increased significantly after they completed the Living Lab.

VII. FUTURE WORK

During the Living Lab development, we found several innovative ways to evolve the lab while taking into account the blending of processes, business practices, and academic rigor.

A. Project Management

In future work, we will implement a SharePoint server incorporating with Microsoft Project to manage the students' projects, documentation, research, and many more. This will be our main base of collecting and storing information. All the incoming project opportunities will also be managed through this server. Furthermore, all the communication between students and staffs or between students and their projects will happen through server services. Therefore, we will have a controllable and centralized system which helps to keep track of students' deliverables, work hours, documentation, etc. This will significantly enhance the Living Lab organization.

B. Assessment Process

In order to improve the assessment process, all the questions in the assessment test need to be revised and restructured. Because the assessment test will measure student's learning through Living Lab process, it needs to cover as many standard skills as possible. Despite that, the assessment can't be too long. Fig. 6 and 7 show an overview of the assessment test which we had used. Furthermore, because each student has a different skill set, it is hard to test him or her based on only one general test. Figure 8 show the new assessment test and includes two parts: general questions and project-based questions. The general questions include all the basic concepts of computer techniques, e.g., shortcut keys, simple command line, standard knowledge about computer information such as policy, network, computer process, etc. The project-based questions will include more specific knowledge of many different areas of IT. Depending on students' background, they will take a different part of the assessment test. As a result, the learning process of students with different majors can fully be assessed.

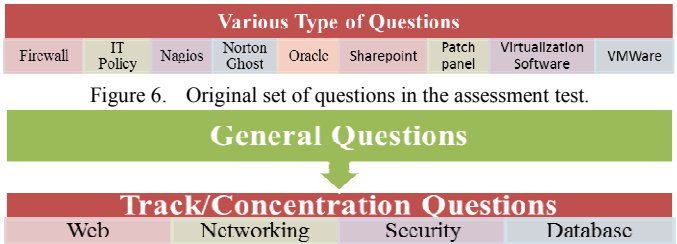


Figure 7. The 2nd generation of the assessment test.

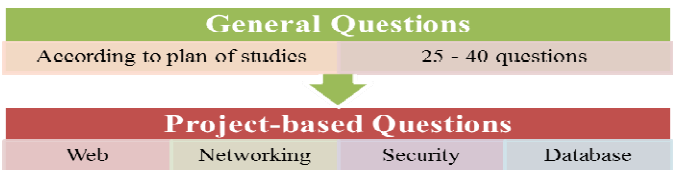


Figure 8. The future of assessment test.

The Living Lab process consists of two aspects, academic and business. The academic portion is based on course outcomes and is graded by a students' performance and final deliverables. The business side, is based on IT current and new project opportunities as well as grant and support. In order to maintain a balance between academic and business, a clear process needs to be defined. Figure 9 demonstrates the interaction among these components.

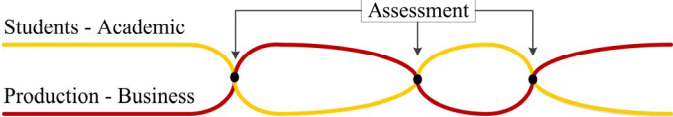


Figure 9. Living Lab streamline.

In conclusion, although the Living Lab is still a new concept, it successfully fulfills its mission. According to the student's learning assessment, the Living Lab significantly helps students improve their skills through the experiential learning process. Furthermore, feedback from the students who took the Living Lab is positive. With constant ongoing innovation, the Living Lab will continue to evolve. It is a very powerful tool of which every educational institution needs to take advantage. Not only does it equip students with knowledge and experience, but it also gives them a solid direction in the way of their professional quest. It is truly one of a kind. It is hoped that this analysis shows the value of the Living Lab, and encourages more institutions to adopt this course.

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Assessment of a Frugal, Virtual and Green Computing Lab Infrastructure of the Future

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Abstract—The impact of the computing field is becoming more profound everyday in all facets of modern society. Despite significant efforts from academia and relatively high demand for computing, technology producers are needed more than ever. This has been corroborated by a recent NSF Press Release [1], stating that computing is the only STEM discipline with more job openings than college graduates to fill them up. A major responsibility for such an outcome rests upon educators' ability to produce professionals capable of handling ever more complex technical challenges.

In this challenging environment, the importance of practical work in science and engineering, supported by lab exercises, is widely known. While it is desirable to create physical laboratories for teaching these technologies, it is not always possible nor desirable. In this paper, we present an effective alternative approach, in the form of an affordable, virtualized laboratory environment that can be used in a variety of computing and engineering courses, as well as in other fields, in lieu of physical labs.

Results of a survey supporting the validity of this approach are also presented. Students in four different classes were surveyed concerning the effectiveness and desirability of this virtual laboratory approach. The survey results indicate that student response to and interest in the virtual environment is very strong.

I. INTRODUCTION

Computer hardware and software continue to evolve into increasing levels of sophistication and maturity, which have allowed computing devices to gain a greater integration into many aspects of human society. Correspondingly, the role and importance of the computing disciplines have increased, with a similarly higher demand for technologically competent information technology professionals in the workforce. A major responsibility for the production of such capable professionals rests in the hands of the computing education community. It is notable that (as reported by NSF [1]) computing is the only discipline among Science, Technology, Engineering, and Mathematics (STEM) with more job openings than graduates.

For the computing educator, an additional complexity is to keep up with the rapid pace of change, advances and new developments in the field. Educators must be able to translate the complexities imposed by rapidly changing technologies into fundamentally sound and practically effective curricula, so that graduates are properly prepared to enter their professions. In other words, computing educators must frequently update curriculum to cope with the dynamics and developments.

These exacting circumstances require educators to be flexible, up-to-date, and able to offer their students practical

experience with continually changing computing technologies. The importance of practical work in science and engineering, supported by lab exercises, is widely known. While it is desirable to create physical laboratories for teaching these technologies, it is not always possible nor desirable. Cost, availability, and environmental effects of physical space represent constraints on building physical laboratories. Additionally, cost effectiveness is becoming increasingly more important, and purchasing a specific technology offers no guarantees that it will not soon become obsolete.

Due to the aforementioned dynamics, it is highly important that undergraduate students are exposed to practical experiences, such as relevant lab exercises [2], [3], [4], internships, and other avenues of practice. Recent advances in high-performance server architectures and virtualization technology allow us to not only avoid the pitfalls of building physical laboratories, but also to introduce significant developments to and expansions of the curriculum. Virtualization enables decoupling of applications, information, and provisioning of resources from the complexities of the physical assets of the computing laboratories. It can also be used to improve exercise repeatability, safety, and flexibility while reducing the overall cost and carbon footprint on the environment.

This paper presents a description of an affordable, virtualized and green laboratory environment that can be used in a variety of computing and engineering courses, as well as in other fields, in lieu of physical labs. This environment allows instructors and students to build more complex environments than are typically available in physical laboratories. The virtualized infrastructure is easier to administer, provides consistent and repeatable setup, and notably frees instructors from technical hurdles that often burden physical systems. To date, the environment has been used for courses in computer networking, operating systems, database, programming, and security, with plans in place for use in additional advanced computer science and information systems courses. In addition to its description, we also present examples of use cases from several classes. The advantages and disadvantages of the virtual approach are discussed, along with the possibilities of augmenting existing pedagogical approaches.

A validation of the approach, in terms of the results of student surveys from four different classes, is also presented. The survey results indicate that student response to and interest in the virtual environment are very strong. Students enjoy

the virtual lab environment and exercises, and in general they find that it presents realistic and practical exercises in a safe environment. Students also report that the exercises present a good value and are applicable to the real world. The virtual lab environment is regarded as safe, cost effective, and environmentally-conscious. It allows students to make mistakes without worrying about breaking anything or breaching security. A practical benefit is that one single server replaces hundreds of physical machines, with enormous power savings. Another benefit is manifest in increasing the quality of experience for distance learners to bridge the learning environment gap with in-class students.

The statistical analysis of survey results shows that the respondents clearly and overwhelmingly agree that the lab infrastructure is an effective tool for improving their learning experience. While the approach is not without its shortcomings, it appears to be very promising for adoption in a wide range of courses, including those outside of the computing and engineering curricula.

The rest of the paper is organized as follows: Section II presents related work. Section III presents technical details of the virtualized laboratory setup. Synopses of several labs we have offered using this infrastructure are given in Section IV. Section V provides a qualitative and quantitative assessment of the effectiveness of this approach. Finally, section VI presents conclusions and future directions for our work.

II. RELATED WORK

In academia, virtualization is mostly used in networking classes of computer science programs, as it naturally lends itself to the curricula of such classes. As we posit in this paper, virtualization shows great promise for other computing classes, as well as many engineering disciplines and other programs of study in which computing labs are inherently needed and used. Since the networking subfield dominates the virtualization literature, we primarily concentrate on this area in the following discussion.

The classic way of realizing networking labs is by means of physical infrastructure, and there are numerous examples in the literature. For example, [5], [6] briefly mention such a lab setup. Similarly, some high-level descriptions (with limited technical content) are presented in [7], as well as [8] and [9].

Tele-Lab [10], [11], [12] introduced a high-level abstraction, in which Linux-specific security labs were virtualized on top of User Mode Linux (UML) [13], [14]. The set of labs are restricted to Linux system administration tasks. Another set of labs specific to older network security techniques are mentioned in [15]. The approach in [16] focused on the fast reconfigurability of lab infrastructure that may be shared by many classes. Other limited networking labs are presented with brief descriptions in [17].

Network security labs can place the students in the role of attacker [18] or defender [19].

The alternative to the classic way of developing networking labs under a physical base is to develop them by means of *virtualization*, which has a rather large scope in terms of its

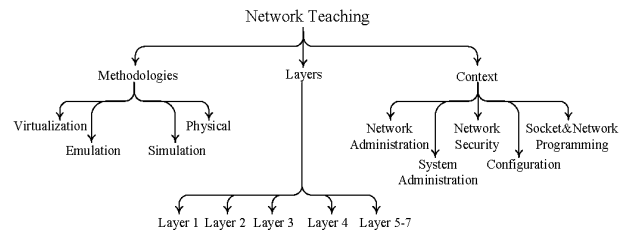


Fig. 1. A classification of teaching networking topics.

applicability and definition. In this project, by virtualization, we refer to the *full platform virtualization* that separates an operating system from the hardware resources underneath it.

Virtualization was first introduced by IBM in the early 1980s [20], [21]. The demise of mainframe computing and rise of peer-to-peer computing, followed by server-based virtualization, has prevented it from gaining much attention. Within the last decade or so, to reduce the cost of IT infrastructure, a centralized approach has gained a lot of attention and has become a useful technique for software testing, dynamic provisioning, real-time migration, high availability, and load balancing [22]. The benefits of virtualization are succinctly summarized in [23]: better security, higher reliability and availability, lower cost, improved adaptability to workload variations, more efficient load balancing, and the ability to run legacy applications in newer, incompatible platforms.

One of the first virtual network labs is presented in [24], which focused primarily on multimedia. The use of Microsoft Virtual PC virtualization for labs on application layer services is presented in [25]. The Open Network lab is introduced in [26] to study protocol performance issues rather than the more practical issues of network design, configuration and maintenance. Another conceptual approach to make use of virtualization is published in [27], where QEMU [28] is used as the underlying machine emulator and virtualizer.

A recent approach most closely related to ours is reported in [29]. However, the usage reported therein is limited to system administration and some security topics, even leaving out many important networking concepts such as layered protocols, programming, performance evaluation, etc., as shown in Figure 1. Further, the authors in [29] did not report any assessment of their environment. In contrast, we conducted an assessment study, presenting a statistically significant analysis of the validation of our environment. Furthermore, our philosophy intends to give a much broader focus to our virtualized lab infrastructure, to include other STEM disciplines, as well as other computational non-STEM disciplines.

III. TECHNICAL DETAILS

Our virtualized lab infrastructure consists of a Virtual Computing Environment (VCE) [30], using high-capacity servers capable of hosting many instances of virtual machines in software. We use VMware vSphere, ESX 4.1, vCenter Server, vMA (vSphere Management Assistant), and vCenter Lab Manager 4.0.2. The price of creating a physical machine used for virtual infrastructure was \$7,943.08 per server; each server has 8 cores, 128 GB of physical RAM, and 2.5 TB of physical disk

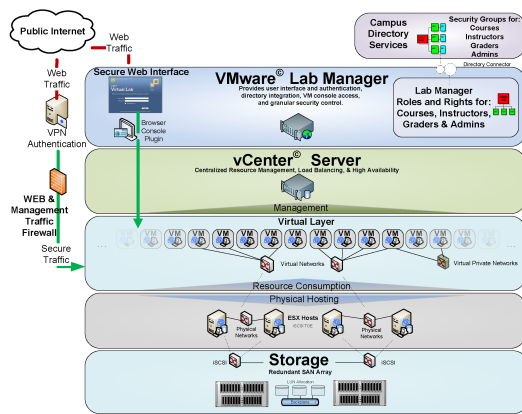


Fig. 2. A sketch of our virtualization infrastructure.



Fig. 3. Log into interface of virtualized infrastructure.

space configured in a RAID-10 array¹. The cost of VMware software through its Academic licensing is nominal. Figure 2 shows a high-level layout of our virtualized infrastructure setup. In the Fall semester of 2011, one of the servers was running about 250 student virtual machines simultaneously, eliminating a significant source of energy waste compared to an equivalent physical infrastructure.

A high-level description of the lab environment is as follows: students log into the host server through a web interface, as shown in Figure 3. This portal provides a management interface, as well as a console interface to let users create virtual machines from cookie-cutter style templates (as depicted in Figure 4) to significantly reduce deploying *sandbox*-style lab infrastructure for a variety of curricular topics. Labs are served for numerous courses in our department, with a current focus on networking classes in two separate programs (computer information systems and computer science). Additional labs have been hosted in operating systems, database, security, and distributed systems classes, and there are plans to integrate the virtual labs in system administration, parallel computing, and mobile computing classes.

IV. LAB SYNOPSIS

The Virtualized infrastructure is currently used in 6 different classes, involving a number of different lab exercises. Below,

¹Considering the ever decreasing per-unit costs of computing, the specific costs and configuration are simply presented to give an approximate idea.

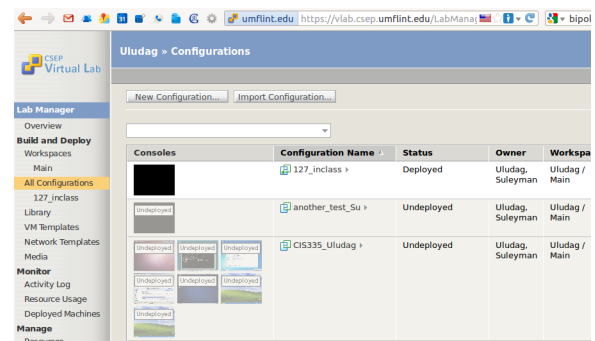


Fig. 4. Management Interface to create new machines.

we present general and concise descriptions (due to page limits) of representative lab exercises and the classes in which they are presented.

Computer Networks: There are four networking classes, including three undergraduate courses in computer science and information systems, as well as one graduate course. In these courses, students are required to configure linux and/or windows machines in a networked environment. Lab exercises require students to configure network hardware and software from the data link layer up to the application layer. Students begin by learning the basics of hardware and software configuration of network interfaces. They continue with exercises in routing, followed by transport-layer experiments. Application layer exercises include Network Address Translation (NAT), web server configuration, Domain Name System (DNS), and security.

Operating Systems: One particularly informative lab is related to kernel configuration and the creation of a new system call as a part of the kernel. System calls are an important early concept in the presentation of operating systems. They simultaneously illustrate several important OS concepts, as well as aspects of software engineering, such as the roles of encapsulation, the separation of interface and implementation, and the operating system's role in managing resources and abstracting the underlying architecture. As such, exercises involving system calls help to illustrate these concepts to the student. This particular lab exercise required the students to download and extract the source for a version of the Linux kernel, add a new system call to the kernel source, and compile and install the new kernel. On rebooting the virtual machine into the new kernel, the students are able to write a small test program that calls the system call and to observe the effects by examining the kernel's ring buffer using the `dmesg` utility program.

V. ASSESSMENT

Table I presents the questions that were asked in the surveys. We have given these questions to all the students in 4 classes: CIS335 (Telecommunication and Computer Networks), CSC336 (Computer Networks II), CSC377 (Operating Systems), and CSC535 (Advanced Computer Networking). The number of students were 22, 14, 18, and 24, respectively,

TABLE I
QUESTIONS OF THE SURVEY

| | |
|----|--|
| 1 | The virtualization infrastructure enabled me to relate some concepts of the course with a realistic and remotely accessible setting |
| 2 | Labs on the virtualization infrastructure helped me to go beyond class discussions and readings to gain practical experience. |
| 3 | Labs on the virtualization infrastructure provided me a safe and secure environment for a variety of experiments |
| 4 | The virtualization infrastructure has more potential to reinforce fundamental course concepts and relate the theoretical topics to a real-world product, if more similar labs are developed and if the lab is more intensely incorporated into the curriculum. |
| 5 | Virtual labs enabled me to have anytime, anyplace individual access with only an Internet connection and a browser. |
| 6 | Virtual labs enabled me to build experience without risking damage to the equipment or infrastructure. |
| 7 | As a result of the Virtual labs, I am more comfortable about approaching course technologies and utilizing them in my professional career and personal life. |
| 8 | Labs on the virtualization infrastructure provided me an opportunity for hands-on experience with several computing technologies. |
| 9 | Virtual labs helped me see how the theoretical principles apply to practical applications. |
| 10 | Virtual labs enhanced the value of this course. |
| 11 | Virtual labs provided me a rich and compelling interaction with realistic technology. |
| 12 | Virtual labs have helped me achieve mastery on custom application(s) or on specific IT skills |
| 13 | I would love to have more time spent on Virtual lab exercises as part of the course |
| 14 | Virtual labs helped me save costs associated with travel, administration and other purchases for a physical lab. |
| 15 | I believe virtualization-based laboratory experiences contributed to my knowledge retention. |
| 16 | I would love to do a project or extended lab on the virtualization infrastructure. |

giving a good statistical significance to our analysis below².

A categorization of the questions in terms of their general areas of assessment is shown in Figure 5. The six major

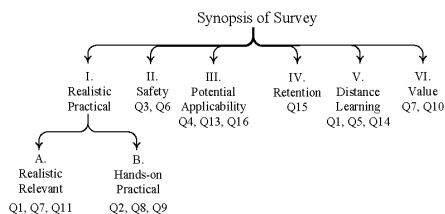


Fig. 5. Categorization of the end-of-term Survey questions.

categories are those addressing whether the labs represented realistic/practical applications, how well they ensured safety, the applicability of the exercises to their career, whether they addressed student retention, how compatible they were with distance learning, and their overall value. In terms of the *realistic* questions, they were also sub-categorized into whether the exercises were relevant to students' career, as well

²The questions related to course content were slightly modified for the operating systems course.

as how practical the exercises were³.

A. Quantitative Analysis

Figure 6a shows the aggregate percentages of students who have responded favorably (Strongly Agree and Agree in the Likert Scale) to the survey questions for each category (see Figure 5 for the classification) for the four courses. On the other hand, Figure 6b plots the the percentages of the students who have not been completely satisfied with the virtualization infrastructure. The results of these two graphs clearly indicate the overwhelming positive reaction of the students across these courses. In particular, they show that the number of students overall who agree to strongly agree is above 70% across all courses, while the number of students who found little value in the exercises is nearly universally a small minority, below 10%. In particular, students in one of our networking courses found high value in the exercises, often in 100% agreement with the questions in categories related to safety, applicability, and retention. These graphs illustrate that there were strong opinions either way on the part of the students, with relatively fewer neutral responses. Moreover, they show that the number of actual negative responses was in fact in a tiny minority.

From another perspective, a plot for a measure of dispersion in terms of an error plot is provided in Figure 6c. The y-axis is the quantized values of the Likert Scale responses, i.e. Strongly Agree = 2, Agree = 1, etc. A low variation of the results is obvious, which are concentrated in high positive averages.

Another statistical analysis of the results is provided in Figures 7a-f as aggregated pie charts of all categories for all courses combined. Pie charts depict the pattern of the student responses that indicate that majority of the students perceive the infrastructure positively.

Finally, Figures 8a-d show the individual course assessment results in terms of the absolute responses, rather than percentages as in the previous plots.

As can be seen from the Figures 6-8, despite the different dicing and slicing of the data from multiple perspectives, the results are consistent, clearly concluding that the students overwhelmingly approve the efficacy of the virtualized infrastructure.

B. Qualitative Analysis

The quantitative analyses presented above support the assertion that students like the environment and they believe it is helpful. There is also a qualitative analysis to present, as we have found that the approach of using a virtualized environment has advantages and disadvantages that are not completely revealed by the numerical results. Some of the advantages have already been highlighted, but we reiterate all of them here. One primary advantage may be in cost savings of various sorts. Use of a virtual environment requires the purchase and maintenance of a small number of server machines, with no need for administrative walk-up (i.e., physical

³Question 12 was omitted from the categorization as it did not fit into any of the other ones and we realized during the analysis that it was too strongly worded, i.e. *mastery on custom applications*.

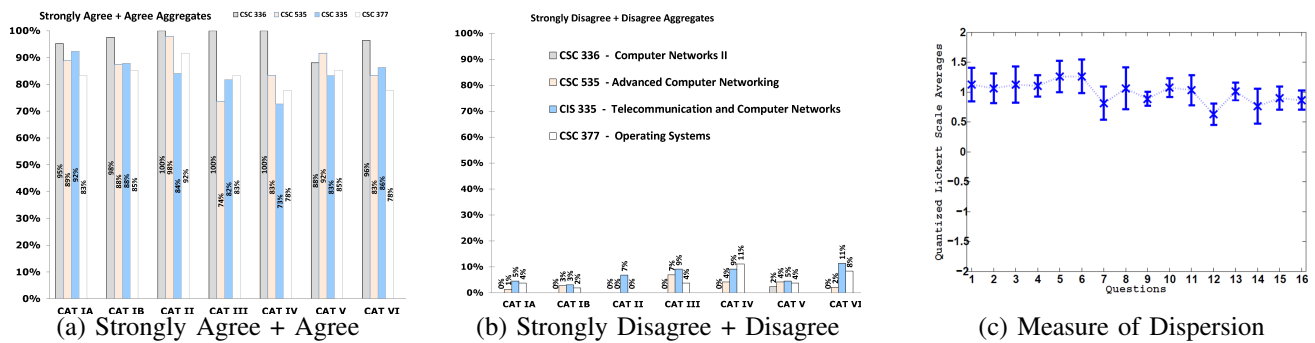


Fig. 6. Aggregate histograms and error plots of the assessment results for all four courses.

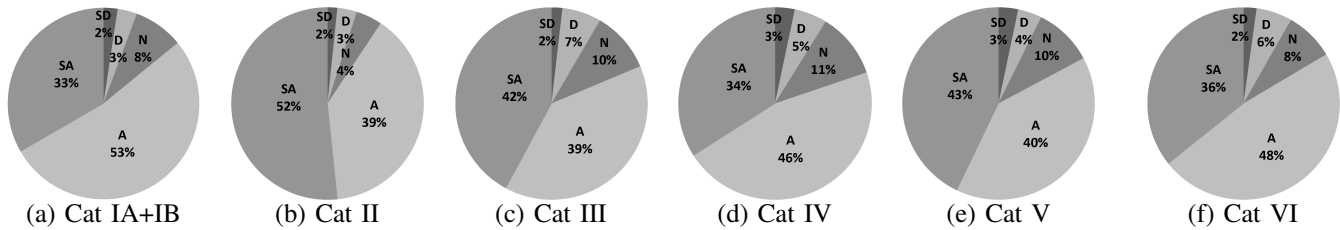


Fig. 7. Pie Charts of the assessment data for all four courses combined in terms of the aggregate percentages for the categories.

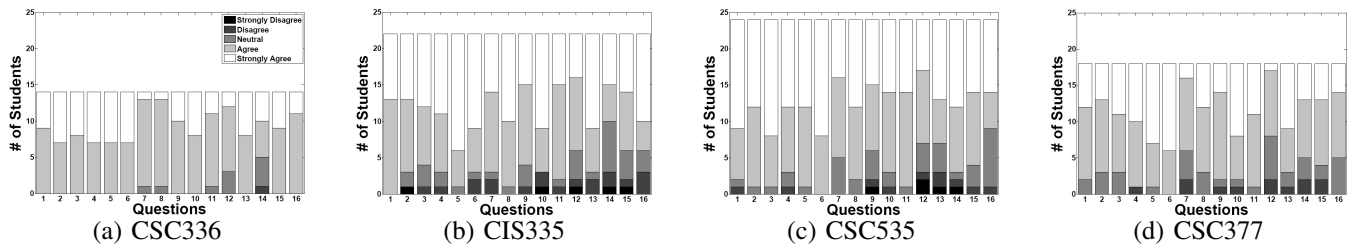


Fig. 8. Individual plots of the four courses in terms of the absolute value of respondents. Note that the legend given in (a) is applicable to all.

maintenance of laboratory PCs, switches, wires, etc.), ease of configuration, provisioning and de-provisioning through virtual machine software, and repeatability due to the ability to save correctly configured environments as images within the virtual machine software. Another cost savings is related to the fact that students may create as many copies of machines as required by their labs. For example, if a student happens to need 5-10 machines, then he/she can create them quickly in the VLAB, and just as quickly, they can be removed.

Another primary advantage is safety, due to the fact that these machines are created within a virtual *sandbox* environment. Indeed, the environment is shielded from the greater Internet by our university network, which filters access in a highly controlled fashion. Furthermore, the machines themselves can be configured in virtual networks such that they never have access to the outside Internet.

Flexibility is another fundamental advantage. As long as we have images of various operating systems available on the primary server, we are able to create as many variants of different configurations as we need. Our system is currently configured to support about 15 versions of Linux and about 7 versions of Microsoft Windows. Images for different classes can be pre-configured for the computational environment needed, so that students can jump right into the actual exercises without any hassle.

As we have also mentioned, this environment is highly compatible with online education. The VLAB interface is presented through a web page, and students may access it via any computer on the Internet, as long as it has the correct software installed as plugins in its browser.

Another side benefit of this approach is that it introduces our students to virtualization software. Although this is not a concept widely taught in our curriculum, it is a highly practical technology that is growing in its usage in the IT field.

A primary disadvantage of this environment is the fact that it is not 100% hands-on. For example, one exercise we have employed in our physical labs involves students manufacturing, testing, and measuring CAT-5 Ethernet cables. In the VLAB environment, it is impossible to create virtual *build a cable* exercises; nothing in this environment is an adequate substitute for the physical process of stripping CAT-5 cables, aligning the wires, crimping the RJ-45 ends, etc.

Another disadvantage is as alluded to in a preceding paragraph. We have found that the virtual software only supports a limited subset of web browsers, although we will consider three commonly used browsers: Firefox, Internet Explorer, and Chrome. Firefox must be confined to a relatively out-of-date (and soon to be obsoleted) version in order to support the plugin required to deliver the X-windows console of virtual machines through the web browser. Internet Explorer works,

but there are issues with configuring it to run in some versions of MS Windows. Chrome is simply not supported. Related to this, the browser plugin introduces a latency over and above network latency in the interactions. Consequently, students accessing their virtual machines from across the network must be patient.

VI. CONCLUSION AND FUTURE WORK

The relevance and importance of computing is likely to remain high, or even to increase in the future. Yet, diffusion of best practices for teaching computing courses seems to be taking longer than the demand emanating from industry. To reduce the gap between the demand for qualified computing degree graduates and its supply, or at least prevent further deterioration, innovative and effective best practices of educational approaches need to be devised. One such approach is briefly outlined in this paper to draw attention to the affordable and easy, yet very promising, method of delivering and complementing computing courses by means of a virtualized infrastructure. Our methodology seems to be equally beneficial and applicable to a wide variety of computing, engineering and other curricula where computing labs are used. The adoption of our virtualized infrastructure by faculty teaching a variety of courses is underway in our department. We have also provided a formal and rigorous evaluation of the efficacy of our approach with a clear conclusion that students overwhelmingly support and benefit from the infrastructure. A description of technical details in a *how-to* type document is a future work to facilitate easier dissemination and replication of our infrastructure for universities.

As for other future work, here are some ideas we are planning to work on: we have not yet examined some more direct assessment related to other manifestations of effectiveness of the virtual lab. In the future, we wish to explore the effects of the VLAB environment on our students' grades. With the premise that experiential learning will improve various aspects of the student experience, but most importantly, their knowledge retention and ability to apply the knowledge, we intend in the future to explore how well the VLAB facility correlates with student performance.

Another avenue of future work is to examine the effectiveness of this environment for use in a variety of other computing courses, which are adopting the infrastructure now. Our campus has historically been a commuter campus, and although we are growing our on-campus student population, it is true that the number and variety of online courses is also growing on our campus. There is a desire to explore offering a greater variety of online courses. It will be interesting to expand the assessment to include these other online and traditional in-class courses.

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Special Session: Race and the Idea of Privilege in the Engineering Classroom

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Abstract—White privilege is an important concept when considering issues such as social justice, the internal “culture” of engineering education and systematic change in engineering education. However, it is not well understood by most engineering educators. This Special Session will help participants explore the idea of White Privilege within the context of engineering education. Through an interactive format, participants will learn some theory and develop some ideas for addressing White Privilege in engineering learning environments. The related idea of stereotype threat will also be discussed.

Keywords—White Privilege; underrepresented minorities; social justice; engineering culture; stereotype threat

I. SESSION GOALS

Participants will leave this session with

- a working definition of White Privilege.
- at least one idea of how to address White Privilege in the engineering learning environment.
- a more complete understanding of stereotype threat in engineering education

II. SESSION DESCRIPTION

Sociologist Michael Kimmel [1] uses the metaphor of wind to describe the subtlety of privilege. If you are walking into the wind, the force of the wind holds you back, it makes you walk more slowly, you squint your eyes; it can be chilly. By contrast, if the wind is constantly at your back, you hardly notice it. It puts a lift in your step, you walk seemingly effortlessly, you reach your destinations more quickly; no force holds you back.

In engineering, to be White and male is to have the wind at one's back; such a person does not have to think much about the natural forces that sustain and allow him to feel comfortable with relative ease. A White male can make mistakes without people attributing it to his race or gender. He can ask questions

or draw attention to himself without worrying if people will make judgments about him based on race or gender. When with other engineers, he can easily find many others who look similar to him. His speech and accent, the jokes he tells, the food he eats, and his social habits seem normal. People do not question his academic abilities on a regular basis, or wonder if he is an “affirmative action” token. A white male can move along fluidly through engineering education as his race and gender seem invisible.

The purpose of this special session's activities were to help the participants gain a better understanding of how White Privilege shapes the experiences of our engineering students and of engineering faculty. In addition, participants left with more strategies to manage White Privilege in the engineering learning environment.

III. SESSION AGENDA

The session organization was as follows:

- **Introduction and Goals** (10 minutes)
- **Kites of Inequality** (15 minutes)
 - Each group is given materials to make a simple object such as a kite. The participants do not know that the materials are stratified so some groups have abundant materials while others have increasingly fewer supplies.
 - After 10 minutes, the groups with the most resources present their work first, followed by the other groups.

This work was supported in part by a collaborative grant from the National Science Foundation (NSF) Gender in Science and Engineering Research (GSE-RES) program (0734085 & 0734062). The opinions expressed in this work are those of the authors and do not necessarily reflect the views of NSF.

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- (15 minutes) **Discussion/Debriefing of Kites of Inequality Activity**

- After all groups have presented, we facilitated a discussion. Someone will likely point out that groups seemed to have varying amounts of materials. The impoverished groups are usually the most vocal, describing it as “unfair” and that they were keenly aware that they did not have enough to complete the project easily. By contrast, groups with the most supplies will likely describe that they did not realize their abundance.
- The goal of the activity is to have participants understand stratification, recognize how privilege operates, understand the effect of low resources on students in our educational system, and identify how power operates “invisibly”. By inhabiting a space of discomfort and frustration, participants begin to understand how marginalization feels. The “rich” participants reflect on how they were unaffected by others’ problems, because they were absorbed in their task.

- **Read White Privilege: Unpacking the Invisible Knapsack by Peggy McIntosh [2] (10 minutes)**

- **Develop White Privilege Strategy Posters (15 minutes)**

In small groups, participants discussed *Unpacking the Invisible Knapsack*. The presenters provided a set of discussion questions and materials for presenting responses. Participants were asked to provide

- examples of how White Privilege manifests itself in engineering education.
- strategies for how to manage White Privilege in engineering education.

- (10 minutes) **Mini Poster Session – Report Out**
Participants will move around the room to learn strategies developed by other groups.

- (15 minutes) **Wrap Up and Next Steps**

- The facilitators provided a list of strategies that were covered depending on what ideas the participants presented.
- The facilitators introduced the related concept of stereotype threat in engineering, along with strategies to address it. “Stereotype Threat” is the experience of heightened anxiety in a situation where a person has the potential to

conform to a negative stereotype about their social group (e.g. race, gender) [3-4].

- The facilitators provided a list of relevant literature
- Contact List, Evaluations and Brainstorm Cards for next steps were circulated.

IV. ANTICIPATED AUDIENCE

The expected audience for this session is engineering educators who are interested in exploring more deeply the implications of their own privilege on their teaching.

V. EXPECTED OUTCOMES

We hope that this session will begin a dialog in the engineering education community about the issues raised. Specifically, we hope to see presentations at future FIE conferences related to White Privilege. White Privilege is an important concept when considering issues such as social justice, the internal “culture” of engineering education and systematic change in engineering education.

VI. SPECIAL SESSION JUSTIFICATION

To our knowledge, there has never been a session at FIE addressing the issue of White Privilege. Given that the majority of engineering educators are White and that there is a desire to increase the racial diversity of engineering students and educators, it seems imperative that those in the majority learn more about themselves and how they can make a difference. This topic is difficult to address in a non-interactive setting. Thus a special session format provides a preferred venue for exploring White Privilege in engineering education.

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Understandings of Value in Engineering Practice

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Abstract— This paper draws on a large body of empirical data from interviews and field observations to suggest that many engineers, even some professional organizations, have difficulty explaining the commercial value of engineering work. This difficulty could contribute to a public and employer perception that marginalizes the significance of engineering work. Research data came from qualitative interviews with engineers in Australia and other material. Data from individual engineers and other studies contributes to a description that educators and engineers could draw on to better explain the value of engineering to students, firms and the community at large. This paper presents a limited sample of the evidence behind this research.

Keywords- *Engineering practice; engineering education; community perceptions of engineers*

I. WHY WOULD A FIRM EMPLOY AN ENGINEER?

What value can an engineer contribute? These are important questions, yet there are few if any useful answers in the literature of engineering education that would help engineering graduates respond quickly with a meaningful reply. The concept of value itself has many different meanings. Looking at economic benefits for different stakeholders is just one of many possible avenues to explore the value that can emerge from engineering.

Why is this discussion important?

First, it raises issues lying at the core of shared identity in the engineering community and the profession. Historical studies have shown how the value of engineering has been articulated at the societal level in terms of building the nation state, maintaining military strength, or advancing industrial competitiveness.[e.g. 1] However, this literature requires careful study for a reader to be able to explain the value of engineering in meaningful terms at the level of a single firm or small engineering enterprise.

Second, young professionals who can easily explain the relevance and value of their work in their community are much more likely to feel respected and valued. There are many indicators that expose continuing concerns among engineers at the relatively esteem in which they are held in comparison to other professions such as law and medicine. The lack of community understanding about engineering can be linked with the lack of discussion on this topic within the engineering community itself, and campaigns to reassert a public image for engineers. A large survey of ASCE members in 2006 revealed a widespread perception that they were undervalued, wanted more respect from the public, and more opportunities to lead project teams [2]. There have been calls for more public awareness in the several countries [3, 4].

Notwithstanding efforts across the professions to raise the profile of engineering, a brief survey of the public advocacy sections of ASCE, ASME, IEEE and EA web sites at the time of writing revealed neither a useful description of engineering nor its social or economic value. None described engineering work. Most emphasized creating new technologies, particularly IEEE and ASME who prominently displayed an iPad on its technology and society page. ASCE emphasized building water and power systems, for which a literal interpretation would be misleading because engineers seldom build anything themselves.

Third, research on engineering practice has revealed many instances in which engineers have had difficulties in understanding the relative priority of different aspects of their practice because they have limited understanding about the value created by their work. This leads to frustration, delays and added costs. The CEO of a large engineering enterprise expressed his frustration in these words:

"Our engineers don't understand the business imperative of this organization. They simply don't get it and it frustrates me immensely."

Similar frustrations from a different viewpoint have emerged from engineers in our research and other studies. Several have alluded to non-engineers in senior management with a limited understanding of engineering issues, for example

"This company is run by f---ing accountants! They just don't understand even the simplest ideas in engineering."

This study has revealed that while engineers have a solid understanding that their work contributes great value, this understanding is not easily articulated. Many engineers seem to have rather simplistic ideas about the economic value that their work creates, possibly placing them at a relative disadvantage in the contemporary post-industrial world of work. A recent US-based qualitative study revealed engineering students' notions of engineering in which economic considerations are not core to engineering as such, although they are key considerations in the working world [5].

The first half of the 20th century perhaps represented a golden era for engineers in the industrialized world. They were regarded as public heroes, providing great advances in material living standards. In the 21st century, engineering is taken for granted and has receded from the public eye. An ordinary person in the industrialized world today can switch on a light, turn a tap, or start a car without any concern that the electricity, water supply will not be functioning, or that the car won't start. The value of engineering, therefore, is much less apparent.

II. ENGINEERING VALUE IS MORE CONSPICUOUS WHEN IT IS ABSENT

The backstreets of South Asian cities provide an opportunity to appreciate the real significance and social value of effective engineering because it is conspicuously absent. We take good engineering for granted in Australia where potable water is piped 24 hours a day to kitchen and bathroom taps and usually costs less than US\$2 per tonne including connection charges. In most South Asian cities, water flows from pipes for an hour or so every other day and it is almost certainly unsafe to drink. Potable water has to be prepared or often carried by women, with the result that the real economic cost is many times higher than in Australia *in equivalent currency terms per ton*. A copious amount of potable water for a house and garden in Australia costs only about 1% of a family income. Obtaining and preparing a minimal 10 liters daily per person can be represent 20–40% of an average family household's economic capacity in Pakistan [6, 7]. For locals, most of these costs are invisible: there is no charge for water from public purification plants and women's labor is regarded as a free household commodity. Indeed, the notion that basic goods could be far cheaper in a wealthy country seems beyond comprehension. The cost of other services that rely on engineering (such as electricity supply and construction), taking into account total costs and comparable end-user service quality, were also much higher than in Australia, though the difference was not as great as for potable water which is heavy to transport.

For people in an industrialized country, many of whom have experienced low cost back packer holidays in the developing world, the notion that essential services they take for granted at home could be so much more expensive for people who have to live there also seems counter-intuitive.

Here is a startling illustration of the economic and social value of a reliable city water supply system providing potable water at high pressure 24 hours per day. Water supply utilities are large engineering enterprises. When they work well, engineering enterprises provide the products and services needed to maintain a civilized society at much reduced cost in terms of human effort and material resources. In other words engineers provide the means to achieve high levels of productivity. This frees up economic resources for all the other human activities that support a civilized society: law enforcement and security, justice, good governance, education, health care, and social services.

I had practiced and taught engineering for more than two decades, and until then I had never questioned the social and economic benefits of engineering. It was only when confronted by the absence of effective engineering that I began to understand the real value that it contributes to a society.

I was employing engineers in Pakistan and I became aware that I had to completely recalibrate my expectations for engineers' performance there, compared with my experience in Australia. I hypothesized that differences between Australian and Pakistan engineering practice might be a significant contributing factor. The near complete absence of research on engineering practice [8, 9] exposed the need for research to establish a body of evidence on practice in Australia and developing countries in order to test this hypothesis [10-12].

The research consisted of a series of mostly qualitative studies on engineering practice in Australia and South Asia informed by a combination of interviews, field studies and research visits.

III. STUDIES ON THE WORK OF ENGINEERS

In the 1970s and 1980s there were studies of engineers using the job analysis method revealing survey data showing, for example, that engineers spent about 60% of their time interacting with other people [13]. Several later studies of engineers explored social relationships between engineers and the wider structures of industrialized societies [e.g. 14, 15]. The rapid economic ascent of Japan relative to other industrialized countries during the 1980s motivated a series of comparative studies [e.g. 16, 17]. Sociologists interested in the details of daily practice have described many difficulties in studying engineers, such as technical jargon and the intellectual nature of critical aspects of the work which cannot be directly observed [18]. Most studies have been written for science, technology and society specialists (STS) and few are easily accessible for engineers or their educators, our primary constituencies. While these studies have contributed to our understanding of engineering practice, our knowledge of technical occupations remains tenuous and it is only recently that a comprehensive understanding of engineering practice with validity in a wide range of disciplines and settings has begun to emerge [e.g. 10].

Research literature on the social and economic value of engineering is even scarcer. A survey of introductory texts and engineering education research literature has exposed the near complete absence of any explanations that could be useful for students [19].

Recent research to build a comprehensive understanding of engineering practice has relied on observations of engineers in their workplaces [e.g. 10, 20-23]. Data from these observations could yield valuable insights on how engineers perceive the value of their work.

IV. RESEARCH METHOD

Qualitative research contributes rich data for an exploratory study of the ways in which people think about ideas. This approach has yielded valuable insights from systematic investigations of engineering practice. This study draws on evidence collected for earlier studies of engineering practice {Trevelyan, 2010 #1045}. Semi-structured interviews with a total of 120 practicing engineers in Australia lasting 90-120 minutes explored their careers, most aspects of their current work, and perceptions related to job challenges and achievement satisfaction. Some interviews included questions on dishonest behavior (of others), checking, and mistakes. In some instances, circumstances required small focus group discussions with up to three participants instead of interviews. Transcripts were prepared from recordings (with participants' consent) or notes (checked by participants). Several students contributed interview data using the same protocol with minor variations to suit their research on slightly different aspects of practice. Some also contributed field study data to triangulate the interviews. Training, joint interviews, and reviews of the recordings and transcripts helped ensure consistent data.

The sampling was partly opportunistic and partly purposeful for maximum variation to include engineers in all major disciplines, experience levels, and types of business (except defense). 6% were female and most had engineering degree qualifications.

Analysis followed standard ethnographic analysis techniques and also drew on the author's extensive first-hand experience of practice. Some recently published accounts from other research teams also helped triangulate data.

Instances of the word "value" and "benefit" in transcripts and field notes yielded a variety of perceptions that engineers have relating to value in engineering. This paper only presents a limited selection of the evidence analyzed for the research leading to this paper.

V. FINDINGS

Value can be a confusing idea, especially for engineers, even more for non-engineers listening in to an engineering conversation.

Many engineers use the word most often to refer to a number, the particular value of a variable quantity. Often the number represents an amount of money, for example 'dollar value' that might represent the total amount of money needed to purchase a machine.

Occasionally engineers referred to 'values' in the sense of personal integrity and honesty. This too can be confusing as many organizations now promote their 'values', building on the work of identity economists [24], because people whose identity aligns better with organizational values are more likely to display higher levels of motivation and loyalty.

Engineers often used the words 'value' and 'benefit' interchangeably to describe positive learning experiences for themselves or colleagues. Here a young engineer talks about the need to seek help from more experienced engineers:

"You can ask the most stupidest question it doesn't matter.. cause at the end of the day you are the one who is going to benefit from it...it is always good to stop and ask questions"

He has used the notion of 'value' or 'benefit' to refer to the personal acquisition of knowledge. Several engineers connected the word 'value' with detailed technical knowledge or information, or greater certainty, and in these cases the word 'benefit' was not used at all. Here is a process engineer talking about the earliest stages of engineering design:

"And then you move through to say a pre-feasibility, where you do a bit more engineering, solving some of the issues, defining some of the ideas and concepts and adding a bit more value to that number."

Here we see the word 'value' being used in association with 'number' but with an entirely different meaning from the notion of a number as a particular 'value' of a variable quantity. Here 'adding a bit more value' refers to the reduction of uncertainty in a number that represents an estimated technical quantity, in this instance the production capacity of a process plant. Engineers work with ever-present uncertainty from natural causes, the limitations of engineering science in predicting behavior of artifacts, and from the uncertainties of

human behavior. Reducing uncertainty, 'controlling risk' is a deep-seated value for engineers, as we shall see later. Safety, or the ability to reduce the chance of events that can cause harm to people, is also part of this engineers' concept of value, as the next quotation from a mechanical services engineer illustrates

"Ensuring that you select the appropriate equipment and appropriate way to develop the project that maximizes the value. It's safe and is efficient and conforms with ... (pause) ... engineering practice."

Although all engineers were asked to comment on discussions with clients or project sponsors, only three out of around 100 interviewed for earlier studies mentioned the idea of value in this context. All of these were the most senior engineers in their divisions of their firms. A senior software engineer talked about his difficulties in keeping design focused on the appropriate requirements:

"We have to make sure that the client's people understand how our systems will help them in their business. It's so easy for their ideas and ours to diverge, for our people to lose track of their needs and you end up with a system that produces little real value for the client. It's a constant struggle."

His understanding of value, in contrast to nearly all the other engineers, was firmly based in terms of the way the software behaved to produce economic value for the client.

One of the engineers who mentioned value in the economic sense identified that reducing uncertainty, usually described in terms of 'risk', was important in their work. This engineer linked 'value' with 'driver' to convey the notion of an important aspect for the economic performance of the project:

"One of the key drivers for the project – value drivers – was reliability."

In this particular project, failures would lead to extremely expensive production interruptions, both because of the cost of purchasing product from competitors to meet contracted customer delivery schedules, and the high cost of repairs to the equipment. This was translated into a need for high reliability from engineered systems being created by the project team.

The realization that describing the value that arises for their work could be a challenging task for many engineers led to two focused studies in a variety of firms. Twelve engineers described the relevance of business-related aspects of their work, including the economic value they create through their work. All found this issue difficult when it came to expressing it in words.

Two focus group discussions with five engineers in a technical consultancy revealed the difficulties that most engineers have with expressing notions of economic value emerging from their engineering work. When asked how they would describe what engineers actually do, one paused with a puzzled frown for several seconds, and then, when prompted that it might have something to do with "problem solving" that was a prominent feature of a company advertising poster displayed in the meeting room, he said:

"Yes, problem-solving, analysis... analyze systems... to make

things better, to make things more efficient."

When asked about the value created by the work they performed, there was another long pause. Finally, another engineer hesitantly said:

"Well, I guess the thing that the client wants most is the results so the value of my work is getting the results from out in the field."

Some of the engineers offered long-winded explanations that ended up at the same point: ultimately the client pays for a report or data. That, they said, would explain the value that emerged from their work.

The second study involved interviews with seven engineers at different firms, this time with more emphasis on business-related aspects of practice. Participants were asked about several aspects of commercial practice including value, negotiations and how they learned about business issues. Three of the participants had studied commerce in addition to their technical engineering degree course. All had difficulty expressing how commercial value emerged from their work. This chemical engineer firmly switched the focus on value back to technical certainty:

"For me, I don't really see value as a massive buzz word. I think there are better words. The word we always focus on is quality, which is basically how well you are able to deliver or exceed what someone is expecting of you."

Others mostly expressed commercial value only in terms of direct costs or time, or in achieving the project objectives without further elaboration. For example a graduate engineer with a few months of experience described value creation in these terms:

"It's making sure that the company does what it wants to do in the budgeted time and the budgeted amount of money, and ensuring that the skill set that I bring ensures that happens."

They also closely connected achieving objectives with 'enhancing shareholder wealth.' They also connected value with safety, a primary concern due to the high risks associated with their work, as seen in the following comments made by an oil field engineer (after the Macondo disaster in the Gulf of Mexico).

"Higher value is when you deliver something that's timely, it's what they wanted and it's been done without any safety problem or anything like this. I guess for me, in my job, the most important thing for me is safety. We work in an industry where there's a lot of potential for things to go wrong."

In discussing the concept of value, only one of the seven engineers in this second focused study specifically identified risk as a factor, a maintenance engineer with four years experience:

"What does the company stand for? It's adding value to the shareholder. I see that as two things: a finance return, i.e. making more money, or a reduction in risk because, if you think about it, all investors have a particular risk profile,

right? So if you can continue to reduce the risk that a shareholder has, whilst keeping the same rate of return, then obviously that's more attractive to more people."

He later confirmed that his understanding of risk and return in relation to investor preferences had been developed through his commerce studies. None of the other engineers with a commerce background made this connection.

In the earlier phase of the study before the focus on business aspects, only the most senior engineers had been able to connect technical work with creating value for clients. One cited an extensive design study for a mine in a pristine tropical location:

"I had to review the work done in the previous year. They had spent tens of millions on engineering, but they had added no value because they had not dealt with any of the ten showstoppers: risks that could cause a major release into the environment, mostly from flood events."

This engineer has directly connected the elimination of risks with increasing the project value for the client who was still seeking finance to implement the project. Yet the engineers working on the project seem not to have understood the link between the need to eliminate major risk factors and the availability of finance to develop the project.

VI. DISCUSSION AND LIMITATIONS

The data reveals that the notion of 'value' posed evident difficulties for the engineers interviewed in this research because of the number of different meanings that appeared in different contexts. These included the value of a variable, namely a precisely defined number, a notion of technical quality, an attribute of technical investigations that helped to clarify an appropriate choice from several different options, reduction of uncertainty, a personal attribute such as integrity, even an attribute that denoted useful learning from a personal experience. This last association was the main one that engineers associate with 'benefits'. Among these, the ultimate value of engineering work for a client or end-user is remote from the day-to-day considerations for most engineers: for most this value is associated with direct cost savings such as reducing the energy needed for a process, or the amount of labour needed, or simply achieving stated objectives. While most engineers see the reduction of uncertainty, usually conceived as the notion of risk, hazards, or threats to human safety, as a useful end in itself, only a few connect this idea with increasing the apparent value for an investor, client or end-user. Studying commerce can help engineers to see this connection, but does not seem to make it obvious. Even the entirely technical links between levels of uncertainty, design safety factors, and additional material weight and cost never emerged in interviews with engineers.

Another illustration that complements the data analysis came from an unexpected source. Engineers Australia are revising statements of competency [25] used to evaluate whether young engineers are ready to be admitted to chartered engineer status, the capacity for independent, unsupervised practice. Engineers Australia have used competency standards for this assessment since the 1990s. A near final draft released

for public comment in February 2012 after extensive consultation devoted an entire section to “creating value” in terms of advanced engineering knowledge – applying advanced theory-based understanding of engineering fundamentals, applying local engineering knowledge, investigating and analysing engineering problems, developing creative and innovative solutions, and evaluating the outcomes of engineering activities. While one of the suggested indicators that an engineer could use to demonstrate attainment of these competencies was “develop and apply new and emerging technologies, engineering applications and systems to create value for customer” the analysis presented earlier in this paper demonstrates that engineers are likely to interpret ‘value’ in this context in terms of technical quality rather than economic value.

As suggested in the introduction, a better understanding of economic and social value created by engineering work could help resolve several issues currently facing professional engineers.

Engineers enjoy a great deal of autonomy in their work. At the same time, engineers are often faced with open-ended tasks such as risk assessment and fault tree analysis that can never be fully explored in the time available. Engineers need to judge how far to pursue these investigations. Expectancy value theory [26] in its simplest form explains how choices to engage in activities are shaped by competency and value beliefs. In other words, engineers who perceive value in terms of technical quality and precision are likely to engage their technical competency in pursuit of quality and precision. This was observed by an engineering manager describing the difficulties of a project that was well behind schedule:

“the engineers were too involved in the design, the paper system, where the endgame is a railway product which has to be delivered”

An equally potent illustration arose from two studies on design checking and review in separate firms with demanding quality assurance regimes [e.g. 27]. The engineers regarded checking as “non-productive” and “work that added little value to the design”. Checking work was delegated to junior engineers, deferred, or relegated to the lowest priority. Some engineers complained that they did not have time for checking. As a result, engineers failed to detect mistakes in design documents leading to schedule slip, additional cost and time for rework and the risk of premature termination of a project. These unnecessary risk factors significantly affect the commercial performance of projects, yet this connection was not apparent to these engineers.

In both these instances, a better understanding of the economic value of technical engineering work might be helpful in refocusing the attention of engineers on tasks that are likely to contribute useful economic value. While the engineers in the studies reported above were often devoting attention to the reduction of risk, they were less able to perceive commercial opportunities and financial constraints on projects such as the amount of finance available, cost of the finance, and payback period, all of which strongly depend on investors’ perceptions of risk.

A training course for junior engineers based on analysis of the interview data ran into unexpected difficulties with their ability to understand the commercial connections with their technical work. They were keen for their company to invest in their technical ideas, yet were unable to build a commercial case for their ideas based on risk perceptions. A discussion late in the course centered on the reasons why a client might employ a technical consultancy to perform a structural integrity review at a significantly higher hourly rate. Even though the facilitator provided considerable help, only one of ten engineers on the course finally managed to realize that a smart consultant could devise low cost ways to reduce failure risks, saving the client several times the total fee for the work. A careful review of the possible reasons for this difficulty after the course led to a decision to review engineering education curricula and texts. This review showed that the relevant technical and commercial issues were not addressed at all in most engineering programs [19].

Helping engineers to create more economic value from their work could also help with another issue perceived by many engineers: remuneration. Labor market economics predicts that remuneration is driven by marginal product, the value that workers contribute. It is possible that difficulties experienced by engineers in perceiving the economic value of their work, and hence engaging in tasks likely to contribute useful economic value, might be related to the widely reported steady decline in engineering remuneration relative to other professions.

Professional associations could help to develop an improved understanding of economic and social benefits provided by engineers working mostly out of sight, providing clean water, ubiquitous sanitation, adequate supplies of healthy processed food, telecommunications (without which most ‘technology’ would be merely of curiosity value), transport systems, robust buildings, healthcare and many other services. Some of the evidence presented in this paper might provide some useful ideas to publicize the social and economic contributions of their members.

The low rate of female participation in engineering in most industrialized countries is an issue that concerns many engineers. Female engineers have to tolerate direct and indirect discrimination to pursue their careers. Perhaps most women contemplating a professional career would prefer a profession with a clearly articulated social contribution. Lawyers fight for justice and doctors deliver healthcare. While engineers contribute to both, their contributions are mostly invisible and unrecognized. A better understanding of the social and economic contributions of effective engineering could help to change these perceptions.

Even though notions of value lie at the core of professional practice, the diversity of meanings and lack of coherent understandings on value in engineering discourse emerged late in this study. Further investigations focused on this issue may produce results that could answer questions raised by this research. One is the degree to which female participation in engineering is affected by espoused and implicit professional values. Ways to locate ideas on the value created by engineering at the core of curriculum require further investigation and experimentation.

VII. CONCLUSIONS

Analysis of interview data suggests that engineers' perceptions of value in their work primarily relate to technical quality and precision. To the extent that they perceived economic value, their perceptions are almost entirely limited to direct cost savings. In engineering practice, the word 'value' has a range of different meanings: it is easy for engineers using the English language to confuse the notion of 'value'.

Educators have a central role to play in helping engineers develop the ability to understand the economic and social value arising from their work. While social justice and caring has received increasing attention from engineering educators recently, one can argue that engineering must first produce tangible economic benefits before discussing how they might be shared between different stakeholders.

Educators could help young engineers appreciate that there would be few opportunities for engineers without investors who are prepared to entrust engineers with their money in the expectation of future financial and economic benefits. The evidence presented in this study suggests that studying commerce alongside engineering is not sufficient to enable engineers to understand the relationship between risk perceptions and financial constraints. Educators need to find ways to integrate an appreciation of uncertainty, risk perception, finance and the appropriate selection of technical options. Researchers need to rectify a lacuna of evidence in this aspect of engineering.

For most of the 20th century, the value of engineering in developing the power of industrialized societies and economies was unquestioned. Governments invested large resources in engineering enterprises though they demanded strict financial controls. [e.g. 28] By the end of the 20th century, however, economics had displaced political ideology as the primary determinant in political decision-making. Governments in most industrialized countries divested themselves their engineering organizations and now outsource their engineering from private sector providers. The commercial imperative now governs engineering priorities. This study suggests that engineers at the working level could benefit from a much clearer understanding of the links between their work and the perceptions of investors that make it possible.

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Work in Progress: Engineering Education and Pragmatism:

Imagining an Undergraduate Engineering Course based on the Educational Philosophy of John Dewey

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Abstract—In this paper, we attempt to envision -- in the spirit of a mind experiment -- a specific and practicable engineering course (an engineering studio) using as our guide the basic principles of John Dewey's educational philosophy, which continues to influence all levels of American education (as can be seen, for example, in references to his ideas on education in the Boyer Report).

Keywords—component; philosophy of engineering; pragmatism and engineering; Dewey and engineering; engineering synthesis; open design

I. INTRODUCTION

The paper first situates Dewey's educational philosophy as one articulation of American Pragmatism, which itself represents one set of responses to traditional or Platonic philosophy. In all currently viable philosophical currents responding to that traditional philosophy, "practice" has become the central epistemological trope. However, despite this tectonic philosophical shift and despite the emphasis on "practice," engineering education continues to justify its curricular choices and pedagogic practices in Platonic terms. This paper attempts to envision a course that envisions those choices and practices in terms of John Dewey's articulation of Pragmatism.

A starting point of pragmatic educational philosophy is its refusal to see thought (and ideation) as fundamentally opposed to practice. This opposition is most visible in the popular image of the "doing engineer" who competently solves the problems of the "thinking boss." In Deweyan educational philosophy, the goal of education is freedom, that is, the student's ability to formulate intelligent purposes^[1-6]. Thus, students cannot be presented with unchanging goals of their education, unchanging results of other people's inquiries as "knowledge," and unchanging paths to achieving those results as "method," and then expected to become inquirers.

Dewey would insist that students must participate in formulating the ends and means of their educational activities, that is, engage in rational assessment of values, whether accepted values (standards) or pursued values (goals), at every stage of their education: By formulating their goals and interests, by critiquing them from multiple angles, by settling on some goals, by actively thinking about the routes to achieving those goals, and by always being

open -- given the resources available -- to revising both the paths and the goals.

In a previous article, the authors proposed a re-framing of the epistemological basis of engineering education in pragmatic terms^[7]. In this work, we would like to offer a mind experiment imagining a concrete, practical engineering course or set of courses based on Dewey's educational philosophy.

Dewey's educational philosophy revolves around the idea of inquiry, that is, an activity (practice) that people engage in when they come out of balance from their environment. Dewey divides this idea into five parts: "(i) a felt difficulty; (ii) its location and definition; (iii) suggestion of possible solutions; (iv) development by reasoning of the bearings of the suggestion; (v) further observation and experiment leading to its acceptance or rejection; that is, the conclusion of belief or disbelief"^[3].

The following aspects of Dewey's idea of inquiry are important for the discussions in this paper. According to Dewey, all thinking begins with a problem. The problem itself arises from already ongoing activities of the inquirer, which are based on the interests, identities, and the values adopted from the social world of the inquirer.

II. DEWEYAN EDUCATIONAL PHILOSOPHY

For Dewey, the goal of education is freedom, "power to frame purposes," to judge wisely, to evaluate desires by the consequences which will result from acting upon them; power to select and order means to carry ends (purposes) chosen by the student into operation. The final goal is creating of conditions of growth both for the student and for society.

Modern theories of knowledge have several pedagogic implications. We will mention some that will be relevant to this work: i) Knowledge remains theoretical, subject to change and revision. ii) The learning environment must demonstrate its openness to change: Instructors may have to change their syllabi, their projects, their overall teaching strategies, etc. iii) Teaching of facts should primarily take place within the context of inquiry

If the curriculum is to succeed in creating conditions in which an accelerated process of real inquiry (an inquiry that matters to the student in that the student has ownership over the problem the theory tries to solve), then of course the student should also be encouraged to doubt and question the theory.

There are many ways in which the Deweyan educational philosophy can be incorporated in engineering curricula. We believe one of the best entry points is the engineering laboratory and engineering design. In the next section, we will briefly look at the role of engineering laboratory and engineering design and discuss how they might be modified to accommodate the principles of Deweyan educational philosophy.

III. ENGINEERING LABORATORIES

A. Laboratories

Laboratories in engineering have always had two purposes. First, focus has been to show, teach, and allow students practice with the known standards, trade know-hows, instrumentation, measurements, and basic blocks of engineering and engineering design. Second, to allow students to practice the art of engineering from identifying a problem, to research the problem, to identify specifications, objectives, and to go through the iterative process of engineering design (Synthesis of their knowledge).

IV. OUR COURSE AND CURRICULAR ISSUES

In order to help engineering students to grow into thinking and educated members of society who can systematically face challenges and push the knowledge base and possibilities to new levels we need to have more integrated forms of synthesis and coaching of our engineering students. We propose a new engineering studio class where a group of student together with a group of faculty, teaching assistance, and student mentors interact. We believe such classes can be most effectively modeled to a Deweyan class. While studio classes are proposed and have been implemented, we believe a Deweyan based studio classes will be most effective for engineering students^[8, 9].

A. Standard Studio Classes

One way to achieve this is to create a modified version of the "studio" class for engineering students. Studios are routinely used in architecture and design programs. Studio classes are less regimented than regular classes and more focused on group work. Class activities include some or all of the following: i) Research, experimentation, hands-on shop work, and other opportunities to learn from failures. ii) Collaboration involving discussion and debate; iii) Ongoing group presentations iv) Documentation of the process for creating a final product (which can be research work, analysis, or final design of a physical product); v) Presentation of the idea, processes, and the product to a review team.

The Studios that are coached by faculty (and at time by a group of faculty) provide such an environment. Faculty will spend more time discussing, listening, coaching, and inspiring students in small groups, and will see and help students progress at all levels. Studios and open labs provide progressive steps and challenges that help students grow in their: i) knowledge integration, ii) active, on-going

learning, iii) team work, iv) learning from trial and error, v) perseverance, and presentation.

V. STUDIO MODEL ADAPTED TO DEWEYAN EDUCATIONAL PHILOSOPHY

The modified studio faces the problem of how to incorporate flexibility in how the ends and means of the course are envisioned. There can be many different venues of effective projects. In general projects with practical goals with some open-ended possibilities and approaches are ideal for such a class. By choosing open ended engineering problems that start with an engineering challenge and following Deweyan knowledge inquiry process, we can create environments that help student growth, emphasis scientific method, democracy, and communication, help decentering the disciplinary authority and reach specific disciplinary goals.

VI. FINAL REMARKS

In this paper we explored some of the ways in which the ideas of John Dewey could help enhance engineering education. By adapting the studio model to Dewey's ideas, students will be presented with more flexibility, diversity of perspectives, and open problems, as well as opportunities for collaboration to enhance students' ability to use their creativity and to synthesize their learning.

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Work in Progress: Phenomenographic Perspective on Engineering Students' Experience of Interdisciplinary Learning

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Abstract— With challenges engineering education faces in meeting societal needs, learning in an interdisciplinary setting has the potential to provide engineering students with opportunities to consider alternative perspectives and engage in deep learning approaches. Few empirical studies have explored interdisciplinary learning situated in other learning literature. This work-in-process explores the variance of students' experience of interdisciplinary settings. A phenomenographic framework is used to guide the methodology of the study. Maximum variation sampling is employed when collecting data using semi-structured interviews with 20-30 engineering students about their concrete experience of interdisciplinary learning. The literature and research on interdisciplinarity as well as adult learning inform the construction of the phenomenographic study and will provide ways to interpret and situate the results. The interpretive framework includes elements from theories of transformative learning, encountering others, and interdisciplinary topology.

Keywords—interdisciplinary learning; phenomenography; encountering others

I. INTRODUCTION

Interdisciplinarity has been described as “a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt adequately by a single discipline or profession... [which] draws upon disciplinary perspectives and integrates their insights through construction of a more comprehensive perspective [1].” One reason to include interdisciplinary learning opportunity in the engineering curriculum is that real world problems are inherently complex and understanding and solving those problems requires different knowledge and perspectives, and team design projects are often used in engineering curriculum to provide engagement with real world problems. Proponents of interdisciplinary learning have also argued that students are more likely to engage in deep learning approaches in such contexts [2].

Existing literature on interdisciplinary learning identified process, outcomes, and barriers of interdisciplinary learning. Nikitina concluded from interviews with teaching professionals and from classroom observation that contextualizing, conceptualizing, and problem-centering are three strategies used in interdisciplinary curricula [3]. Frutchter and Ritcher proposed that becoming interdisciplinary

is a journey from the state of *islands of knowledge* to *understanding* [4]. Schaffer, Lei, and Paulino have also identified the process of *identification*, *formation*, and *adaptation* as a framework to understand interdisciplinary learning and teamwork [5]. Additionally, Adams et al. found that engineers experience interdisciplinary practice in qualitatively different ways, and two of those include *working together* and *intentional learning* [6]. However, Ritcher and Parretti found that students often failed to connect the problem at hand to their identified fields of expertise and to value the contributions of multiple fields [7].

Other studies explored factors associated with interdisciplinary learning. Gender and disciplinary association are found as factors influencing how students frame an interdisciplinary design problem [8]. Additionally, class standing is associated with improvement in self-efficacy of interdisciplinary learning in project-based teams [9].

II. PURPOSE

No study has explored the nature of student learning experience in different interdisciplinary settings. To address the need, this proposed study seeks to examine the qualitatively different ways engineering undergraduate students experience learning in interdisciplinary environments.

III. METHODOLOGY

The design of the study is shaped by a number of frameworks. A phenomenographical framework is chosen as the methodological framework since it allows the exploration of critical variation among students' experience. Phenomenographic studies usually use interviews as the primary mode of data collection. A semi-structured interview protocol is used to probe concrete experience of interdisciplinary learning. Most phenomenographic studies include 20 to 30 participants. Data analysis is done at the transcript level, meaning no experience can be understood without others [10]. The outcome space of a phenomenographic study is a critical variation in the experience called “categories of description” and that has an “inclusive structure” relating the different categories forming a hierarchical structure [10]. The categories should emerge from the data instead of being pre-determined. Data collection will

be ongoing until no more new categories emerge. The outcome space provides a way to look at the collective experience of interdisciplinary learning of engineering students.

The literature and research on interdisciplinary learning and teaching topology [11], transformative learning [12], and engagement with others [13] also guides the design of the phenomenographic study in terms of sampling. These frameworks might also be able to help situate the results of the study once the categories of description emerge from the data.

IV. STUDY DESIGN AND PARTICIPANTS

Participants are recruited from engineering undergraduate programs at a Midwestern university. A purposeful maximum variation sampling is used to recruit participants of the study. A pre-interview survey is filled out by prospective participants to ensure participants have a wide range of interdisciplinary learning experience. Instead of only considering participant attributes such as gender, race, academic class, and discipline affiliation, we recruit participants with experience and coursework reflecting variations of the following characteristics:

A. *Topology of Interdisciplinary Learning Experience [11]*

- Informed interdisciplinary (courses and projects informed by other disciplines), such as cross-listed courses
- Synthetic interdisciplinary (courses and projects combining identifiable disciplines), such as a course that analyze an event from the perspectives of engineering, sociology and art
- Transdisciplinary (courses and projects no longer associated with single disciplines), such as the Africa water supply project and haptics project

B. *The Degree of Engagement with Others [13]*

- No partners or clients
- Projects with team members and local clients
- Projects with team members and remote clients

C. *The Extent to which Experience Reflects Elements of Transformative Learning [12]*

- Different degrees of instructor support and scaffolding

Prospective participants are recruited from programs and courses that satisfy the described criteria. Some of these courses and programs include the global engineering program, a service-learning program, an engineering undergraduate summer research program, and cross-listed courses.

V. INTERVIEW PROTOCOL

A phenomenographic interview focuses on discussion of concrete experiences in order for the participants to share their understanding about a specific aspect of the world. The

interview protocol is semi-structured beginning with participants' background information. Then, participants are asked to describe one concrete experience involving learning in an interdisciplinary setting. Afterwards, they describe another interdisciplinary learning experience and explain how it differs from the first experience. Finally, participants are asked questions that are intended to probe meanings they associate with interdisciplinary learning. The interview is meant to provide reflective data situated in concrete experiences.

VI. IMPORTANCE OF THE EDUCATIONAL COMMUNITY

All accredited engineering programs include interdisciplinary learning opportunities of team-based design project as part of their curricula. However, being in a team does not guarantee students can learn to function in a team and learn to work with other perspectives. By capturing the critical variations of student learning experience of interdisciplinary courses and projects, this study seeks to provide insights on the design and structure of these learning opportunities. The outcome space will also provide a developmental perspective of increasing comprehensive view of interdisciplinary learning.

VII. PROJECT STATUS

Interviews are currently being conducted and will be ongoing until categories of description saturate. Analysis is being conducted concurrently. Participants encountered differences in instructor coaching style and team dynamics which influenced how they experienced learning. So far, all participants chose to talk about their formal education experiences in classrooms when they are asked to describe an interdisciplinary learning experience, but when asked to describe another interdisciplinary experience, some participants drew from less formal experiences such as residential life, internships, and entrepreneurial competitions.

Results of a phenomenographic study are only meaningful when the comparison of all transcripts is completed. Preliminary results of the outcome space on interdisciplinary learning will be available at the time of the conference.

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Applying philosophical inquiry:

Bringing future engineering education researchers into the philosophy of engineering education

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Abstract—An ability to apply philosophical inquiry to both create and critique arguments about the current and future state of engineering education is a critical capability for future engineering educators to develop. However, there are few, if any, examples of how to do this. In this paper we describe a course that we have been offering for four years at Purdue University, *History and Philosophy of Engineering Education*, as an example of how to address this gap. We describe the learning objectives, conceptual frameworks used, learning and assessment activities, and examples of course assessments that illustrate learning outcomes.

Keywords – philosophy; epistemology; graduate education; professional development; engineering education research, history

I. INTRODUCTION

The philosophy of education is the study of education problems such as the goals of education, access to education, the process of education, and the role of government in education [1]. Philosophers of education draw on a variety of tools to examine and critique these problems, in particular philosophical inquiry. Philosophical inquiry involves exploring positions, or “arguments”, about what is and should be, critiquing the likely outcomes or consequences of these arguments, and persuading others that these consequences should be valued [1]. As such, philosophical inquiry can guide education transformation initiatives and play a critical role in shaping new fields or disciplines. Therefore, an ability to apply philosophical inquiry to both critique and produce arguments about the future of engineering education in postsecondary institutions is a critical capability for future engineering educators to develop [2].

In this paper we describe a novel and unique course that we have been offering for four years at Purdue University, *History and Philosophy of Engineering Education*, as an example of how to prepare future shapers of engineering education. The course may be viewed as an example of “scalable scholarship” [3] for training the next generation of engineering education scholars. The course is considered unique because of its specific focus and approach for preparing engineering education professionals, and the interdisciplinary effort to bring together scholarship from educational philosophy, history of higher education, science technology and society studies, and philosophy of science, engineering, and technology. This involves integrating research from a variety of professional communities, journals (e.g., *Engineering Studies*, *Research in*

Higher Education, *Technology and Culture*, and *Studies in History and Philosophy of Science*) and conferences (e.g., Philosophy of Engineering¹ and the Forum on Philosophy, Engineering and Technology², and the American Society for Engineering Education). In the following sections, we describe the course objectives, structure, frameworks, and topics and content. We also provide examples of student evaluations and coursework that illustrate some of the insights students gain through the course, as well as challenges they face as they encounter paradox, ambiguity, and competing paradigms.

II. COURSE BACKGROUND

In this graduate-level course, we examine the history and philosophy of engineering education through tools that guide critical analysis of philosophical, epistemological, ontological, and historical arguments such as: what is (and should be) engineering, what is (and should be) the purpose and process of engineering education, who gets to be an engineer (and who should be), and what shapes these decisions (and what should shape these decisions). Learning objectives focus on developing a culture of critical reflection and a tolerance of ambiguity, identifying and understanding tools to inquire into the history and philosophy of engineering education, using these tools to form arguments for oneself and for others about engineering education, and developing a perspective or identity as an engineering education scholar.

This course is taught during the first term of the graduate program and represents a foundation course required of all graduate students. As a foundation course, it sets students on a pathway of inquiring deeply, early, and often into critical questions about engineering education that shape choices about research goals, questions, designs, and impact plans. It is also an entry point for students to learn how to understand and value multiple perspectives or new ways of thinking, and to link their personal professional goals with what it means to be an engineering education scholar and change agent.

Inquiry tools used in the course include (see Appendix): (1) reflective practice and “sitting comfortable with paradox”, (2) drawing on insider (engineers) and outsider (those who study engineers) perspectives to reveal what engineers know and how they know it, (3) philosophies of education that argue for particular aims, purposes, and processes of education, (4)

¹ <http://www.raeng.org.uk/societygov/philosophyofeng/default.htm>

² <http://philengtech.org/>

archival research and historical documents that reveal enacted philosophies of engineering education, and (5) boundary work metaphors to understand the managing and policing of ideas about the aims of engineering education, the nature of engineering knowledge (epistemology), and the nature of engineering being (ontology).

III. COURSE STRUCTURE

The course is three credits in a 16-week semester system, offered for the last four years in one three hour class period held once a week. The course is set at the 500 level, as an introductory graduate-level course primarily for engineering education graduate students. Graduate students in other programs have been encouraged to enroll, and each year the course tends to include students from other engineering and education disciplines, as well as students from technology and psychology.

Four course tasks support the course's learning goals:

- Weekly discussions on readings in class. We have used Nel Noddings' *Philosophy of Education* [1] as a key reference text, and have produced a reading list of articles and book chapters to provide additional breadth and depth (see Appendix). Class periods usually entail a mixture of individual reflection, group discussion (in small groups and amongst the whole class), specialized activities, and peer review opportunities.
- Reflective essays students share with each other on a course blog or protected discussion page. The purpose of the reflective essays is to help students prepare for class discussion, develop reflective practice skills, and gain confidence with actively participating in discussions whether they be in class or in public communication forums.
- Three short synthesis papers in which they receive peer and instructor feedback and on which they can iterate. The papers parallel the course content: What is engineering? What is education? What is engineering education? Papers are evaluated on the quality of the arguments they make, their completeness (whether they address the overall guiding questions), whether they are grounded in the literature we have discussed in class (or additional literature), and whether they are well-organized (both macro and micro-structure), clearly written, and engaging. The last essay, treating the question of "what is engineering education?," is expected to be of the quality that students could include it in a portfolio of their graduate work.
- A YouTube video, produced in groups of 3 or 4, that presents a philosophy for the future of engineering education. The YouTube project was designed to provide opportunities to reflect on course ideas and to translate them into action in a way that may engage the broader engineering education community. The YouTube video project has been presented in more detail elsewhere [4], and are publicly available on YouTube at <http://tinyurl.com/ene502-youtube>.

Course assessments include an end-of-course evaluation, open-ended student feedback at multiple times through the course, and feedback forums through our Graduate Student Association.

IV. COURSE FRAMEWORKS

Choices regarding frameworks for designing the learning experience were made based on insights from engineering education research capacity-building programs [5-6] and efforts to help students connect the course objectives to the graduate program as a whole and to the broader profession. A particular challenge was helping students move from a problem solving mindset to a problem framing mindset that involves developing persuasive arguments about the past, the present, and the future. Over the multiple offerings of this course, it became clear that students would experience questions such as "what is engineering" as something that has a correct answer, rather than something that might have many plausible answers. As such, it was important to help students become comfortable with ambiguity and living with paradox.

Other work illustrates the challenges of transitioning from disciplinary to cross-disciplinary mindsets, learning and valuing new language and ways of thinking, navigating the existing literature, dealing with the complexity and ambiguities of education research particularly qualitative research, and evolving interdisciplinary identities [5-10]. Efforts to alleviate or address these challenges involve supporting a community of practice through group projects and peer feedback on course reflections and essays, attending to language and epistemological differences in course readings, focusing course essays on synthesis and identity formation, and scaffolded instruction on difficult concepts such as "what is an argument" and "what does it mean to ground an argument".

To help students connect their learning to the graduate program as a whole, we mapped the course objectives to the School's competencies required for student graduation³. We also used Shaffer et al's [11] epistemic frame structure of knowledge, skills, identity, values, and epistemology to communicate course objectives as a broader set of professional lenses.

V. COURSE TOPICS AND CONTENT

The course has been structured into three key questions for students to consider:

- What is engineering?
- What is education?
- What is engineering education?

These have been addressed in different orders over the various iterations of the course, with the most recent iteration in the order given above.

We begin the course with a discussion about "tools for thinking" that we use throughout the course: reflecting in and on action [12], paradoxes, and sitting with tension [13], boundary work [14-15], and classification as a political act

³ <https://engineering.purdue.edu/ENE/Academics/Graduate/competencies>

[16]. To discuss “what is engineering,” we treat engineering as a science and as a profession [17-19], as design [20-22], and as sociotechnical practice [23-24]. We also explore how engineering is viewed by outsiders compared to insiders [25-26], using the tool of boundary work to help us position ourselves.

To discuss “what is education,” we work through the majority of a text by Noddings [1], regularly taking time to collectively synthesize the arguments she represents through tables on the shared discussion board on Blackboard, allowing us to summarize different goals/aims/purposes of education as represented by various philosophers of education, who they think should be educated, and what the consequence of this philosophy has been on modern US educational systems.

The topic of “what is engineering education” is treated in more depth than the previous two. We spend two class periods looking at historical perspectives on engineering education, both reading engineering education reports [e.g. 27-28] as primary sources, and scholarly works [e.g. 29-30] describing different historical aspects of US engineering education. We particularly look at how engineering education systems have explicitly and implicitly excluded women and people of color except in times of national need [e.g., 31-33]. We then shift to more contemporary perspectives on engineering education [34-36], including some of the more recent reports on engineering education reform. In the most recent iteration of the course, we broadened perspectives from the US-centric perspective to incorporate more cross-national perspectives [37-38]. We also have added an explicit discussion of engineering education research as a topic, again treating this from a US perspective [39-43], then cross-national perspective [42-44]. We end the course with a final activity to help students synthesize key ideas discussed, and the YouTube Extravaganza where students present their videos to their peers and the broader community.

VI. COURSE EVALUATION AND STUDENT WORK

Course evaluations were conducted at the course and program level. Each year students complete an end-of-term survey that includes questions about the overall experience and questions targeted towards specific aspects of the course. In particular, some questions ask students to rate the quality of the learning environment (i.e., clarity and organization of course, quality and balance of assignments, collaborative learning, team teaching, and supportive and respectful culture), and others ask students to rate the impact of the course on their learning (i.e., contributions to personal and professional growth, improved critical and reflective thinking, improved synthetic reasoning abilities, and broader perspective). The overall course evaluation has consistently been 4.7 out of a possible 5.0, and students’ average rating of the extent to which instructors “ask questions which challenge me to think” was 4.9 out of 5.0. An example of course evaluations from one offering is provided in Table I.

Course evaluations also include open-ended questions. Students often comment about how the course helped develop a tolerance for ambiguity and multiple perspectives, and provided tools to inquire into engineering education issues that they can use now and into the future. Some examples of these are provided below:

“...before this class, I was not a huge fan of history OR philosophy. However, thanks to this course I have come to appreciate these subjects and plan to go back over some of the readings at a later time. Thanks for making the content interesting and showing how it applies to ENE. The engineer-in-me loved the practical element of this course.”

TABLE I. COURSE EVALUATIONS , FALL 2010, N=15

| Evaluation Survey Questions | Mean out of 5.0 |
|--|-----------------|
| CLARITY AND ORGANIZATION OF COURSE | |
| Course requirements are clear. | 4.6 |
| Required course activities are consistent with course objectives. | 4.4 |
| The course appears to be well organized. | 4.6 |
| QUALITY AND BALANCE OF ASSIGNMENTS | |
| This course strikes a good balance between reading, discussion, and writing. | 4.5 |
| Assigned readings help me understand concepts discussed in class. | 4.5 |
| Course assignments help me learn on my own. | 4.4 |
| This course helps me clarify my ideas through writing. | 4.5 |
| One real strength of this course is the classroom discussion. | 4.3 |
| Class discussions are helpful to my learning. | 4.3 |
| This course provides an opportunity to learn from other students. | 4.6 |
| COLLABORATIVE WORK AND TEAM TEACHING | |
| Collaborative work is a valuable part of this course. | 4.5 |
| The group work contributes significantly to this course. | 4.1 |
| The teaching methods used in this course enable me to learn. | 4.3 |
| Team teaching is effectively used in this course. | 4.5 |
| Team teaching provides insights a single instructor cannot. | 4.4 |
| SUPPORTIVE AND REFLECTIVE CULTURE | |
| When I have a question or comment I know it will be respected. | 4.7 |
| I am free to express and explain my own views in class. | 4.5 |
| Class sessions were interesting and engaging. | 4.5 |
| CONTRIBUTIONS TO PERSONAL AND PROFESSIONAL GROWTH | |
| This course builds understanding of concepts and principles. | 4.4 |
| This course contributes significantly to my professional growth. | 4.4 |
| This course gives me an excellent background for further study. | 4.4 |
| My work is evaluated in ways that are helpful to my learning. | 4.5 |
| IMPROVED CRITICAL / REFLECTIVE THINKING, SYNTHETIC REASONING, AND BROADER PERSPECTIVE | |
| This course effectively challenges me to think. | 4.7 |
| This course has been intellectually fulfilling for me. | 4.4 |
| This class provides a meaningful learning experience. | 4.5 |
| This course stretches and broadens my views greatly. | 4.7 |
| My critical thinking skills improved because of this course. | 4.3 |
| This course helps me synthesize information from several sources. | 4.5 |

“Instructional team was excellent at facilitating the class as a whole through a fairly intense learning process. They both did an excellent job of balancing our need for reassurance and comfort with their demand for excellence and high-level, synthetic thinking.”

“I really believe I walked into a class that was designed

to intentionally grow students in a way that balances self discovery and instruction. Concepts were linked without the information being forced, students can trace the connections on their own...I felt pushed at times, given an adequate break at other times, and important topics came full circle in the end....The dialogue was also appreciated and huge part of my learning, it could also be that I come from a discipline where dialogue does not happen very much and this all very exciting and new."

"I thought this class was exceptionally difficult, but I can't recall a time where I feel like I made so much progress in such a short period of time."

"Great at asking questions that cause me to pause and think. I need more of that type of questioning perspective."

In addition, in the spring of 2009 our graduate students conducted a full program review where more than half of the student body participated in two 1.5 hour discussions on what is working well in the program and opportunities for improvement. This was designed and led by our Graduate Student Association, who synthesized the discussion and submitted a report to the Graduate Committee. Regarding the course discussed in this paper, there was strong support for the iterative assignments and how they help students develop over the course of the semester. When asked to describe how the course prepares them for the future or fits within the rest of the program, students responded: "This course works to shift our thinking beyond our preconceptions and assumptions about engineering and engineering education" and "helps build a community of intellectual questioning and discussion that can be used throughout the curriculum."

Finally, the YouTube project videos are developed to be public, and are showcased at an end-of-semester celebration open to the school, college, university, and community. They are posted to YouTube and collected into a playlist (<http://tinyurl.com/ene502-youtube>). Readers of this paper are encouraged to review and critique students' YouTube videos and the ways they demonstrate students capabilities to inquire into the history and philosophy of engineering education and the extent to which they can present arguments that are clear, organized, grounded, and engaging.

VII. CONCLUSIONS

Drawing on the work of Gramsci, Downey uses the term "scalable scholarship" to describe how academic teachers and researchers might critically participate in worlds of practice. Situating his remarks at the productive intersection of science and technology studies (STS) and engineering education, he explains: "[S]caling up involves inquiring into what is taking place when scholars not only conduct research on engineers and engineering but also design and teach courses for engineering students, serve on official panels and advisory committees, offer presentations to engineering audiences, and help build a new discipline focused on engineering education" [3]. When one embraces scaling up, it requires showing how critical, theoretical analyses of practice have meaningful implications for practice, all the while remaining wary of the dangers of co-optation, resistance, or worse - being ignored.

Classrooms can help open up new spaces of opportunity for relating ideas to life, and linking critical inquiry to concrete action. By engaging foundational philosophical questions about what counts as engineering, education, and engineering education, the course described in this paper encourages graduate students to undertake critical self-reflection, which may in turn place them on transformative learning pathways [45-46]. In part, we are successful when we are able to help people see the world in new and different ways, including through productive dialog with both one another and the ideas, texts, and authors explored in the class. Yet ultimately, the real test of our labors is whether our students are able to carry the course with them into future situations and contexts, using it as a foundational scaffold to proactively interrogate and transform dominant practices in engineering education and professional practice. Such is the spirit of scalable scholarship.

ACKNOWLEDGMENTS

We'd like to acknowledge the contributions of Karl Smith, who helped design the first offering of the course, and Holly Matusovich, who was an Apprentice Faculty for that first offering. We also thank the students who have taken this course over the last few years and contributed to its iterative development.

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APPENDIX

| Week | Preparation needed for this class |
|--------|---|
| 0 | Read Schön [11] and Palmer [12], and group behaviors handout |
| 1 | Introduction; talking tools → Tools: Paradox, sitting with the tension, knowing in/on action Assignment: Bring in a photo that represents engineering to you Reading, references: [11, 12] |
| 2 | What is engineering? Engineering as a science and a profession → Tools: Boundary work Assignment: "What is engineering?" essay assigned Reading, references: [16, 17, 18], and Noble, David F. (1979). <i>America by Design: Science, Technology, and the Rise of Corporate Capitalism</i> . New York: Alfred A. Knopf, Inc. Chapters 2-3, pp. 20-49. |
| 3 | What is engineering? Engineering as design → Tools: Classification as a political act Reading, references: [15, 19, 20, 21] |
| 4 | What is engineering? Engineering as sociotechnical practice Reading, references: [22, 23], and Bovy, Michel, and Vinck, Dominique. (2003) "Social Complexity and the Role of the Object: Installing Household Waste Containers." In Dominique Vinck, Ed., <i>Everyday Engineering: An Ethnography of Design and Innovation</i> , Ch 3, pp. 53-75. MIT Press. |
| 5 | What is engineering? Engineering by outsiders → Tools: Insider/outsider perspectives (designers and non-designers), reflective practice Assignment: Draft of essay to peer reviewers due (bring paper copy to class), YouTube group assigned Reading, references: [24, 25], and Latour, Bruno. (1987). <i>Science in Action</i> . Harvard University Press. Introduction, pp. 1-17. Johnson, Ann, (2009). <i>Hitting the Brakes: Engineering Design and the Production of Knowledge</i> . Duke University Press. Ch 1: Design and the Knowledge Community, pp. 1-22 |
| 6 | What is education? Foundational philosophies of education, Part 1 → Tools: Matrix of goals-aims-purpose/process/who is educated/consequences Assignment: "What is engineering?" essay due, "What is education?" essay assigned Reading, reference [2] Chapters 1-4 |
| 7 | What is education? Foundational philosophies of education, Part 2 Reading, reference [2] Chapters 6, 8-9, 11 |
| 8 | What is education? History of education in the US → Tools: historical lens Reading, reference [2] Chapter 10, and History of Education in the United States – http://en.wikipedia.org/wiki/History_of_education_in_the_United_States |
| 9 | What is engineering education? Historical perspectives on engineering education, Part 1 → Tools: Archival research & primary historical documents Assignment: Bring paper copy of "What is education?" to class for peer review Reading, references: [28, 29] Read ONE, as assigned: Mann, Charles Riborg. (1918). "A Study of Engineering Education." Carnegie Foundation for the Advancement of Teaching, New York. (Selected sections TBD) Society for the Promotion of Engineering Education. (1930). "Report of the Investigation of Engineering Education 1923-1929." Pittsburgh, PA. (Wickenden Report: selected pages) (2004). "Journal of Engineering Education Round Table: Reflections on the Grinter Report." <i>Journal of Engineering Education</i> : 69-94. Goals Committee. (1968). "Goals of Engineering Education: Final Report of the Goals Committee." American Society for Engineering Education, Washington DC. |
| 10 | What is engineering education? Historical perspectives on engineering education, Part 2 Assignment: "What is education?" essay due Reading, references: [30, 31, 32], and Bix, Amy Sue. (2005). "Engineering National Defense: Technical Education at Land-Grant Institutions during World War II." In Alan I. Marcus, Ed., <i>Engineering in a Land-Grant Context: The Past, Present and Future of an Idea</i> , pp. 105-133. Purdue University Press. |
| 11 | What is engineering education? Contemporary perspectives → Tools: Boundary work Assignment: "What is Engineering Education?" essay assigned Reading, references: [14, 33, 34, 35], and ASCE. (2008). Civil Engineering Body of Knowledge for the 21st Century Preparing the Civil Engineer for the Future (Second Edition). Executive Summary and Chapter 1. |
| 12 | What is engineering education? Cross-national perspectives → Tools: Historical ethnography Reading, references: [36, 37] and ONE additional paper/chapter focused on a specific country (see Blackboard). |
| 13 | What is engineering education research? Origins and American perspectives Assignment: Draft design of YouTube videos for peer review Reading, reference [2], Chapter 7 and references [38, 39, 40] |
| 14 | HAPPY THANKSGIVING – no class! |
| 15 | What is engineering education research? Cross-national perspective and current trends Reading, references: [41, 42, 43] |
| 16 | Synthesis of the course Peer review of engineering education synthesis essays done in class |
| Finals | Final presentations: YouTube videos and rationale Electronic copy of "what is engineering education?" essay and YouTube rationale due |

A Philosophy Driven Curriculum: the Example of an Engineering Science Course in England

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Abstract

During the last thirty or more years a number of articles about engineering education have suggested that one of the reasons why the goals of engineering have not been achieved is the lack of a proper philosophical base to provide the guidelines needed. At the same time a number of those involved in engineering course design have found it necessary to use the term philosophy when talking about the rationale for their courses. Inspection of such descriptions suggests they are describing a “naïve” philosophy rather than a curriculum that has an “operational” (working) philosophy that drives curriculum design, implementation and evaluation.. This paper describes a course in engineering science at ‘A’ level for university entry in England and Wales that was epistemologically driven, and examines the extent to which it achieved its goals.

The discussion is prefaced by a short description of the system of selection to universities in England at the time of the development. At that time students seeking admission to university engineering departments were expected to have performed well in examinations that corresponded to first and or second year university courses in other parts of the world in physics, and pure and applied mathematics taken as separate subjects. It was proposed that physics should be replaced by engineering science. A major reason for this was the well documented attraction that students had for physics as opposed to engineering. It was argued by the product champion that more students would be attracted to engineering if they understood that it was a different way of thinking to physics. Thus the examination had to be equivalent to physics yet encourage a different way of thinking. It was found that in order to achieve this goal, different approaches to examining and assessment had to be introduced. It was also found that for curriculum goals to be achieved assessment had to become an integral part of the teaching-learning process rather than an afterthought. The paper describes the introduction of this examination as an alternative to physics and considers what it achieved, and why over a twenty year period it eventually failed.

Key words *Assessment; Curriculum development; examinations; operational(working) philosophy; syllabus*

INTRODUCTION

There has been increasing interest in the philosophy of engineering and engineering education since Bucciarelli [1] and Koen [2] made major contributions to these topics in 2002. Since 2006 conversations have taken place in a series of international workshops focused on the philosophy of engineering [3], and separately through special and paper

sessions at successive Frontiers in Education Conferences that focused on the role of philosophy in engineering education. These culminated in a workshop at the 2011 Conference sponsored by the ERM Division of ASEE, the IEEE Education Society, and NSF. The associated bibliography and accompanying commentary [4] did not develop the concept of “operational (working) philosophy”, or find examples of curriculum that were philosophically driven. As a contribution to these discussions this paper presents an example of the development of an engineering science curriculum in the UK that was philosophically driven.

In the context of education operational (working) philosophy describes the value (belief) system that drives a particular curriculum, syllabus (detailed list of content), course or teaching session. It is the personal motivation of individuals that sustains them or drives them to change or seek change. It is analogous to the working capital required for a firm to keep functioning. Sometimes the statement that emerges is so brief as to be meaningless; at other times it is substantive. The need to define a philosophy seems to be felt when new courses are proposed and the new course needs to be justified. A basic need has been to establish what is distinctive about engineering education when compared with physics. Is engineering education simply the application of physics or is it something more? [5] This paper describes the operational philosophy and its effects on the development of a public examination for university entry in engineering science intended as an alternative to physics in England for university entry. It had a profound effect on the design of the examination and assessment, and also led to an epistemology of practical work in engineering. A major innovation was a statement of attitudes, motives and interests that the curriculum should foster. This innovation continues to be of interest because it illustrates problems in the process of curriculum design and evaluation, and it is the progenitor of the model that a committee of the US National Research Council used to illustrate balanced system of school and national assessment [6], [7]. The paper complements the semi-official history of the development [8].

II THE SYSTEM OF ENTRY TO UNIVERSITIES IN ENGLAND AND WALES CIRCA 1965

A very small percentage of students in 1965 entered university from state funded schools. These came mainly from grammar schools. The principle requirement for entry was that students

at the end of their schooling (aged 17 or 18) they should have obtained good grades in three or four subject examinations nicknamed 'A' levels (General Certificate of Education-Advanced) [9]. University departments specified what 'A' levels a student should offer. Engineering departments required all students to take physics and mathematics (pure and applied – or taken as separate subjects). If pure and applied mathematics was taken as a single subject departments would ask the candidate to offer another science subject such as chemistry. 'A' levels were considered to be of the same standard as first year courses in four year programmes offered by universities in the English speaking world [10]. These examinations were set by matriculation boards [11], and the examination for each subject consisted generally of two three hour written papers, and in the sciences some form of practical (laboratory) work. This paper is about the development of an 'A' level syllabus in Engineering Science by the Joint Matriculation Board (JMB) as an alternative to physics for entry to university engineering departments. A major purpose of some of the players was to attract a better quality of student into university departments of engineering. Others were concerned with the educational possibilities on offer.

III ENGINEERING SUBJECTS AND THE JOINT MATRICULATION BOARD CIRCA 1965

The functions of these examining authorities were to issue syllabuses (statements of required content), which they designed, implemented and examined. It was a stated principle that they did not interfere with the way the subject was taught. This was the responsibility of the schools and their teachers. Most schools in the north of England took the examinations set by the JMB.

Between 1956 and 1965 there was a continuing debate about the need for examinations in the general area of engineering at 'A' level within the JMB. Nothing had come of various suggestions but a syllabus for Engineering Science at A level had the conditional approval of The Schools Council, a body delegated by the Ministry of Education to regulate the system. The Council was concerned that the extensive coursework required would only be used as a hurdle and not graded. Concern was also expressed by one of the JMB's constituent universities that the syllabus would not be acceptable for admission to university departments.

At this stage the Dean of the Faculty of Engineering Science at the University of Liverpool suggested a major re-appraisal of the syllabus which took two years. During this time Professor Edels became the product champion of new syllabus, which began the emergence of the philosophy to be discussed [12].

IV THE EMERGING PHILOSOPHY

Edels believed that able high school students preferred physics to engineering because they did not understand what

engineering was about. He felt that in high school pupils should be exposed to the engineering habit of mind [13]. This was the purpose of replacing physics with engineering science as an entry requirement to university engineering departments. At the same time it would have to be seen to be the equivalent of physics, if university admissions officer were to select candidates with good grades in engineering science. Thus the examination had to be firmly based in science (physics) and at the same time convey the essence of engineering. Edels had to campaign among his colleagues and school teachers that the habit of mind was as important as the principles, but those principles would not be sacrificed if this approach was adopted. This approach placed a major constraint on the development of the syllabus. This was acceptable to the progenitors since they understood engineering to be the application of science to practical problems.

V ORGANIZATIONAL HELP

The JMB was advised that teachers who were likely to be physicists may need considerable help to adjust to the philosophy and delivery of the subject. Accordingly it created a co-ordinating committee in December 1966 with a remit to supply extensive resource material. At the same time with the support of the Schools Council Project Technology it was able to finance an education officer for four years, to advise schools about the subject and service the committee. This was a major policy departure for the Board. It meant that the syllabus could be developed independently of a subject committee, in this case either physics or craft and technical subjects, and the committee could engage, with some limitations, in curriculum development. It established four working groups. (1) A teacher training group engaged with teachers through regular meetings, usually of a day's duration. (2) A group to write textbooks for each of the sections of the syllabus - were Mechanics, Materials Science, Transport Phenomena, Wave Phenomena, Field Phenomena, Basic Systems Analysis, Electron Physics and Devices, and Thermodynamics. The texts and teaching were to be written and conducted on the basis that "many physical and engineering concepts and processes are analogous and that concurrent study of such analogues would develop the integration and synthesis of thought required in the solution of relevant engineering science problems" [14]. (3) A Laboratory and Project Group; and (4) A Validation group that had the task of developing assessment procedures that would ensure the philosophy was met. Only through assessment could a "distinctive Engineering Science flavour that was not substitute for, or extension of, a pure science subject" [15] be achieved. It is the perceptions that students have of the requirements for assessment that governs student learning in assessment-led-for learning systems of public examination [16]. They had to take into account an edict "That, the course of study should provide an understanding of the constraints which operate in real life engineering situations" [17].

VI THE EPISTEMOLOGY OF PRACTICAL WORK

Early in the deliberations of the working parties a memorandum from two members pointed out that no attempt had been made consider the implications for the development of students as engineers that were a consequence of the original philosophy [18]. There was a need to consider the factors that lead to “the development of certain features characteristic of the personalities of engineers and physicists”. These differ because the approach to solving engineering problems is fundamentally different to solving physics problems. They distinguished between two types of student. The first was an engineering scientist who dealt with the physics of engineering, and the second was an engineering scientist who dealt with design. They argued that the first document on practical work favoured the first type. They thought it should be re-balanced.

To reinforce their point they gave operational definitions of engineers and physicists. They went on to argue “the balance and ordering of cognitive skills seems to be different between the two, thus physicists probably need more skill in comprehension and analysis (Bloom’s Taxonomy), whereas engineers require greater development of the skills of synthesis, application and evaluation”.

They believed that this could be rectified through the emphasis of design in the 50 hour project and the inclusion of short design projects for training for the compulsory project. (It had been approved that during the two year programme a student would complete a project investigation chosen by h/herself, to be completed in 50 hours of laboratory time).

They argued for greater flexibility in teaching and assessment, and supported their case with a substantial appendix of research carried out by Price and his students. In the event one of the six assessment categories was for design, and when the objectives for the whole syllabus were declared in the 1972 syllabus “synthesis” was linked with “design” (see exhibit 1) [19]. Examples of projects that had been undertaken by students in the previous three years were given in the 1972 Notes for Guidance on the subject. Most of them were prefixed with instruction “Design” (see exhibit 2) [20]. Prior to beginning a project students were required to demonstrate to their teachers and moderators that their chosen project would meet the requirements of a criterion referenced assessment system base on the abilities listed in exhibit 1 and other abilities stated in the syllabus. The candidate was provided with a quite specific list of questions that the project plan had to give answers. As indicated below the design debate did not go away. The 1972 syllabus also included a statement of attitudes, motives and interests.

VII ATTITUDES, MOTIVES AND INTERESTS

In a major departure from practice, one that was hotly debated in the Board the 1972 and subsequent syllabuses (published annually) included a statement of attitudes, motives and

interests [21]. The co-ordinating committee recognized that there were a group of aims that were associated with the “outlook and personality of the individual”. They did not believe that they could be measured directly but could “be detected in the way students tackle problems based both on syllabus content and on coursework. They published a list that was intended to help students develop an “engineering attitude to its highest level”. The list is shown in exhibit 3.

D. Knowledge, understanding and abilities to be tested
[...]

4. Synthesis and design

The ability to

- (a) Design the manner in which an optimum solution may be obtained efficiently and to propose alternative solutions taking into account the restraints imposed by material, economic and social considerations.
- (b) Make a formal specification, having decided on the design or scheme.
- (c) Make a plan for the execution or manufacture of the design or scheme.
- (d) Use observations to make generalizations or formulate hypotheses.
- (e) Suggest new questions and predictions which arise from the hypotheses formulated.
- (f) Suggest methods of testing these questions and predictions.
- (g) Find the optimum solution to an engineering design or other problem and give valid reasons for the rejection of alternatives.

Exhibit 1. The Synthesis and Design category in the Statement of knowledge, Understanding and abilities to be tested pp 3 and 4 in *General Certificate of Education. Engineering Science Advanced: Syllabus and Notes for the Guidance of Schools. Manchester, Joint Matriculation Board* [19]. The other categories were, knowledge and understanding; comprehension, communication; analysis; and evaluation and judgment. At the time it was thought these were hierarchically ordered.

VIII AN EXPERIMENTAL EXAMINATION

The freedom provided by this committee structure enabled the validation group to have a proposal for an experimental examination undertaken in four schools that had indicated they would enter students for the first sitting of Engineering in 1969. Set in 1968 the experimental examination broke with the convention of having two three hour papers of questions requiring long and short answers. Its authors were influenced by Furneaux’s study of engineering examinations at Imperial College [22], the *Taxonomy of Educational Objectives* [23], and a JMB examination in General Studies that tested the categories in the *Taxonomy* [24]. Furneaux had found that there was only one major factor tested in each of the written examinations. He suggested that it reflected an ability to pass examinations. An alternative explanation suggested that the factor was a particular form of mathematical analysis [25]. The Taxonomy showed that there were other important objectives

The design construction and evaluation of a model homopolar motor.
 The design and construction of a remote control land yacht
 The design and construction of a suspension and propulsion system for a chassis containing an electric motor for a mono-rail system with selected nylon track.
 The design of a roller towel machine.
 To design, construct and investigate a polariscope.
 To design, construct and test a vortex tube for amplification in a fluidic system.
 To design and construct a machine to record vehicles entering and leaving a car park.
 To design and construct an automatic level crossing for an "00" gauge model railway.
 Design a simple pile driver and investigate the forces acting during its operation.
 Development of a demonstration gyroscope.
 To design and construct a teaching aid for the demonstration of mechanical resonance and damping.

Exhibit 2.. Examples of projects completed by students cited in the 1972 *Notes for the Guidance of Schools*. Pp 29 and 3 [19].

(outcomes) that should be tested. Therefore, an examination was designed that would test specific domains (skills) related to what it was thought engineers would need in the workplace. They designers understood that this examination could have a profound effect on teaching.

The first part of the examination was of the traditional kind requiring short (10 minutes) and long (30 minutes) answers to the questions set.. The second part, together with coursework, attempted to meet the philosophical challenge of causing and engineering way of thinking or 'habit of mind'. Section 1 of this part was a "comprehension" exercise; Section 2 was a "design-problem formulation and reasoning exercise", and Section 3 was an exercise in "engineering reasoning". Although not well done, both students and teachers wanted questions of this type included in the public examination.

The Board acceded to this request and in 1969 a multiple-objective (later called strategy) examination was set. This comprised of one traditional three hour paper with short and long answer questions that focused on problem solving (application and analysis) in the applications of science and some questions of the engineering reasoning type of question that dealt with commonly used artifacts. "The aim of this question was to see to what degree candidates could analyse the physical principles employed in a common piece of equipment, in this case an electric kettle and to analyse the important features of design from the point of view of the user, manufacturer and the supplier. In other words this question extends the Engineering Science into other aspects of engineering design" [26]. The need for instruction in how to approach this type of question and the depth of understanding required was revealed, as many answers were not of the depth sought. This illustrated how assessment could improve

"The recognition of the need for a method which is organised, careful and intellectually honest-particularly in respect of experimental observation".

"The acceptance of the need to consider parallel social and economic bases of engineering".

"An awareness of the advantages of deriving the more particular relationships from basic concepts".

"An awareness of the advantage of seeking parallels in other fields to relate one kind of phenomenon to another".

"An awareness of the advantage of attempting to reduce a social, economic or scientific situation to a simple system".

"The recognition of the fact that it may be necessary to exercise judgment as well as reason when dealing with a problem".

"The recognition of the fact that a perfect answer to a problem may not exist, and that the best available answer must be sought".

"The recognition of the fact that not all the information necessary to tackle a problem may be available, and that some which is available may not be relevant".

"The acceptance of the fact that more than one way of thinking exists, and that different ways may be more appropriate to different problems or different stages of the same problem".

"The recognition of the fact that the required exactness of calculation may vary from case to case (for example, from preliminary, quick 'order of magnitude' estimate to precise forecast of performance".

Exhibit 3. Statement of relevant attitudes in the 1972 *Notes for the Guidance of Schools* [19].

learning and in consequence this type of question was set in subsequent papers.

The other three hour paper included a one hour objective test designed to assess knowledge of concepts and principles across the syllabus with some short-chain problem solving. A one hour 'comprehension test', but set against an article from an engineering magazine rather than newspaper article, and a project design and planning exercise of one- hour duration. As indicated above it was designed to replicate the exercise that a student would have to carry out for the 50 hour laboratory project required of coursework. A candidate was not allowed to proceed with a project unless h/she could demonstrate to h/her teacher and the moderators that the project was viable and would meet the requirements of assessment. The

examiners described the philosophy (purpose) of this question to the Validation working party as follows;

“The aim of this question was to test the candidate’s ability to undertake a design problem of a similar nature to that facing him when presented with a project. The nature of the problem is of secondary importance and will determine the form of the answer [...] In this particular case a common mechanical component was given and the candidates were required to set up an investigation to determine, as fully as possible, the properties and behavior of the device. This type of problem is reasonably common, except that in the majority of cases the approach would be reversed, i.e. the design of the piece of equipment would call for a device of particular properties and the task of the designer would be to find or produce a device most nearly corresponding to his need. This inversion of approach is not of major importance however. Even in the situation now being considered, standard components are often used and it is therefore important to know as much as possible about the behavior of these components. [...] The component under consideration was a small spring requiring a tensile force of approximately 10 N to double its length” [...] In an endeavour to assist the candidate the task was divided into four parts and clear guidance was given on the aspects of design the examiners were looking for. The candidates were asked to list five mechanical properties of the spring to be determined and to sketch-design the apparatus that they would use to determine each of these properties and to outline the experiments to be carried out. Finally they were asked to draw up a time-table of operations. Attention must be drawn to the last sentence of the question which stated “It is very important that where possible and relevant you should explain the reasons for your choice of design apparatus or procedure” [27].

IX THE ENGINEERING DESIGN DEBATE

It was expected that there would be a high correlation between scores for the 50 hour project and the written planning exercise since incorporated in those scores was a project planning exercise for the actual project. This turned out not to be the case and this led to a debate between the proponents for a separate section on engineering design in the syllabus and those who thought that it would overload the syllabus [28]. Although the proposal was overturned a note was included in the 1972 *Notes for Guidance* [29] that said, “It is strongly recommended that the students familiarise themselves with the book *Introduction to Engineering and Engineering Design* by Krick (New York, John Wiley)..

X SOCIAL STUDIES IN THE ENGINEERING DESIGN CURRICULUM

From the beginning it was recognized that engineering had social consequences for society. How that should be accommodated within the engineering science programme was problematic. J. F. Gamlin, the Education Officer produced a

substantial document on the problem [30]. He suggested core material for the syllabus. While this was rejected some of his ideas were accepted. From time to time some of the comprehension exercises and projects included a strong social content.

On the basis of an experimental course in industrial studies that integrated organizational behaviour, economics and the history of technology given to participating students at one of the schools Heywood proposed an ‘A’ level syllabus in Industrial Studies [31]. While it received support from the co-ordinating committee it did not progress within the Board. The problem was never satisfactorily resolved.

XI COMPETITION WITH PHYSICS AND THE DEMISE OF THE SUBJECT

In spite of the small numbers taking the subject annually, the subject was retained by the Board for more than twenty years. In the semi-official report it is argued that its demise could have been predicted [32]. There were three reasons for this remark. The first was that it was already apparent that the demand for a qualified technological workforce was declining. The second and more significant was the competition with physics. From the nineteen seventies there were continuing discussions with the physics subject panel, and attempts were made to integrate some of content.

The third reason for its demise was the failure of the senior engineering professoriate to give full support to the subject and recommend that schools should encourage intending entrants to engineering departments to take engineering science rather than physics. Beliefs that engineering was simply the application of physics were deeply embedded and an objective evaluation was never undertaken by this key group in spite of the fact that evaluation data had begun to be made available as early as 1972 [34].

However, the semi-official report shows that the subject boxed well above its weight. It discussed the influence of the subject on the Board.. If it had been written fifteen years later it would have been able to record that in the United States the Committee on the Foundations of Assessment of the National Research Council in its report, *Knowing what Students Know?* -called for “balanced” systems of assessment to be struck between classroom and large scale assessment [35]. The principles enunciated seem to apply to any system of assessment. The nearest example found of such a system was the Physics B syllabus that Kelly accounted for above for which engineering science had been the progenitor. Elsewhere it has been shown that the principles of enunciated are directly applicable to the assessment of learning in engineering.

XII ACHIEVEMENTS AND DISCUSSION

Furneaux’s findings challenged the designers of the engineering science examination to question the validity of

what they were trying to achieve. Rather than have two papers that tested the same ‘thing’ their written examination comprised 4 components that could clearly be differentiated by the abilities they sought to test. Repeated analyses of these yearly examinations led them to conclude, that in addition to a factor that isolated the whole of coursework, they were measuring different qualities in each of the sub-tests. Their general evaluations clearly showed the impact that assessment had on learning and teaching, and the importance of integrating assessment into the curriculum process. This led to the design of curriculum process models that took into account assessment and at the same time indicated the dynamic nature of the process [36]. Within that framework an integrated philosophy of curriculum and assessment was developed [37]. Unfortunately there is little evidence to show that curriculum is understood to be an integrated process and assessment remains an afterthought of the educational activity. This is the challenge that continues to face engineering educators.

A serious weakness in the evaluations was that they focused primarily on the effectiveness of the examination and assessment procedures rather than on the effect that the subject had on the perceptions that students had of engineers and how they think and act in the workplace situation. There continues to be a need for investigations that explore these perceptions and the impact that teaching has on them.

This model was severely criticized at the time by industrialists because it was based on beliefs rather than facts about what engineers actually did. Studies of the kind initiated by the criticism [38] are rare even to this day. In any event the focus was on abilities rather than knowledge required to do the job which is where research should now be directed

Much of what was discussed over forty years ago is being discussed today in the various discussions on the role of philosophy in the development of engineering education. In this context the experience of engineering science continues to be relevant and it is fortunate that much of the documentation is extant

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An assessment of stress factors on engineering academics in a regional context

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Abstract— The Australian higher education sector has accepted that increasing work-related stresses can have a negative impact on the quality and productivity of academic life. Workplace stresses can have significant financial impact both on university budgets and the overall economy due to poor decision-making, health issues and accidents resulting from illness. Engineering academics that teach and/or research within higher education institutions have been reported anecdotally to have a high prevalence of stress. The actual (self-perceived) level however has been largely unquantified. The research reported in this paper was conducted to assess self-perceived stress levels and identify the stress factors within a cohort of engineering academics at the University of Southern Queensland (USQ), a small regionally based Australian university renowned for its distance education. The questionnaire was applied using a mix of validated and non-validated survey instruments and incorporated a set of questions previously applied at the University of Adelaide (UoA). Findings from USQ are broadly in line with those independently reported elsewhere for Australia and the UK, with some minor exceptions. In summary the USQ project indicates that engineering academics have higher perceived stress levels than the validated health threshold, with significant variation based on age, academic type (teaching-research), and for staff with English as a second language. The results from both universities also indicated that there are significant stress contributors related to the pressure to obtain grants and to publish and to the (low) resultant levels of recognition from employers for any success. More specific to distance education providers (such as USQ), there are stress contributors related to servicing and dealing with the external mode of course design, delivery and lecture preparation.

Work-related stress, workplace practices, faculty development, academic development.

I. INTRODUCTION

Academics in today's competitive workplace must work in an increasingly complex and stressful environment. The

Australian higher education sector and universities internationally have accepted that increasing work-related stresses can have a considerable impact on the quality and productivity of an academic's professional life. Workplace stresses can have significant financial impact both on university budgets and the overall economy as outcomes from poor decision-making, health issues (such as obesity, cancer, and heart disease) and accidents resulting from illness such as stroke and heart attack. This environment generally encompasses a variable blend of teaching, research and service responsibilities. Engineering academics that teach and/or research within higher education institutions have been reported anecdotally to have a high prevalence of stress.

Research from Medibank Private and the Australian Productivity Commission [1][2][3][4] reveals workplace stress costs the Australian economy more than \$14 billion a year. Absenteeism, and "presenteeism" where staff are present, but not productive, cost more than \$10 billion a year. The impact of negative workplace stress includes poor decision-making, an increase in selfishness (including a greater reluctance to help co-workers or customers) and an increase in workplace accidents

Unhealthy employees take up to nine times more sick leave than their healthy colleagues and healthy employees are nearly three times more productive than unhealthy employees. Prolonged stress can cause or contribute to all manner of health issues including obesity, cancer and heart disease. At its most extreme, workplace stress can cause sudden death via stroke, heart attack and suicide. The Japanese have a word for workplace stress, "karoshi", which literally translates as death from overwork.

The tertiary education sector in Australia is a significant contributor to Gross Domestic Product [5], and was valued at AUD \$18.6 billion in 2010 [6]. However, the impact of workplace stress on academics in research and teaching

environments does not appear to be widely understood or acknowledged [7][8]. In light of the introduction of a market driven, post-Bradley Review [9] deregulated higher education sector environment it is paramount to review the “health” of the tertiary education sector, in terms of workplace stress. Current studies that are being undertaken nationally include “Work and Careers in Australian Universities” by Griffith University and University of Queensland funded by the Australian Research Council [10].

In this research a study was conducted within a regional Australian university in the Faculty of Engineering and Surveying. This study mirrored a similar conducted at the University of Adelaide (UoA), considered to be a research intensive university [11]. This study aimed to assess the level of stress and identify individual stress factors (stressors), and stress variables that are unique to distance education (or online education) providers for engineering academics that have teaching-only and teaching-research responsibilities. Furthermore, it is envisaged that this study will inform further studies that aim to investigate the correlation between stress levels and perceived performance of academics in their duties.

II. METHODOLOGY AND METHODS

A. Methodology

The methodology adopted was a quantitative research approach; a systematic empirical investigation of social phenomena via statistical techniques [12]. Though the approach is far from a positivist framework or explanative in nature, it is intended as a pilot study with a limited cohort to inform the development of a larger multi-disciplinary study. The hypothesis for any future studies is that there is an empirical relationship between the levels of stress (and the stressors) and performance.

While the study is probably not extensive enough to generalize the findings, it will be useful to help inform further studies and university managers of distance education providers within an Australian context. The study is also an opportunity to solicit further insights into the specific experience of engineering academics.

B. Methods

There are 3 parts to the questionnaire developed for this study using a combination of validated and non-validated instruments. Part 1 is a validated instrument “General Health Questionnaire (GHQ-12) consisting of 12 questions [13] with Likert scale for responses. Question responses were assigned a score value of 0 to 3 to give a possible total Likert score of 36 which represent the highest stress level. The health threshold for unhealthy stress is a Likert score of > 12 [13].

Part 2 consisting of 15 questions was developed for the purpose of identifying individual stress factors (stressors) of which were created and piloted within a small interfaculty group [11] at the UoA, and is not validated. This part is designed to specifically solicit insights to highlight stressors of concern. The questions were divided and categorized as Tier A, B and C.

Part 3 consisting of 8 questions are stress issues that could be considered to be unique to USQ as a regionally based

distance education or online teaching provider with majority of students studying off-campus, and is not validated. The questions were divided and categorized as Tier A and B.

The survey instrument was applied using SurveyMonkey® to academic staff within the Faculty of Engineering and Surveying at USQ. Ethical clearance was applied for and approved for the study.

III. RESULTS

The survey was carried out between 10th Oct and 4th Nov 2011. A total of 39 staff responded out of a possible 70 academics equating to a response rate of 56%. This reduced to 34 valid responses which included 30 male and 4 female academics equating to a response rate of 49%. In comparison to the UoA’s study as illustrated in table 1, there seems to be a consistency across a number of indicators. This includes age and gender variables, in that academics are more likely to be more stressed if they were “mid-career” in terms of age and/or female. Overall mean GHQ-12 scores are fairly consistent between the two institutions, though UoA is slightly higher if Teaching-only staff was included. However, both institutions have higher stress scores against the GHQ-12 threshold (>12), indicating unhealthy levels of stress. Interestingly, the UoA’s study suggested that there is a stress trend decrease as age increases. This was not reflected in the USQ’s study though there is consistency in stress levels between the ages of 40 to 60.

TABLE I. COMPARISON OF USQ STUDY VS UoA STUDY

| Items | USQ | The Univ. of Adelaide |
|--------------------------|--|---|
| Participations | 34 Male | 49 Male |
| | 4 Female | 9 Female |
| Response Rate | 48% | 38% |
| Stress under 60 Year old | >12 | >12 |
| Female Stress | > Male | > Male |
| Overall Mean Score | 15.1 | 14.7 (16.1 including Teaching Only Academics) |
| Stress Trend | Not very clear. Stable among age groups between 40-60 years old. | Mean Lickert Score decreases as the age increases |

Figure 1 provides the GHQ-12 stress scores (mean, maximum, minimum) against age of the engineering academics surveyed. The 30-60 years age groups have stress levels higher than the GHQ-12 threshold of 12. The 51-55 years age group has the highest value of 18, followed by 56-60 at 17.8, and then 61-65 at 17.7. The deviation between maximum and minimum scores is the widest within at the 61-65 age groups

Figure 2 illustrates that female engineering academics (GHQ-12 score of 20) have significantly higher stress levels than their male counterparts (GHQ-12 score of 14).

Figure 3 illustrates that engineering academics from an English as-a-second-language background (GHQ-12 score of 16.2) have moderately higher stress levels than their English as a first language counterparts (GHQ-12 score of 13.2).

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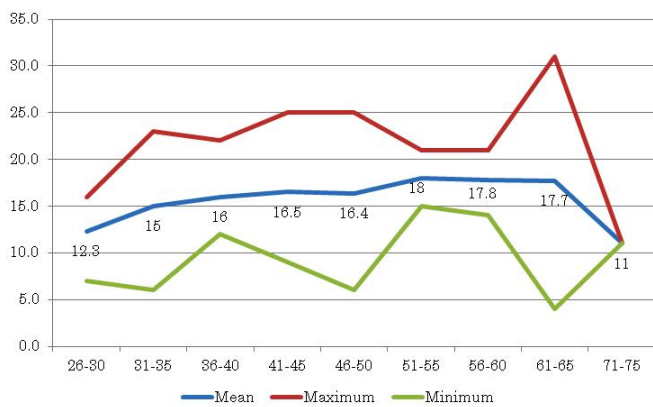


Figure 1. GHQ-12 Stress Likert Scores vs Age of academics surveyed

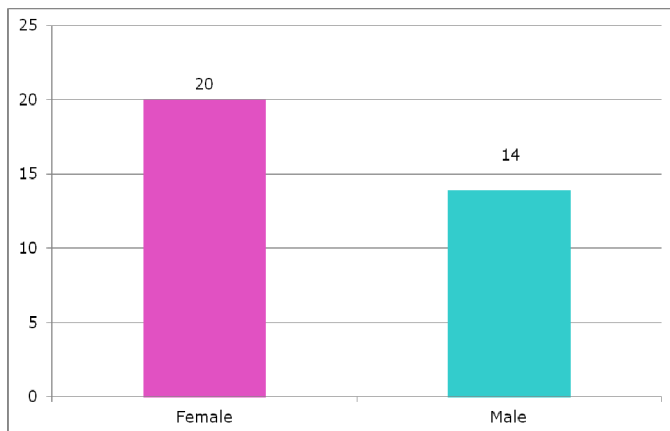


Figure 2. GHQ-12 Likert score averages of Female vs Male academics surveyed

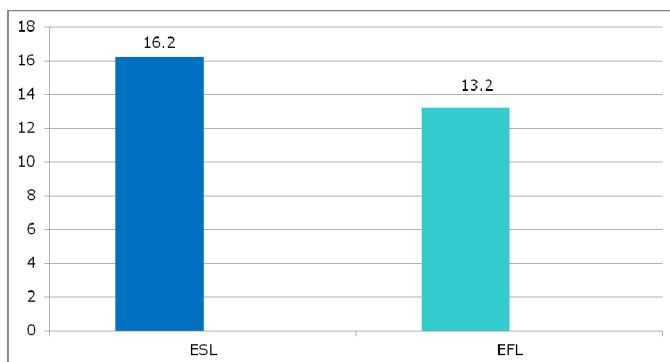


Figure 3. GHQ-12 Likert score averages of English second language vs English first language academics surveyed

Figure 4 shows that engineering academics with Teaching-only responsibilities (GHQ-12 score of 20.5) have significantly higher stress levels than academics with Teaching-Research responsibilities. This trend is consistent with the UoA's study.

Figures 5 to 9 highlight the sensitivity of the engineering academics to the different types of stressors, of which figure 8 and 9 are unique to distance education and/or online teaching providers.

Figure 5 illustrates that engineering academics are perceived to be highly stressed by the pressure to obtain

research funding, and to publish research outcomes. There were also stress issues arising from the commercially driven attributes of modern universities, resultant lack of confidence in its strategic direction, a perceived lowering of recognition, and lack of opportunities for genuine scholarship.

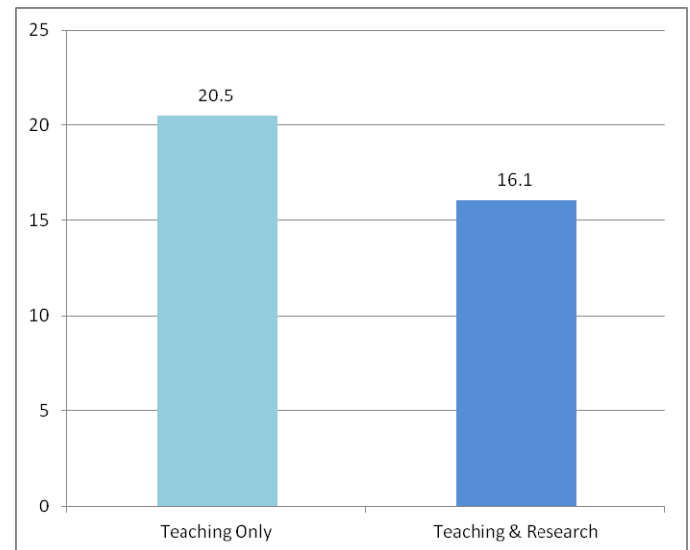


Figure 4. GHQ-12 Likert score averages of Teaching-Only vs Teaching-Research academics surveyed

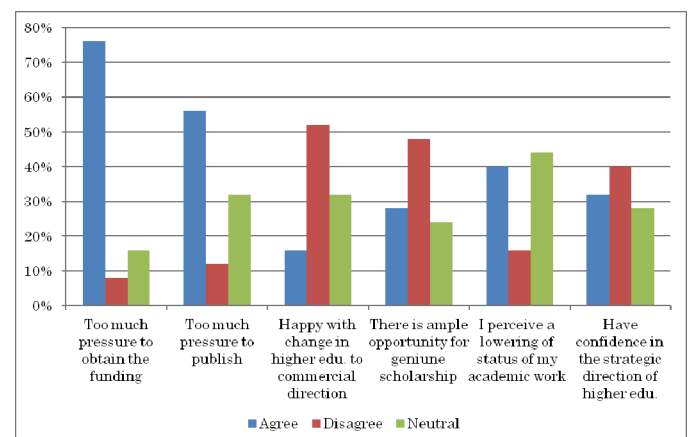


Figure 5. Responses for Stressor identification (Tier A)

Figure 6 shows the divide in the engineering staff profile in terms of stress associated with work-life balance, but there are some concerns with the administrative workload that are required for engineering academics. The results indicate that there is adequate support for teaching and maintenance of quality in the education the institution provides.

Figure 7 illustrates that original research is valued by the institution and expectation of academics' responsibilities are clear. Engineering academics surveyed think that class sizes are manageable and are not threatened by the possibility of job redundancies (within a commercially driven context as identified earlier).

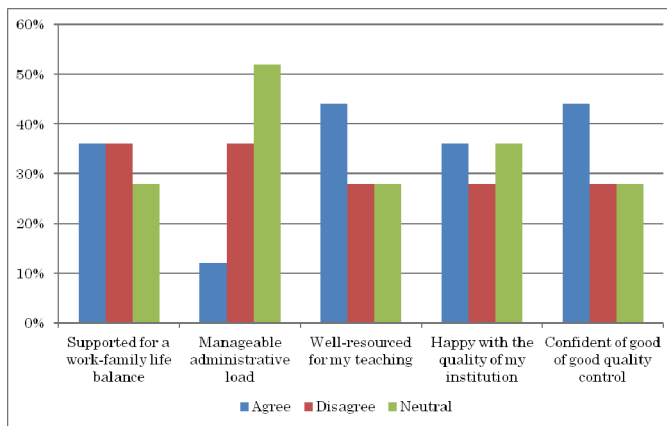


Figure 6. Responses for Stressor identification (Tier B)

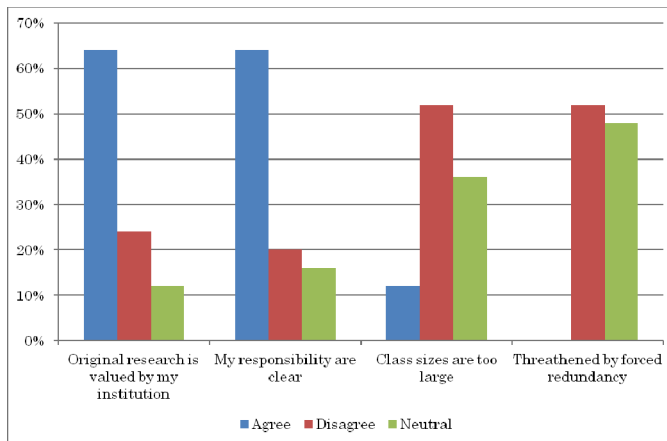


Figure 7. Responses for Stressor identification (Tier C)

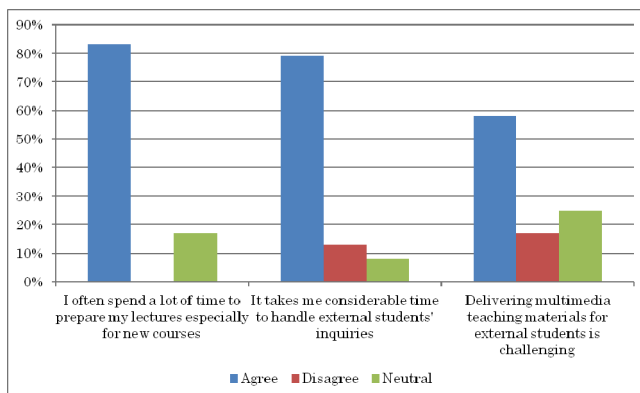


Figure 8. Responses for Stressor identification unique to USQ (Tier A)

Figure 8 illustrates there are stress issues around the preparatory requirements associated with development of “new” courses for teaching into on-campus and off-campus modes, but importantly, considerable effort is required to support off-campus students. This is in addition to the stress issues around the development and delivery of multimedia learning and teaching resources to both cohorts.

Figure 9 illustrates that there is stress issues associated with a moderate proportion of engineering academics that are finding it difficult to balance teaching and research pressures,

though they have an optimistic view of their career future, and are not overly concerned with impact of the levels of teaching commitments on overall quality and productivity on academic work. Small class sizes are not considered as a stress issue in terms of productivity of engineering academics.

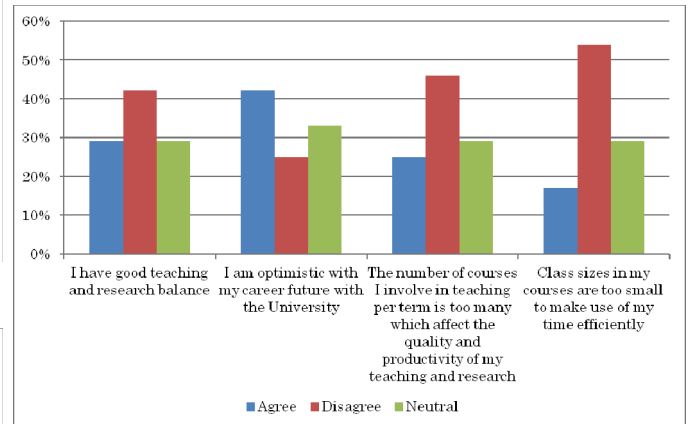


Figure 9. Responses for Stressor identification unique to USQ (Tier B)

IV. DISCUSSION

Though the response rate was significant within the cohort being investigated, the outcomes cannot be generalized across the tertiary sector. However, it is useful as a reference for further broader studies across disciplines or universities. The question of validity is confined to the faculty being studied with its associated influences; e.g. regionality, multi-teaching modes, online learning environment, male biased sample, and the Australian academic context.

The results have indicated that the overall self-perceived stress levels of engineering academics within the Faculty of Engineering and Surveying at the USQ are above the GHQ-12 threshold, and that “mid-life” age grouped and/or female engineering academics are significantly more stressed than other colleagues. It is also noted that the academics whose English is their second language are more stressed. Also teaching-only academics are more stressed than teaching-research academics. It may be that there are relationships (hypotheses to be tested) of perceived higher stress values evidenced in the surveys linked to:

- Gender imbalance within the faculty and the pressure associated with performance as a minority group;
- Difficulties experienced and lack of confidence in communicating effectively with colleagues and students in the English language. This is somewhat associated with performance as a minority group within a wider context in the community.
- Lack of time flexibility associated with Teaching-only workload allocation (eg. research activities are not tied to timetabled classes).
- Lower tolerance for functional and performance-related changes as age increases.

The study also provides insight into the growing pressure of engineering academics to obtain research funding and

publish research outcomes within the faculty. This is perhaps an indirect impact of the discourse and policies within the faculty to encourage engineering academics to pursue external funding and to publish extensively. However, this contradicts the finding that there is a perceived low level of resultant recognition of any success from the employer. Hence, the discourse and policies within the faculty and university may need to be explicit (rather than implicit) in recognizing significant achievements in both grant successes and publication achievements. Self perception of the value of academics' research output may also be a contributor to this contradiction but is not part of the scope of this research.

The study indicates there is a perceived lack of opportunities for genuine scholarship. Hence, it does suggest the growing financial discipline (including tightening workload based on activity-based costing) within a commercial-driven academia is affecting the traditional flexibility and affordability that were available to academics to experiment and explore scholarship within their respective discipline. This is perhaps an expectation that academics have retained their value system but felt constrained in the new competitive and commercially driven environment. This is supported by the finding that the respondents have a lack of confidence in the strategic direction, and are unhappy with the environmental changes in higher education.

The study shows there is a divide between those engineering academics who are satisfied with a work-life balance and those that are not. The cause of this divide is worth investigating further. However, it may be deduced that overall higher administrative workloads have played a significant part (whether it is from general, teaching and/or research related activities). It does suggest that the increased pressure to source funding and to publish may have played a part in creating this divide. However, it is worth noting that, overall, respondents are satisfied with the resources provided for "teaching", though it is unclear whether this response included administrative duties associated with teaching. This observed divide also explained the divide seen in the evaluation of quality of oneself and the institution. About a third of engineering academics surveyed felt the quality of their research and/or teaching "artifact" are compromised in some ways due to the time pressures.

Despite the pressure to source funding and to publish, original research is perceived as highly valued within the institution. This does indicate that the rewards or incentives are adequate, but that "value" could be better linked to public recognition (explicitly as mentioned before). Perhaps there is a systemic disconnect between the financial reward system within the Faculty and the university promotion system. It is seen that respondents are clear in their responsibilities in teaching and/or research. The issue then is if the expectations of academics were clear and that original research was highly valued, why is it that respondents felt they are not adequately recognized? Perhaps the university hurdles for academic promotion may be the cause, and worth investigating further in future studies.

Respondents felt that class sizes are not too large, indicating that the administrative burden identified earlier may

not be directly associated with teaching activities, but rather with either general or research activities. The stress issues around forced redundancy were not of concern for respondents indicating the value system associated with traditional academia are still strong and have not been affected by evolution towards a more commercially driven context.

Unique to USQ and possibly other distance/online educators, most respondents agreed that preparation and servicing students from both on- and off-campus modes takes considerable effort. This was of special concern when dealing with the multimedia expectations of teaching resource materials and servicing off-campus student enquiries. In some ways, this explained that traditional academia values have not caught up with technological and environmental changes within the higher education system. It may also be that the workload expectations for preparing and servicing off-campus teaching are not accurately reflecting the actual effort required. This may also explained the divide between respondents in that some prepare and deliver courses with larger off-campus student cohort than on-campus; or, co-exist in large teaching teams (hence smaller and targeted responsibilities) than small teaching teams (all teaching and administrative responsibilities) when teaching into courses. This finding (along with "teaching" being well-resourced and class sizes are not large) indicates that there is possible stress issues around the administrative workload (rather than direct teaching workload) associated with preparing and servicing off-campus student cohorts.

V. RECOMMENDED FURTHER WORK

Further work in the form of a qualitative study with semi-structured interviews should now be conducted to investigate the reasons for the causes of stressors. This will assist to help confirm some of the discussion points and generalizations made in this paper. In addition, further work in a broader cross-faculty study should be conducted within USQ, and possibly a much wider national or international study of engineering and science-related faculties across institutions in Australia with some international input.

VI. CONCLUSIONS

The Australian higher education sector has accepted that that increasing work-related stresses can have a negative impact on the quality and productivity of academic professional life. Workplace stresses can have significant financial impact both on university budgets and the overall economy due to poor decision-making, health issues (such as obesity, cancer, and heart disease) and accidents resulting from work related illnesses such as stroke and heart attack.

Engineering academics that teach and/or research within higher education institutions have been reported anecdotally to have a high prevalence of stress. The actual self-perceived level however has been largely unquantified. The research reported in this paper was conducted to assess self-perceived stress levels and successfully identified some of the stress factors within a cohort of engineering academics at USQ, a regional Australian university renowned for its distance education.

The questionnaire was applied using Survey Monkey with a response rate of 56% with a mix of validated and non-validated

survey instruments and incorporated a set of questions previously applied at the University of Adelaide (UoA), a more research intensive university. Although the scope of the study was focussed on USQ the findings correlated well with those from the UoA and should be useful to help generally inform academic managers across the sector. Findings from USQ are broadly in line with those independently reported elsewhere for Australia and the UK, with some minor exceptions.

In summary the USQ project indicates that its engineering academics surveyed have higher perceived stress levels than the validated health threshold, with significant variation based on age, academic type (teaching-research), and for staff with English as a second language. The results from both universities also indicated that there are significant stress contributors related to the pressure to obtain grants and to publish and to the (low) resultant levels of recognition from employers for any perceived success. More specific to distance education providers (such as USQ), there are stress contributors related to servicing and dealing with the external mode of course design, delivery and lecture preparation.

The findings in this study, supported by the earlier UoA study should be useful for academic managers such as Executive Deans, as they highlight some of the challenges and difficulties faced by their staff in an increasingly competitive and complex higher education sector.

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Starting a New Conversation: An Engineering Faculty Advisor Development Program

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Abstract— This work addresses a gap in the professional development of engineering faculty: student advising. The development and assessment of the Designated Faculty Advisor program is described, including training components, student and faculty responses, and future plans.

Keywords- advisor; advising; mentoring; faculty development; four-player model

I. THE MISSING CONVERSATION

It is widely agreed that challenges exist in the education of future engineers [1]. In California, Silicon Valley employers are concerned about the supply of “home-grown” engineering talent and urge K-12 and higher education sectors to promote STEM education to young people [2], and the nation’s demographics make it clear that tapping into the large pool of underrepresented minorities as well as women is a wise investment for increasing the number of future engineers. Review of many conference programs and journal issues in the engineering education domain shows how much effort the community has invested in bringing into, and retaining, non-traditional students in engineering programs through K-12 outreach, improvement in the effectiveness of classroom teaching, first year programs, awareness of diversities of learning styles, and summer research opportunities, to name a few. However, discussions of the quality of engineering faculty advising have not been widespread. This paper describes efforts to examine and improve this quality.

In the context of undergraduate engineering education, the term “faculty advisor” can refer to the intellectual advisor to a senior project, research experience, or other curricular-related project or activity; to the organizational advisor for a student section of a professional society; or to the academic advisor, with the primary role of helping students select courses and complete the prerequisite chain, and the secondary role of performing career mentoring and resource referral. The focus of this discussion is on the latter role of academic advising, specifically as practiced by engineering faculty.

Academic advising and mentoring share traits related to promoting student success but are not identical, as academic advising includes elements of curriculum and scheduling assistance that may be absent from mentoring situations. Mentoring also may involve a more intentional effort to role

model for students. There is a robust literature on mentoring in academic contexts, much of it aimed at faculty-student interactions related to research environments [3]. Some recent work has focused on the need to improve engineering faculty professional development in the mentoring arena [4]; one project, Engage [5], has identified faculty-student interactions as a key area on which to focus, developing workshop training materials for improving such interactions and exploring ways to efficiently embed best practices, based on research, into engineering colleges [6]. Muller has deeply examined both the need for, and the barrier to, more effective faculty-student mentoring interactions [7]. There is also a significant literature on academic advising for professional staff, with much recent focus on First-Generation students, under-represented student populations, and developmental student populations [8]. However very few published conversations about the significance of the faculty academic advisor role have occurred in the engineering education community [9].

Student advising involves a blend of direct teaching and indirect mentoring, and is frequently mistaken by both parties as a simple transaction. Consequently training for faculty advisers is often ad hoc, and the advising role may be seen as an unimportant part of a faculty member’s service component, not worthy of serious training or effort. However, for faculty to be effective advisors, they require explicit instruction in the policies and practices of the institution, in the mechanics of the institution’s processes and information systems, and to some extent in the theory of student development. They may also need practice in techniques for effective dialogue.

II. THE NEED FOR ADVISOR TRAINING

In the terminology of academic advising, there are two general styles: prescriptive and developmental advising [10]. Engineering faculty frequently engage in prescriptive advising, a model in which the student is the “patient”, the advisor is the “doctor,” and the “prescription” is a set of courses. The relationship is unilateral, transactional, unequivocal, and there is an implied contract stating that if the student takes the “medicine,” (i.e. enrolls in and passes the courses), the outcome will be positive (i.e. a degree will be earned). The prescriptive style is attractive because it does not require any training of the advisor beyond rules, policies and curricular roadmaps. The “doctor” needs to know his meds, but doesn’t

need any “bedside manner.” This style of advising may be effective for some students, particularly those who are highly self-motivated, come prepared to advising sessions, and do not have any personal, emotional, financial, academic or other barriers to a smooth academic path. However, even for the most well-prepared students, mentoring opportunities will be lost by using only the prescriptive style in all situations.

Given the complexity of our actual student population, the developmental style of advising is likely to be more effective; but this style requires a deeper understanding of student development, and also requires training of the advisor in the art and science of dialogue. In addition to a comprehensive understanding of all of the policies, programs and resources available on campus, the advisor needs to understand our students and their challenges and contexts, which are often far outside of the advisor’s own experience. Professional advising and counseling staff are expected to gain pertinent skills and knowledge in their masters-level, pre-professional training or through professional development, but faculty may be assigned an advisor role without being offered opportunities to gain these skills. This is unfortunate, particularly at public institutions, because as academic budgets shrink, as the reliance on part-time adjuncts increases, as accrediting bodies look more closely at graduation rates, and as the student body becomes increasingly more diverse and less traditionally prepared, the lack of attention paid to faculty advising is emerging as a serious issue.

The idea of offering faculty development related to advising skills is not unlike the issue of training faculty to teach more effectively. Over the last 25 years, awareness that engineering doctoral programs generally train faculty in research methods, but not in teaching methods, has given rise to thousands of articles and hundreds of faculty training seminars, workshops and conferences on effective teaching strategies [11]. The expectation that a new faculty member will come either prepared to teach effectively, or will attend professional development opportunities in order to become effective, has become the norm, particularly at undergraduate institutions.

Engineering has a significant dependence on faculty advisors rather than professional staff advisors, due to the complex nature of the disciplinary training. In addition, part of our responsibility as educators is to turn students into novice professionals. This task is not easy – and it mostly happens outside the classroom. The notion of academic mentoring for undergraduate students, much of which needs to take place in a one-on-one setting, particularly for more vulnerable students, is not commonly on the syllabus of professional development for engineering faculty. This work describes a first step in building a syllabus for faculty advisor professional development.

III. THE DESIGNATED FACULTY ADVISOR PROGRAM

A. Context for the Development of the DFA program

SJSU is part of the 23-campus California State University system and the 7th largest in terms of undergraduate population with nearly 25,000 students. The Charles W. Davidson College of Engineering serves approximately 2500 undergraduates and

1500 masters’ students, and awards almost 350 bachelors’ degrees and 600 engineering masters’ degrees annually (average of 2008-2012 data). Fall 2011 data show our engineering undergraduate population as about 14% women; 41% Asian-American/Pacific Islander, 18% Hispanic, 23% White, 3.3% Black, 0.2 % Native American, 6% international and 7% other or decline to state. About 40% of our undergraduates enter as junior transfers, primarily from the California Community College system. About 35% of incoming engineering freshmen place into calculus, while the remainder place into either pre-calculus, college algebra or developmental math. Helping students complete the degree in a timely manner is a high priority of the University, thus faculty advisors have responsibility for the challenging endeavor of helping students remain on the pathway to success.

The College is a major supplier of engineers to Silicon Valley employers and most of our alumni stay in the area. We have eight ABET-accredited undergraduate degrees, as well as degrees in Industrial Technology and Aviation; the faculty comprises 62 tenured or tenure-track faculty along with about 150 part-time lecturers. The Engineering Student Success Center staff includes the executive director, five peer mentors, one student support staff, and two FTE academic advisors who focus on general education and probation advising. Engineering students are also required to see a faculty advisor in their major every semester (enforced by a registration hold until advising is complete). Improving the effectiveness of faculty-student interactions in the advising domain (and by extension in the classroom domain) is a priority for the University and for the College.

For the past three years, the College of Engineering has been engaged in a significant effort to improve faculty advising [12]. Beginning in AY 2009-10, the College brought together faculty advisors from the eight departments to share best practices and to establish new academic policies on progress to degree. It soon became clear that to reach convergence on new college-wide advising practices, a program with faculty support and recognition was needed. Consequently in AY 2011-12, the College launched the Designated Faculty Advisors (DFA) program, for which the Dean and the Provost provided funding for one course release time for 16 faculty advisors. The components of the program are described below.

In addition to this program within the College of Engineering, the University also launched various programs to bring together advisors all over campus, including the Faculty Advising Liaisons, the Advising Council, which includes administrators from both Student Affairs and Academic Affairs, and a campus Advising Coordinator who maintains the online Advising hub and communicates campus-wide about events and presentations of interest to advisors. In addition, over the last four years, Student Success Centers have been opened in four different colleges including Engineering. The campus-wide increased focus on student success has raised the bar on expectations for faculty contributions both inside and outside the classroom.

The 2011-12 DFA cohort included 16 funded faculty advisors, chosen by department chairs. Some had been advisors for many years, while others were new to the activity.

All advisors were given one course release time for both semesters; some department chairs participated in all or some of the program, which consisted of an all-day retreat in August, and three meetings each semester in Fall 2011 and Spring 2012.

B. Components of the DFA program

A description of the Designated Faculty Advisor (DFA) Roles and Responsibilities are provided to the faculty before their selection for this program. DFA faculty are required to attend an Orientation Training in August (see Table I), as well as monthly DFA lunch meetings. The yearlong syllabus for faculty advisor professional development includes speakers, workshops and discussions on topics related to policies, practices, theory and mechanics of student advising. Each of these areas is discussed briefly below.

1) Policies

Academic policies on campus change frequently, especially during times of budget cuts and enrollment limits. Thus it is critical for faculty advisors to be kept up to date on policies, as well as to help develop specific policies for the College of Engineering. Working together towards college-wide practices prevents departments from diverging too widely in their academic policies, which in turn prevents confusion among students. For example, over the last two years a new College policy on Progress to Degree was formulated, adopted and implemented, after six months of consultation with advisors regarding curricular roadblocks, advising issues, and improvements to advising processes.

2) Practices

Documentation of student advising sessions is important for many reasons, including accreditation. Sharing best practices and developing new uses of technology in advising is an important benefit of having college wide advising group. When the University instituted new restrictions on change of major, the College was able to respond quickly by developing effective practices to help students navigate the new requirements while still making progress towards degree.

3) Theory

Engineering faculty have rarely had the opportunity to study the field of student development. The program includes a series of presentations by on-campus experts called "Knowing our Students Better," which includes topics such as cultural expectations and differences between various ethnic groups, special issues facing veterans and students with hidden disabilities, and general topics regarding student development.

4) Mechanics

DFAs are encouraged to use a variety of on-line tools to improve advising including the Student Administration database on Peoplesoft, as well as the **Advisor Blog**, an on-line discussion group site (built on BuddyPress) which provides a confidential location for faculty to ask difficult advising questions and serves to build the advising community. A **google group** is used primarily for communication about upcoming meetings, opportunities for professional development, and dissemination of policies and changes. Almost all departments now use an **online appointment system**, making it easier to get students to come in for advising

well before registration opens. A group of students and faculty are developing **mobile advising apps** and online **FAQs** for Engineering students.

IV. FIRST YEAR ASSESSMENT OF THE DFA PROGRAM

The development of the DFA Program was based on the twin hypotheses that (1) more effective faculty advising would result in improved student outcomes, and (2) that engineering faculty could be trained to be more effective advisors.

Student outcomes of interest include increased student satisfaction with their SJSU experience, higher retention rates, reduced time to graduation, and attainment of early professional success after graduation. First-year assessment of the program included measures only of student satisfaction. Assessment of the other outcomes is complex and compounded by many factors.

Much of the first-year program assessment examined whether faculty did become more effective advisors. The assumption was that by providing faculty with knowledge and skills, and by building an advisor community, "better" advising would result. The effects were measured in terms of faculty perception of personal change and student perception of their advising experience.

In order to assess the effectiveness of the first year of the DFA program, we used four instruments: a DFA orientation assessment survey, an online student survey administered during Fall 2011 and Spring 2012, a yearlong online faculty Reflections Log, and an online faculty survey at the end of the academic year.

A. Faculty Perspectives on the DFA Program

The DFA Orientation training components were assessed by an online survey immediately after the event. Formative assessment and perspective was gathered from the Major Advisors throughout the year by inviting them to submit reflections on their advising experience to an ongoing Reflection Log. A total of seventeen log entries were submitted. Since the entries were anonymous and since multiple submissions were encouraged, it is not possible to determine how many of the 16 or so different Major Advisors contributed to the log. A faculty survey was administered online at the end of the academic year, sent to all the DFAs as well as their department chairs. Fifteen individuals completed the survey, including 11 faculty advisors, 2 department chairs, and 2 chairs who also serve as DFAs.

The DFA August orientation agenda is shown in Table I. The training session was very well received; one respondent commented: "Great meeting – well organized, easy to understand. I learned a lot – thank you." The DFA Orientation was the first time many of the College advisors had met as a group, or met with the Engineering Student Success Center staff, and also the first time many of them had met professional staff from campus student support units such as counseling services, the disability resource center, and the University advising center.

A large majority of participants (88%-94%) found nine of the ten training components to be "useful" or "extremely useful." The toolkit training component was rated by the

largest number of participants as “extremely useful”. It was also noted that the use of advising tools is very uneven across the tools and across the group of advisors. There is thus an opportunity to increase both awareness and use of these tools. Participants also selected among six proposed themes for additional training, and identified very clearly as their top choice “informal discussions about effective Major Advising sessions,” which can be interpreted as an expression of the desire for community among advisors, reflected in later feedback about the program as well.

In addition to expanding their advising repertoire, the presence of engineering faculty from every department lent legitimacy to the advising activity, positioned advising as an important contribution, and encouraged the untenured faculty that advising would be considered a significant aspect of their faculty portfolio.

TABLE I. DFA ORIENTATION AGENDA

| Policies, Practices, Theory and Mechanics of Student Advising | |
|--|---|
| College of Engineering Faculty Advisor Program 9 am - 5 pm, August 17, 2011 | |
| 9am | Moving Towards Excellence: A Look at the Data |
| 930am | Who Are Our Students? Student Development/Student Involvement 101 |
| 1030am | Knowing When to Make Referrals to Counseling and Disability Resource Center |
| 1130am | Advisor Toolkits: Peoplesoft/Custom CoE Advisor Toolkits/Case Studies |
| 1pm | How Do We Know We're Getting Better? Assessing our Work |
| 2pm | Policy and Process: Probation/DQ/Reinstatement/Change of Major Processes |
| 3pm | Working Together for Student Success: Coordination of Campus Advising Resources |
| 4pm | Meeting Graduation Requirements: Requirements, Substitutions, Mechanics of Transfer |

In their Reflection Log entries, several DFAs comment that they believe the quality of advising is increasing and point to the value of belonging to a community of advisors. “It is great for the faculty because we are building a community of excellence in advising, and you don’t feel you have to walk a hard path alone,” one Major Advisor notes. Another indicated, “I think the [DFA] meetings are very important for the following reasons: 1) We get to know each other. This makes interacting to solve student problems smoother. 2) Everyone is on the same page (at least in theory) and is informed of the rules and challenges. 3) It raises the profile of advising to a higher level.” The importance of quality advising is expressed in another log entry: “I am much more comfortable with the quality of academic advising that I know students are getting now than I was before the pilot started.”

Several of their comments expressed satisfaction about having dispensed advice that made a difference. “There were many sessions where I felt my input was very helpful for charging an efficient and personalized education plan,” one advisor noted. Another expressed satisfaction at “...letting

them know the department cares that they succeed, and pointing them toward behaviors that will work for them and resources for help really feels like a good thing.”

Table II shows some of the responses from the end of year faculty survey. Of note is that more than half the respondents indicate change in the content of their advising session conversations. One advisor noted, “Now the questions change depending on what stage the student is at. New questions: What do you want to do with your EE degree? What is your favorite class? How are things going?”

TABLE II. SELECTED FACULTY RESPONSES TO YEAR-END SURVEY

| Since the start of the DFA program have you... | | |
|--|---|--|
| | Effectiveness of your advising increased? | Accuracy of your advising improved? |
| Yes | 40% | 33% |
| No | 27% | 47% |
| Not sure | 33% | 20% |
| | Expanded the referrals you propose? | Changed the content of your advising sessions? |
| Yes | 57% | 56% |
| No | 36% | 25% |
| Not sure | 7% | 19% |
| | Getting to know students better? | Feel part of an advising community? |
| Yes | 43% | 100% |
| No | 43% | 0% |
| Not sure | 14% | 0% |

Advisors noted changes in students as well, “I feel students have accepted our intent to have a quality program built on fundamentals. I feel that it is much less likely that at-risk students will be overlooked,” while another observed “The students are better prepared, and less likely to get into problematic situations. The path to success is clearer, and the failure modes better identified.” Another notes that “more students are coming in to ask about program/career...Also, I'm observing students stopping by to just share information about how their job search or internship search is going.”

B. Student Perspective on Advising

Assessment of student perception of advising effectiveness was accomplished by means of an on-line survey conducted with students after they met with their major advisor. The survey was designed to generate information that would address the following evaluative questions: How satisfied are students with the major advising? What do they like and not like about the major advising? What suggestions do they have for improvements?

A draft survey design was distributed for review and comment at the first professional development session for the

Major Advisors. Input received from the group was incorporated into a revised version which was tested with a group of students. After final revisions, the survey was introduced and first disseminated about 5 weeks into the Fall 2011 semester. Each week every department provided lists of the email addresses for students who had seen their Major Advisor that week, and the Dean's Office staff emailed the survey link to students as soon as possible following their major advising session. The email that arrived in each student's mailbox was introduced by a letter from the Associate Dean, encouraging students to participate and ensuring them that their responses were anonymous. Incentives in the form of \$20 gift cards were used to increase the response rate. A similar protocol was followed for the Spring 2012 survey, after it was revised and some new questions designed and tested. Some departments were more diligent than others in providing lists of appointments, so not every student who saw an advisor received a survey.

A total of 434 students responded to the Fall survey and a total of 590 in the Spring, giving a 27% response rate in Fall, and a 36% rate in Spring. The respondents represent 14% of the Fall undergraduate enrolled student population, and 21% of the Spring. The survey respondents matched other college data in terms of the gender distribution, the ratio of native versus transfer students, and the self-reported GPA distributions.

TABLE III. STUDENT RESPONSES: ADVISING TOPICS

| Advising session topics: | % discussion was "very" or "somewhat useful" | | % topic was NOT discussed | |
|--------------------------------------|--|--------|---------------------------|--------|
| | Fall | Spring | Fall | Spring |
| Internships and career opportunities | 21% | 36% | 71% | 59% |
| Graduate programs in engineering | 18% | 30% | 75% | 65% |
| Strategies for academic improvement | 26% | 41% | 67% | 55% |
| Resources for academic success | 30% | 40% | 64% | 55% |
| Scholarships | 14% | 25% | 79% | 72% |
| Balancing school and work | 25% | 34% | 69% | 62% |

Table III shows the change in advising session topics between the Fall and Spring semesters. In every case, a wider diversity of topics was discussed in a useful way during Spring than in the previous Fall, many of them pertaining to improving success or long-range planning. The percentage of students reporting that they talked with advisors about strategies for improving academic success increased from 26% in the Fall to 41% in the Spring; this may be attributable to the various advising workshops attended by the DFAs where they learned

about campus resources as well as observed role models for listening to students more carefully. In addition, more advisors became familiar with the academic probation reports and thus were able to identify which students were at-risk and bring up these issues during advising.

While some of the increased discussion of "career planning" topics, such as thinking about graduate school (increased from 18% to 30%), could be the result of increased Spring semester student focus on summer internships and graduation, the faculty responses provided earlier do indicate a sense of qualitative shift in the content of their conversations. Overall student satisfaction with their advising experience increased, and the percent that were dissatisfied dropped from 15% in Fall to 5% in Spring.

In open-ended questions during the Fall survey asking students to indicate what they liked best about the advising, 37% of respondents pointed to the advice they received. "[I received advice on] how to balance the rest of my time at SJSU," one student commented. "Good advice from professors who know the best route to graduate on time," another student noted. For 32% of respondents, the best aspect of the advising was the person-to-person interaction and/or the advice. "My advisor actually advised me and cared about my class selection," one student wrote.

An open-ended question from the Fall survey about what students liked the least about their advising session identified opportunities for improvement. One student noted: "[I did not like] the rushed feeling I got due to the high volume of students trying to get in with the advisor." Some students did not like their personal interaction with the advisor. "I wasn't comfortable asking questions. I felt he was judging me because I'm behind and because of my grades," one student noted. Many students pointed out that they would like more time with advisors and opportunities to talk about internships, scholarships and graduate school; advisors learned about this need and responded with improvements during the Spring advising sessions.

V. CONCLUSIONS AND FUTURE DIRECTIONS

Four main themes were reflected in responses from both faculty and students. From Fall to Spring, there was higher satisfaction with, and efficacy of, advising sessions. Both students and faculty indicated that a broader and more useful range of topics were discussed, which moved the experience of advising from "registration hold removal" to "academic success and career planning."

There was an emergence of personal and community transformations as a result of advising sessions. More students indicated they were likely to make a change in either course selection, future career, or study and work habits after their advising session. Faculty indicated a growing sense of community and openness to bringing up topics outside of a narrow script, as well as that they became more likely to identify and pay attention to at-risk students, as a result of the DFA program.

Survey questions about online advising highlighted the importance of face-to-face meetings. Fall and Spring student data shows that a significant majority favor meeting an advisor

in person. For example, students responded that “I was able to talk to a human and not a computer,” and “[I like] personal attention and ability to ask specific questions and receive specific answers immediately.” Although many suggestions were made for online improvements, they all pertained to processes and paperwork rather than communication.

Students’ responses to “most liked” and “least liked” open-ended questions mirrored each other around the theme of caring, knowing and respect. Students liked advising the most when an advisor cared about them and knew them, for example as illustrated by having already reviewed their records. Students liked advising the least when they felt disrespected, for example for weak academic performance, or when the advisor was late, or when they had an appointment and had to wait for long times. Advisors showing caring and respect were highly valued, as indicated in these quotes, “My advisor actually advised me and cared about my class selection,” and “It gives me confidence that [the advisor says] I’m headed in the right direction.”

The human interaction and sense that somebody is interested and cares about their progress is extremely important to a large group of students. This confirms what we already know about college students: faculty have a strong influence, and a relationship with a faculty member is very important to student success [16]. Thus, faculty development resources that would improve this aspect of advising would be most beneficial.

Preliminary results from the Designated Faculty Advisor Program show that training faculty in the policies, practices, theory and mechanics of student advising is a significant task, and one that has been heretofore largely ignored. The development of a professional syllabus for engineering faculty advisors will continue over the next several years using lessons learned from the assessment of the first-year program. For example, in response to student suggestions and in concert with a broader technology push on campus, more online tools and mobile apps are being developed to make advising records easier to use and document, while freeing up time in advising sessions for more substantive interactions.

The next phase of the program will focus on enhancing faculty-student interactions through the development of a Four-Player Dialogic Conversation model [13]. This is a model for developing dialogue which emerged originally from the family therapy domain [14], but has been adapted to business settings [15]. Work is planned in which this model will be adapted to developing training methods for faculty-student interactions. One workshop was held in Fall 2011 to introduce these ideas to the DFA group, and it received very positive comments and had faculty participating actively [12]. In addition to its use as a training method in person, this model may be very adaptable to use as an interactive video training method. These ideas will be explored in the coming year.

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Work in Progress: Empowering Teaching Assistants to Become Agents of Education Reform

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Abstract— In an effort to create education reform by promoting students' intrinsic motivation (IM) to learn, we are developing a program to train IM-supportive teaching assistants (TAs). We present our preliminary analysis of the first two TAs' reflective teaching journals and discuss what IM-supportive instruction looks like and how we can improve our training program.

Keywords- *motivation; intrinsic motivation, teaching assistants; training; reform*

I. INTRODUCTION

Although traditional efforts to improve engineering education focus on changing faculty's pedagogies [1], we believe that these efforts need to be complemented or even preceded by efforts that focus on improving instructors' support for students' intrinsic motivation (IM) to learn [2]. To test our beliefs, we created a pilot IM course conversion initiative to convert existing, large enrollment courses at a research-intensive university with minimal effort from the faculty instructor. The IM converted course looks like a traditional course: lecture taught by the faculty followed by discussion sections taught by teaching assistants (TAs). However, the IM TAs help the students learn how to direct their own learning rather than lead specific active-learning exercises. We have previously shown that this emphasis on IM rather than active learning can improve students' understanding of the course content and their learning experience [2].

In this work-in-progress, we discuss how we trained the first two IM TAs to be IM-supportive. We plan to continue developing this TA training program. This analysis will identify the habits of effective TAs, provide insights into the effectiveness of our training, and support recommendations for improvements in TA training. As TAs develop IM-supportive behaviors and have opportunities to transform their classrooms, they can become powerful agents of change.

II. CONTEXT AND TA TRAINING

We recruited TAs from a large-enrollment (more than 250 students), sophomore-level, computer architecture course. Two TAs volunteered to lead these IM discussion sections and attend a weekly one-hour training meeting on IM-supportive pedagogies and for peer support. IM is supported by increasing the students' sense of *autonomy, competence, relatedness*, and

purpose [3]. For example, IM-supportive teachers spend more time listening, articulate fewer directives, ask more questions about student needs, give fewer solutions to problems, make more empathetic statements, and offer greater support for students' internalization of learning goals (e.g., providing more rationale for why an assignment should be accomplished or for the value of the learning goals) [4].

In addition to training the IM TAs on these skills, we empowered the TAs to create course structures that reinforced students' senses of autonomy, competence, relatedness, and purpose [2]. For example, the TAs were given permission to let student learning teams create their own design project in place of an exam. Further, the TAs focused their attention on guiding these teams rather than presenting content or example problems during class time.

III. RESEARCH DESIGN

Each week, the two TAs wrote about 300 words in response to journaling prompts about their experiences. These prompts guided the TAs to identify challenges and successes as well as outcomes related to students' IM.

Based on a grounded theory approach, we started the analysis with by describing and conceptually organizing the TAs' journal reflections [5]. We used an open coding scheme to categorize the TAs' statements and actions to describe when and how the TAs used IM-supportive or controlling strategies in their interaction with students. A more detailed account of this analysis can be found in the I-STEM report [6].

IV. FINDINGS

Analysis of the TAs' journals revealed two contrasting behaviors: IM-supportive behaviors and controlling behaviors. Adoption of an IM-supportive mindset was challenged and revealed in two particular situations: identification of success as an instructor and responses to unwanted behaviors.

A. Identification of success as an instructor

An IM-supportive TA defines success in instruction by continual improvement. He has the mentality that all students can become intrinsically motivated to learn and aims to see that growth. This improvement orientation leads to constant reflection on himself as a teacher and how his actions impacted

the students. He explores and questions the sometimes competing demands of supporting students' learning while needing to promote specific behaviors to certify that the students have learned the required material.

"One of the hardest things to do while teaching is to find balance points. The balance comes between giving students autonomy and directing them explicitly, and between being open and friendly with them and having to chastise them if they screw up."

Similarly, IM-supportive behaviors were linked to critical reflection, a constant goal for improvement, and concrete plans of actions to create improvement. He evaluates his policies based on how those policies might affect his students (emphasis added):

*"I think it's a trait of a good teacher to have a set of relatively clear policies in place at the beginning of the semester; during the semester the teacher should not modify these policies. **This can allow students to focus their attentions on learning rather than policies.**"*

In contrast, controlling TAs define success by achievement of pre-determined goals. For example, since a controlling TA's goal is to evaluate students' IM to learn, he focuses on categorizing students as intrinsically motivated or unmotivated rather than critically reflecting on his actions.

"When I was a sophomore, I wasn't particularly concerned with grades, I was more interested in learning and understanding the material. I think the focus on grades is what separates the intrinsically-motivated students from the unmotivated/disinterested."

For example, one TA, after labeling his students, was slow to notice when students' motivations changed. When a "bad" group asked him to attend their group meeting on a Sunday, he failed to notice this auxiliary meeting or extra effort as a motivational change. Perhaps more telling, when a "bad" student approached him to get help with managing a project, his actions indicated an unwillingness to help and a lack of reflection on how to improve the situation:

"I told him that it wasn't my responsibility to make sure his group meets outside of class and distributes the project workload evenly, and that he should try to explain to his group that they should contribute more."

B. Responses to unwanted student behavior

IM-supportive TAs respond to unwanted student behavior with reflection on students' needs in addition to discipline. For example, in response to students' cheating, an IM-supportive TA identified the students' lack of a sense of competence (trust in their own ideas and freedom to fail) and relatedness (trust in the instructor) as barriers to motivation:

"...students need to learn to be creative and to trust their own ideas. This demonstrates students' current understanding, which may be slightly flawed, but as a teacher it's my job to gain students' trust and to structure

the course such that students feel comfortable making mistakes without a significant detriment to their grade."

In contrast, a controlling TA responds with quick-fixes to surface problems that do not identify students' needs.

"I'd prefer that students be relatively autonomous, but if they don't come to discussion, I can't help them. I'd prefer to never take attendance, but if the situation doesn't improve, I may start."

V. DISCUSSION AND RECOMMENDATIONS

The TA training raised the TAs' awareness of IM. Both TAs mentioned the importance of IM and sought to engender it among their students. The TAs also frequently referenced the IM-supportive goals of supporting students' four needs: senses of autonomy, competence, relatedness, and purpose. Although both TAs intellectually agreed to the importance of IM, they varied in their level of adoption of IM-supportive pedagogies.

In much the same way that intrinsically motivated students always seek to better understand a domain, IM-supportive TAs need to become relentlessly reflective to better understand their students. When students fail or appear unmotivated, TAs must reflect on how their actions meet students' four needs rather than label students as "good" or "bad." This emphasis on students' needs may be fostered by focusing the TAs reflections more explicitly on students' needs. Although we primarily intended for the TAs' reflective journals to be used as a research instrument, we discovered that reflection may be even more important as a training tool and empowering TAs to become agents of change. In response, we plan to develop tools to help TAs practice these reflective behaviors while they are in the classroom. By combining deep reflection with a solid theoretical foundation in motivation, we believe that TAs can play a major role in promoting students' intrinsic motivation to learn and creating a new learning culture.

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Department Climate: A Key to Recruiting and Retaining a Diverse and Successful Faculty

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Abstract—A *department climate* is the set of factors that affect whether department personnel feel appreciated, safe to express opinions, and respected by their administrators and colleagues. A 2006 study conducted by The University of Wisconsin *Women in Science and Engineering Leadership Institute* (WISELI) demonstrated that climate significantly impacts faculty members' job satisfaction and effectiveness and their decisions to stay or leave. Research also shows that climate problems have the greatest impact on members of underrepresented groups.

A project supported by the NSF ADVANCE-PAID program was carried out over a three-year period at a large public university. Heads of 25 departments (16 STEM, 9 non-STEM) participated in a series of workshops on the effects of climate on faculty recruitment and retention; faculty and staff from each department were surveyed using a variation of the WISELI Climate Survey; and the heads, faculty, and staff of each department formulated action plans to improve their climates. This paper summarizes and discusses the project implementation and outcomes, identifies the conditions that have the greatest positive and negative effects on climate, and suggests measures administrators and faculty members can take to improve their departments' climates.

Keywords: *Department climate, faculty recruitment, retention, diversity*

I. INTRODUCTION AND BACKGROUND

The *Collaboration on Academic Careers in Higher Education* (COACHE) regularly surveys 4500 tenure-track faculty members at 51 colleges and universities. In a 2006 report they reported a marked shift among junior faculty toward "caring more about department climate, culture, and collegiality than they do about workload, tenure clarity, and compensation" [1]. The data indicate that climate was as much as five times more important than compensation in predicting job satisfaction. Recruiting and retaining a diverse faculty is a continuing challenge in most STEM disciplines. In view of the dramatic finding just cited, deans, department heads, and faculty would do well to ask, "What is department climate, and how can we improve it for all our faculty, including women faculty and faculty of color who may be experiencing the climate differently from many of their colleagues?"

The *Women in Science and Engineering Leadership Institute* (WISELI) at the University of Wisconsin defines climate as "behaviors within a workplace...that can influence whether an individual feels personally safe, listened to, valued, and treated fairly and with respect." A widely disseminated WISELI study [2] indicated that department climate significantly impacts faculty members' job satisfaction, effectiveness, engagement, productivity, and decisions to stay or leave. Research also shows that members of underrepresented groups are more negatively affected than their majority colleagues by climate problems.

WISELI began offering a workshop series for department heads in 2003 as a part of their National Science Foundation ADVANCE (Increasing the Participation and Advancement of Women in Academic Science and Engineering Careers) grant. Department heads committed to attend three workshops during an academic year to learn about climate and ways they could effectively improve it in their departments. A climate survey was administered electronically to faculty and staff (and sometimes graduate students and postdoctoral fellows), and the ratings were shared with the department heads. Between 2003 and 2009, the survey was administered to 39 departments at the university with response rates varying from 27% to 76%.

Two notable findings of the WISELI project were these:

- While a majority of faculty and staff reported a positive overall climate, significant minorities ($\approx 13\%$ of faculty, $\approx 15\%$ of staff) reported a negative or very negative climate.
- Common issues emerged that contributed to negative climate ratings, including respondents' (a) feeling underappreciated for their work ($\approx 21\%$ of faculty, $\approx 22\%$ of staff) and isolated ($\approx 24\%$ of faculty, $\approx 18\%$ of staff), (b) lacking adequate resources for doing their job ($\approx 19\%$ of faculty, $\approx 11\%$ of staff), and (c) mistrusting those making decisions that affected them ($\approx 23\%$ of faculty, $\approx 20\%$ of staff).

The project described in this paper was supported by National Science Foundation ADVANCE PAID Grant Number 0820013.

II. PROJECT DESCRIPTION

In 2009, a public land-grant university with one of the largest undergraduate engineering student enrollments in the country received an ADVANCE Partnership for Adaptation, Implementation, and Dissemination (PAID) grant. The grant included (among other things) adapting the WISELI climate workshop series for department heads and the climate survey of faculty and staff [3]. This paper reports on the results of administering the adaptations to 25 departments over three academic years. Institutional Review Board approval was obtained for each component of the work to be described. The author functioned as the internal project evaluator, whose tasks included participating in all workshops, administering the survey, and compiling and analyzing the responses.

In 2009, two leaders of the grant activities went to the University of Wisconsin for training on the WISELI workshops and climate survey. In the 2009–2010 academic year the program followed the WISELI format of three workshops with the climate survey administered between the first and second ones. After the first year, the leadership team made a few minor changes to the survey in response to department head suggestions and comments from respondents and increased the number of workshops from three to four to allow more time for discussion of the survey results and their implications.

In the second and third academic years, the program organization was as follows:

- *Workshop 1: Introduction to climate and sharing of relevant COACHE data.* The value of the COACHE results is that they enable comparisons with peer institutions.
- *Workshop 2: Discussion of ways to improve climate and preview of the climate survey process.* Department heads were made aware of resources on climate improvement [4,5] and examined key ideas for improving climate and preventing biases from influencing hiring decisions. Procedures for administering and collecting the upcoming climate survey were then reviewed.
- *Administration of the survey to faculty and staff.*
- *Workshop 3: Discussion of the survey results and formulation of plans for sharing the results with the department faculty and staff.* Only the department head and project evaluator saw the results for each department's survey. The heads shared surprises and problem areas in the results and discussed possible actions to address identified problems.
- *Workshop 4: Discussion of faculty and staff responses to the reporting and of corrective actions taken in the departments and additional actions planned for the coming year.*

III. CLIMATE SURVEY

A. Survey structure and response rates

In the years 2009–2012, heads of 25 departments (16 in STEM disciplines, nine in non-STEM disciplines) participated in the workshop series, and faculty and non-teaching staff from each department were surveyed using a variation of the WISELI climate survey [3]. Respondents were given the WISELI definition of climate and were then asked to rate the overall climate in their department and their agreement or disagreement with each of 26 statements about the climate. They were also asked open-ended questions about factors affecting their department climate and the expectations they had of their department head. Surveys were sent to 1235 faculty and staff, and 913 responded for a 74% response rate, which is considered an outstanding rate of return for survey research. The breakdown of response rates by faculty and staff is shown in Table I.

TABLE I. SURVEY RESPONSE RATE

| | Surveys Sent | Responses Received | Response Rate |
|---------|--------------|--------------------|---------------|
| Overall | 1235 | 913 | 74% |
| Faculty | 829 | 625 | 75% |
| Staff | 406 | 288 | 71% |

B. Overall climate ratings

Climate ratings (5=very positive, 4=positive, 3=neutral, 2=negative, 1=very negative) were compiled for individual departments and the complete set of respondents, and the latter data were broken down into faculty and non-teaching support staff and into STEM (science, technology, engineering, and mathematics) and non-STEM disciplines. The results are shown in Table II. The heading “%neg” denotes the total percentage of “negative(2)” and “very negative(1)” responses.

TABLE II. OVERALL CLIMATE RATINGS

| | Ratings | | Dept. Range | |
|------------------------------|---------|------|-------------|----------|
| | Mean | %neg | Mean | %neg |
| Faculty (N=609) ^a | 3.90 | 11% | 2.9–4.7 | 0%–42.9% |
| Staff (N=275) ^b | 3.85 | 9% | 3.0–5.0 | 0%–32.0% |
| STEM (N=679) | 3.79 | 12% | 3.1–4.7 | 0%–32.5% |
| non-STEM (N=205) | 4.07 | 6% | 3.4–4.8 | 0%–25.8% |

^aWISELI data: Faculty mean = 3.69, %neg = 13%

^bWISELI data: Staff mean = 3.59, %neg = 15%

While roughly 70% of each group reported a very positive or positive overall climate, 11% of the faculty and 9% of the staff reported a very negative or negative climate (13% and 15% in the WISELI study). When thinking about climate, it is important to remember that underrepresented groups such as women in engineering often experience the climate differently from their majority colleagues. (Confidentiality requirements precluded separate compiling of survey results for different genders and ethnicities.) The consistency of the faculty and

staff ratings with those found in the WISELI study is quite good, suggesting that the survey data might be generalizable to comparable institutions (i.e., to large public universities).

C. Ratings of individual climate factors

Table III shows abbreviated forms of the 26 climate survey statements that respondents were asked to agree or disagree with (5=strongly agree, 4=agree, 3=neutral, 2=disagree, 1=strongly disagree), the mean responses of all faculty and staff respondents, and the responses for the departments with the highest and lowest overall climate ratings. Differences of one unit or more in the latter responses are shown in boldface.

TABLE III. AGREEMENT WITH INDIVIDUAL SURVEY STATEMENTS.

| Item | Mean | Dpt1 | Dpt2 |
|---|------|------------|------------|
| Overall climate rating | 3.9 | 4.7 | 3.1 |
| 1. Welcoming department environment | 4.0 | 4.6 | 3.3 |
| 2. Understand my role & responsibilities | 4.3 | 4.5 | 4.2 |
| 3. Have adequate resources | 3.6 | 4.5 | 3.6 |
| 4. Feel appreciated for my work | 3.7 | 4.2 | 3.0 |
| 5. Opinions & contributions respected by head | 4.0 | 4.6 | 3.7 |
| 6. Opinions & contributions respected by faculty | 3.7 | 4.1 | 3.5 |
| 7. Opinions & contributions respected by staff | 4.1 | 4.5 | 4.1 |
| 8. Trust in people who make decisions that affect me | 3.6 | 4.3 | 3.1 |
| 9. Influence decisions made in department | 3.3 | 4.0 | 2.9 |
| 10. Head appropriately consults or delegates decisions | 3.9 | 4.8 | 3.4 |
| 11. Feel safe voicing feelings in front of others | 3.7 | 4.3 | 3.2 |
| 12. Have heard faculty make biased remarks | 1.7 | 1.2 | 2.3 |
| 13. My work contributes to department mission | 4.4 | 4.6 | 4.2 |
| 14. My colleagues recognize my contributions | 3.7 | 4.1 | 3.4 |
| 15. Satisfied with professional relationships with others in department | 3.8 | 4.4 | 3.4 |
| 16. Satisfied with personal relationships with others in department | 3.8 | 4.4 | 3.4 |
| 17. Had a thorough performance review in past year | 3.7 | 4.3 | 3.2 |
| 18. Someone in department promotes my professional development | 3.4 | 3.8 | 2.9 |
| 19. Department emphasizes importance of diversity | 3.8 | 4.8 | 3.2 |
| 20. Resources are allocated fairly in department | 3.4 | 4.3 | 2.9 |
| 21. "Even though other people are around, I feel isolated." | 2.4 | 1.9 | 3.0 |
| 22. Work commensurate with my training and experience | 4.1 | 4.3 | 4.1 |
| 23. Same level of responsibility & recognition as my peers | 3.6 | 4.3 | 3.6 |
| 24. Head accommodates personal & professional conflicts | 4.0 | 4.5 | 3.5 |
| 25. Aware of places or people to go to with problems or issues | 3.9 | 4.5 | 3.7 |
| 26. Differences among people are valued | 3.6 | 4.4 | 3.0 |

On average, high ratings were given to statements regarding the respondents' sense of the importance of their work, their understanding of their roles and responsibilities, and the respect they received for their opinions and contributions, and relatively low ratings were given to their perceived influence on decisions made in the department, the existence of someone in the department promoting their professional development, and the fairness of resource allocations in the department. There were no consistent patterns of differences between responses of faculty and staff.

Some interesting results can be seen in a direct comparison of the responses to individual questions submitted by the departments with the highest (4.7) and lowest (3.0) overall climate ratings. The highlighted differences of one unit or more suggest measures that department heads and faculty wishing to improve their department climates might consider adopting. They include taking steps to make all faculty and staff members feel like valued members of a professional community; publicly acknowledging and expressing appreciation for their contributions and achievements; seeking and giving serious consideration to their opinions before making decisions that affect them; providing them with regular performance reviews; making sure that resources are fairly allocated among them; strongly discouraging any biased or demeaning language directed against any faculty member, staff member, or student for any reason, and countering it if it occurs in a public forum.

D. Preliminary analysis of open responses

Inspection of the survey respondents' open comments supports the recommendations made in the previous section. The comments suggest that both faculty and staff would welcome more opportunities for social interactions with their colleagues, greater transparency about department decisions and more opportunities to influence and inform those decisions, and less negative and bullying behavior. Staff in particular wanted more frequent communication about information and events and for others to notice and appreciate the work they do. Faculty sought more mentoring relationships and greater participation by their colleagues in seminars and social events.

IV. DEPARTMENT HEAD ACTIONS

The participating department heads received survey results for their departments and reported the results to their faculties and staffs. In some cases they transmitted all the results but more often they simply summarized response patterns, and then they discussed the results and identified actions that would be taken to improve their department climates. Actions taken included:

- establishing a task force or standing committee charged with developing plans to improve the climate;
- organizing more social events to promote interaction and reduce isolation;
- recognizing staff and faculty accomplishments in regular newsletters or in announcements in faculty meetings;
- including one or more staff representatives in faculty meetings;
- organizing brown bag lunches for the department head, faculty, and staff to discuss concerns and increase interaction.

V. FUTURE WORK

The survey responses contain a substantial body of information. Future work will include grounded theory analysis of the responses to uncover patterns and themes that may help

identify additional actions to improve department climates and reveal significant differences between faculty and staff responses and between STEM and non-STEM personnel responses. In addition, departments will be revisited to identify changes the heads made following their participation in the program and the impact of those changes on their departments' climates.

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Work in Progress: Developing and Evaluating Tutor Training for Collaborative Teaching

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Abstract—The use collaborative of pedagogies in undergraduate engineering courses are usually implemented by academics who place value on the student experience and their students achieving deep as opposed to surface learning. The professional development and understanding of appropriate theories needed to prepare materials and support student learning in these different teaching environments is often left to the academic to pursue independently, if at all. Whilst individual academics who revitalise courses in line with collaborative learning practices have the motivation, personality and teaching skills necessary to facilitate a class or groups of students, it may not be so for additional 'tutors' allocated to assist. Their differences in philosophy, personality and skills may have major impacts on the student learning experience. Even where tutors may be experienced academics in their own right, they may not fully understand the rationale and methods being employed and may need skill development. Professional development of academic staff is often overlooked in universities but it is vital for staff to engage in new learning and teaching practices and skill development if collaborative teaching strategies are to be sustained and make a positive contribution to the student learning journey. These factors become even more important as universities move into the online environment where meaningful engagement with the student cohort is significantly more than just making content available and having electronic submission of assignments. This paper describes the development of a strategy to train engineering tutors in online PBL facilitation, and the evaluation framework used to assess the effectiveness of this training. Results of the evaluation of training and subsequent behavioural changes of the tutors are given. The evaluation revealed a variance between the message of the training and subsequent practice. The method of evaluation, and subsequent findings were enabled, rather than constrained by the online environment.

Keywords—component; Problem Based Learning; professional development; tutor training; evaluation; online teaching

I. INTRODUCTION

The Engineering Problem Solving Strand is a core strand of four courses offered in all of the Faculty's undergraduate programs (Bachelor of Engineering, Bachelor of Technology and Associate Degree programs across all majors). The courses use a Problem/Project Based Learning paradigm and students work in teams to meet a wide range of course objectives. The team size varies in the courses from eight student per team in first year to four students per year in the

final year course. Objectives include both technical skills and knowledge as well as several key graduate attributes e.g. teamwork, communication, problem solving etc. The problems are open ended contextualized engineering problems. These courses have been recognised through several national awards for innovation in curriculum.

These types of courses have a high staff workload allocation due to the interactive and facilitative nature and often use a large number of part time (sessional) staff. Full time academic staff are also regularly rotated into the courses to balance workloads. Due to the unique nature of courses of this type and the general flexible learning environment offered at the institution, staff development is critical because each semester sees a new wave of staff who need to be quickly up-skilled in the learning and teaching philosophy, pedagogy, facilitation skills and procedural processes of a particular course. As a result of this concern, staff development resources and workshops were put in place to make sure that tutors understood the rationale of the course and how best to operate within it. However, until now they have been run on an ad hoc basis, with no formal mechanism to monitor staff requirements or evaluate either the workshop or the courses in terms of facilitator training.

PBL courses require high energy maintenance to keep delivering their promised benefits year after year. In developing staff resources it came to our attention that some of the pressure of this maintenance could be relieved by instituting ongoing monitoring and evaluation structures which would let course controllers know at any point in time how the courses were travelling and make informed decisions about change when necessary.

This paper researches and evaluates the success of the training program in changing tutors conceptual knowledge of PBL and how it operates, particularly in the online environment. We have analyzed tutor interaction with teams through postings to discussion forums to determine if this increase in knowledge changes tutors behavior from a transmission mode focusing on tasks to *facilitating* student learning and team work skills.

II. THE ROLE OF THE TUTOR IN PBL

PBL requires special skills in its teaching staff because it is a form of learning in which the learner constructs their knowledge based on prior skills, knowledge and their overall views [1]. The

prompt for the learning is an ill structured problem which is complex and does not have a single correct answer. Students have the opportunity to develop skills in problem solving, critical thinking and self directed learning [2-4].

PBL has three characteristics:-the learning is situated in a real life context or problem; students are responsible for their own learning and the direction of their own research; learning and ideas are elaborated and tested by group discussions [5]. In this student-centred discourse, students drive the discussion and the teacher serves to guide the learning process. Thus tutors or teachers of PBL do not „primarily disseminate information“ to students but guide the students to find their own answers, provide feedback, and stimulate student interest and learning [6]. Tutors scaffold student learning.

The effectiveness with which facilitators can do this is influenced by the conceptions the facilitators themselves have about effective teaching and learning [7]. Rando and Menges [8], propose that these personal theories of teaching and learning are often implicit and may be inaccurate. The theories may be broadly categorised into two main areas: „learning facilitation“ and „knowledge transmission“ [7]. Lecturers who see their role as transmitting knowledge are more focused on content than on learning. They have a didactic approach to teaching, seeing themselves as the content expert and their role is to pass on this content to the students, who passively absorb the knowledge. Many participants in our workshops have expressed concerns about how best to get the information across to students, thus revealing a transmission model. Other lecturers see their role as „facilitating“: encouraging students to learn for themselves and explore the content. These two different approaches to teaching may explain the different profiles and effectiveness of PBL tutors. [5, 7].

[6] reported on the major trends in studies investigating tutors in PBL. Not surprisingly perhaps, it concluded that the „content expert“ tutor took a more directive approach, using their content knowledge to direct the group discussions, whereas the non-content expert took a more supportive role and used „their process-facilitation expertise more to direct the tutorial group“. In addition, the research concluded that a tutor should „...know how to deal with the subject matter expertise“, although not necessarily be an expert, and know how to facilitate the learning process. Professional development for PBL tutors is therefore a matter of encouraging a truly facilitative rather than instructional pedagogic approach.

Recognition of the *skill* of facilitating and recognition that a tutors performance is not a stable characteristic but is partly situation specific are important factors to be considered by Faculty. This can be supported by opportunities that stimulate personal reflection and providing a good background in relevant educational theory and a thorough understanding of the key concepts of PBL. Our tutor training program aims to provide such opportunities by placing tutors in the role of students in a PBL session, supported by relevant resource materials and active discussion.

III. TUTOR RESOURCES AND TRAINING

Effective training programs for staff are an essential ingredient in the long terms sustainability and success of the PBL course or program [9]. It is critical that these professional development programs are ongoing, so as to support the program after the first flush of enthusiasm is over and that they can be delivered „just in time“ to meet the needs of new staff coming into the program or old hands who need to be revisit the rationale and methods of PBL.

In planning the training, several basic elements must be considered [9]:

- The educational goals and outcomes of the course or program, including the curriculum content.
- The resources which can be directed to the training program. This includes the time staff and management may be willing to devote to professional development activities.
- The evaluation of tutors/facilitators.

Our training program consists of a day-long immersive exercise, a thorough and up-to-date library of reference works to support tutors and an evaluation framework. In developing this program we have tried to tailor material for our specific implementation of PBL, our course objectives, but maintain some generic material which enables it to be used in other courses in other faculties with different goals. In time, some of the basic material will be in an online interactive format, enabling staff to undertake at least some preparation in their own time and review material as needed. All staff from the senior academic in charge of the course through to part time sessional tutors (of facilitators) were strongly encouraged to attend the course by Heads of Departments, Program Coordinators and the Associate Dean Learning and Teaching.

In line with PBL theory the training is presented as a PBL exercise using the Triple Jump Process as developed by McMaster University. The trigger for discussion and exploration of PBL is a video which shows a PBL lesson in a primary school. From the video, key concepts of PBL are explored and the participants generate a hypothesis which can be further explored in the available literature. From this exercise misconceptions and misunderstandings about PBL can be addressed and ideas for further self directed learning can be stimulated. This approach has the advantage of putting tutors in comparable situations to those faced by their students in PBL courses, which can include uncertainty about the objectives, the process and the outcome.

The second half of the training elaborates the insights of the PBL session through group discussion, typically of such topics as:

- Developing „questioning skills“; task orientated questions and monitoring questions can help students set goals, monitor progress (individually and of the group), activate prior knowledge and focus attention. These are in line with the facilitators educational goals for the student [2].

- Identifying common or recurring problems which arise in student teams and developing strategies and resources to deal effectively with these problems.
- Understanding the need for reflective practice both in

- students and for a in-depth examination of the tutor's own practice
- Understanding the implications of working in an on-line environment.

TABLE I. MATRIX FOR MONITORING ACTIVITIES

| FOCUS | PERFORMANCE INDICATORS | DATA SOURCES | DATA COLLECTION METHODS | RESPONSIBILITY FOR COLLECTION | TIME FRAME |
|--|--|-------------------------|-------------------------|-------------------------------|------------|
| <i>Objective: to encourage tutors to facilitate and scaffold learning through timely, well-placed, supportive guidance</i> | | | | | |
| Outputs Tutor participation in online discussions | Tutor responds to discussion at least once a week Tutor identifies and responds to learning process | Online discussion lists | Audit | Course controller | 2xsemester |
| Outcomes Students exchange ideas and identify learning | All students in group participate at least once a fortnight Students identify what needs to happen next | Online discussion lists | Audit | Course controller | 2xsemester |

With the clear need to redefine the tutor's role from instruction to facilitation, this day of training challenged tutors to begin their own learning journey. Although an evaluation of the day is carried out at the end of it, the true outcomes and impact can only be gauged after tutors have had some time to think over the issues presented, practice on their students and use the support materials. Since the courses build on one another from semester to semester there is also the possibility that needs and strategies will change over semesters and years. Our evaluation framework was designed to meet this reality.

IV. MONITORING AND EVALUATION

We have followed the lead of major development organisations, the World Bank and government departments in taking a program logic approach to monitoring and evaluation [10]. The approach identifies all relevant inputs, outputs, outcomes and impacts so as to decide what needs to be monitored and evaluated [11-13].

Table I shows part of the matrix we used in planning monitoring activities. For the sake of space we have dealt with only one output, tutor participation in online discussion lists and one outcome from that output. In practice several outputs and outcomes are usually associated with each goal.

The act of articulating the logic of the program in this way commonly reveals previously hidden and perhaps conflicting assumptions about what the program is designed to achieve and how it will achieve it, which immediately provides a rationale for this approach. However, once all the elements of the program have been articulated it is then possible to examine what needs to be monitored and how.

V. DATA COLLECTION

One of the goals of the project was to evaluate how well the initiative had worked and to make plans to monitor progress in order to be able to adjust training and tutor support in a timely manner if necessary. To this end a Program Logic analysis was undertaken [14]. At that time the monitoring decided on resulted in the following data collection strategy illustrated in Table II (although this may need alteration in the light of experience). The same process produced a list of evaluation questions for the first year implementation of the training and

resources which again may need to change with time. The data collection strategy was implemented using the cohort of first of the PBL courses (run in semester one of first year for all students). This is the largest course with approximately 550 students in 75 teams and 12 tutors (facilitators).

Only six of these tutors attended the training. As the course runs with the majority of students working in fully online teams the remainder of the tutors are not actually on-campus and hence could not participate. In time we plan to be able to run the training in an online format.

The tutors come from varied backgrounds including graduate students, experienced academics, a professional practicing engineer, senior school mathematics and physics teacher, a geologist and a physicist. Throughout the running of the course this team of tutors are supported to work as a team themselves with a staff discussion forum etc so as a group they can discuss student team issues, clarify „technical“ questions from the problems, moderate marking, share strategies etc. All tutors have access to all discussion forums so they can observe the work of all teams, but they generally do not post to the forum of another facilitator.

TABLE II. DATA COLLECTION STRATEGY

| Data Collection | Timing | Report |
|--|---|---|
| Exit surveys | Training day | Immediate to course controller Add to data log – annual report |
| Analysis of discussion lists – tutor behaviour | Scan Half way through semester End of semester | Feedback to tutors Add to data log – annual report |
| Analysis of discussion lists – student behaviour | Scan Half way through semester Annually | Feedback to tutors Annual report |
| Peer discussion | End of semester | Feedback to tutors Add to data log – annual report |
| Course reflection | End of semester | Feedback to tutors Add to data log – annual report |
| Library list | End of semester | Add to data log – annual report |

VI. ANALYSIS

Due to space limitations only a brief analysis from exit surveys, analysis of discussion forums and tutor course reflections will be discussed.

A. Exit surveys

The exit survey looked at both questions responses on a Likert scale and short answer responses. The survey covered the following questions. The training session:

- a) helped clarify my understandings of group learning
- b) helped clarify the role of the tutor
- c) motivated me to focus on learning processes not content
- d) gave me strategies for focussing on learning processes

A qualitative approach to the survey also asked the following questions:

- In my case the barriers to a more process-centred approach are
- Mechanisms I might use to overcome those barriers are
- The thing/s I like most about the workshop
- The thing/s I like least about the workshop

B. Discussion threads

An analysis of online teamwork and facilitation was used as a major source of data for consideration of the evaluation questions. The research team sampled the forum threads for each workgroup for one course in one semester. In order to restrict the volume of data to be analysed, a number of parameters were applied to the data collection. Only threads with greater than six posts were included for analysis, unless there was insufficient data from other threads for a given workgroup. The threads included were those in which the group facilitator contributed and responded to student discussion or interaction. Threads which were set up for the students to approach the facilitator with questions were not included, as these interactions constituted student initiated learning, rather than facilitator initiated. Likewise, posts from tutors which contained standard or generic course information or advice were not seen as significant for indicating facilitator performance, unless that information was particular to undertaking learning in PBL. Included in the data are the numbers of threads for each tutor which yielded data for analysis.

In analyzing the data, facilitator posts were coded according to seven observed nodes of interaction type. These were:

- **Confirmation**, in which the facilitator confirms a point from the discussion on the forum

- **Pointing out problems**, in which the facilitator points out a problem or potential pitfall with the team's work or procedures
- **Prompting content**, in which the facilitator prompts students to include some form of content in their report or assessment
- **Prompting learning behaviours**, in which the facilitator makes a post which encourages a certain learning behaviour or task to be performed by students
- **Providing content**, in which the facilitator gives students content to include in their report or assessment
- **Questioning**, in which the facilitator asks students a question about their learning or processes
- **Recognition**, in which the facilitator provides a positive acknowledgement that student work or processes are effective or appropriate
- **Reminders**, in which the facilitator includes a reminder regarding a task to be performed, content to be included or a procedure to be followed.

C. Course reflection

Reflections from tutors were collected in the form of responses to a structured template. Questions covered:

- **My background before joining the course** (e.g. background in Engineering, background in tutoring, new to facilitation, past experience as a student of the course, facilitated for several years, participated in training sessions, etc):
- **How I saw my role in the course**
- **My focus for facilitation during the course** (what I tried to work on and how with regards to facilitation, what I see as important in the course and how worked on this with students) :
- **My impressions of the course** (could be about course design, the role of the facilitator, the subject matter being learned, student responses, assessment, admin procedures, academic aspects, etc):
- **Conclusions/Recommendations for the future** (based on the above observations that were significant for me)
 - Problems (administrative or academic)
 - Positives (what things went well, what should we definitely keep)
 - Priorities (what should we be focusing on e.g. problem solving, technical aspects, teamwork etc) List in order
 - Processes (how can we structure the course to minimise the problems, keep the positives and hit the priorities); can be administrative, academic, resources etc

- **Comments to expand on the above (if necessary)**

VII. RESULTS

A. Exit surveys

The use of a PBL structure to teach the tutors about PBL appears to have been well received and judged appropriate as shown by the exit survey results and the comments of tutors at interview. However, some of the gap between tutors' knowledge of PBL and their practice of it may be attributable to the fact that a single workshop session may not constitute sufficient exposure to the method. One authority [15] is of the opinion that it takes five weeks for classes to adapt to the method. Nevertheless we are of the opinion that the format of the workshop was effective in changing tutors' *thinking* about what PBL means in terms of facilitation but a longer term strategy is necessary to change consistently *behaviors* and practices.

B. Discussion Threads

According to the theory of PBL, questioning and prompting learning behaviours are the most appropriate and effective facilitator behaviours. Confirmation, pointing out problems, questioning, recognition and reminders are also appropriate, as they do not contradict the tenets of PBL and they support effective learning processes, especially when used in combination with questioning and prompting learning behaviours. Prompting and providing content, on the other hand are seen as less appropriate, as they do not actively encourage student self-directed learning.

To give an idea of how each of these types of facilitation appear in practice, following are examples of each (taken from a variety of tutors).

- **Confirmation:** "You have it exactly right. For the best marks in almost every assessment criteria you should be endeavouring to demonstrate (not just theorise) this principle."
- **Pointing out problems:** "I get a lot of reports submitted where it's obvious that one person has come up with the design objectives and another has done the evaluation strategy, with barely any relationship between the two."
- **Prompting content:** One other thing that I would advise is to include your CoC within an appendix and refer to it within the TE&R."
- **Prompting learning behaviours:** "You should see your lack of knowledge (or inability to contribute further) as an opportunity to do steps 3 and 4 of the Problem Based Learning process."
- **Providing content:** "Ideas such as planting native vegetation on the W-WSW side of the shed to protect it from the hot sun in the afternoon should be part of your strategy."

- **Questioning:** "Do these evaluation questions stem from your background research and design objectives?"
- **Recognition:** "Having the two different lists is a good idea as it gives you a certain amount of flexibility for the next report."
- **Reminders:** "I would like you all to reread my opening post in this thread."

TABLE III. ANALYSIS OF DISCUSSION THREADS

| Facilitation Technique | Number of instances for each tutor | | | | | |
|-------------------------------|------------------------------------|---------|---------|---------|---------|---------|
| | Tutor A | Tutor B | Tutor C | Tutor D | Tutor E | Tutor F |
| No of threads yielding data | 10 | 8 | 8 | 2 | 2 | 1 |
| Confirmation | 4 | 3 | 4 | 3 | 1 | |
| Pointing out problems | 7 | 4 | 5 | 1 | | |
| Prompting content | 1 | 10 | 9 | 1 | | 1 |
| Prompting learning behaviours | 18 | 6 | 11 | 1 | 4 | 1 |
| Providing content | | 4 | | | | |
| Questioning | 12 | 2 | 1 | 1 | 3 | 1 |
| Recognitions | 7 | 10 | 13 | 1 | 1 | 1 |
| Reminders | 3 | 3 | | | | |

The Table III summarises the results by facilitation technique across each tutor for which data was available. However, a number of tutors' results are worth examining in closer detail.

Tutor A provided the best exemplar for PBL facilitation, by frequently displaying the desired facilitation techniques of prompting learning behaviours, questioning, pointing out problems and recognition. This tutor's discussion forums yielded a high number of instances of facilitation compared to other tutors, suggesting that this tutor was frequently, consistently and effectively involved in their groups' learning processes, without unduly directing them.

C. Tutor reflections

The tutor reflections provided a rich source of data and only a preliminary analysis can be provided in this paper. Tutors provided 'at the coal face' insight to many administrative aspects of the course from assessment criteria to the supporting technology available to the students teams e.g. wiki, synchronous and asynchronous communication mechanisms e.g. "Students found the university chat and wiki services unreliable at times" and "Students were generally unhappy with the time to receive assessment feedback."

Generally tutors believed in the aims of the course and through it provided a realistic grounding from students in many of the transferable skills which were in line with the course objectives. Given that several of the tutors were also past students who have since graduated and entered the work force their input is invaluable. However, despite the training the difficulty of „facilitation“ and understanding PBL remains a confounding issue.

However, few of the tutors made direct reference to the *training* in their reflections. The most valuable aspect of the training was in fact the „training evaluation strategy“ which they perceived as giving direct feedback to their facilitation styles and skills and directly supported student learning outcomes e.g. “Would like to get feedback on my „performance“ from other facilitators as well as students. I know we can look them up ourselves [from standard university course evaluation questionnaires] but might be a good idea to compile reports at end of semester. I liked getting feedback from [the evaluator] last semester to confirm strengths and highlight weaknesses.”

VIII. CONCLUSION

Following the training of tutors, a content analysis of online teamwork forums was undertaken to identify key appropriate and inappropriate facilitator behaviours. In comparing this data with the results from in-depth interviews with selected tutors, and broad exit data obtained following the workshops, it was found that the facilitation versus transmission message of PBL was effectively communicated, accepted and understood by participating tutors. However, key facilitation behaviours did not transfer to instances of actual practice in the online environment. It is argued that whilst the training was appropriate for promoting the required pedagogies, such training should be combined with a number of supporting strategies to be optimally effective. These strategies include specific and detailed development of questioning techniques appropriate for the PBL environment. Effective questioning needs to be continuously practiced and monitored to ensure a consistency of approach across the staff team. Further, these techniques, and facilitation in general, need to be considerate of the online environment, accommodate its constraints and capitalise on its inherent strengths.

A key component of PBL is reflection and this is true for staff as well as students. Staff need to be encouraged to maintain a program of self reflection on their facilitation practices in order to maintain and develop their skills and knowledge of PBL. It is clear that there is a requirement for on-going faculty-level development and support for academic

professional development in the area of facilitation. Without such continuous support and opportunity for skill development, PBL and other cooperative pedagogies are unsustainable, and may lead to reduced learning outcomes in collaborative learning environments.

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Developing Innovative Thinking Among Engineering Undergraduates:

Examining the Role of Slate Enabled Technology

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Abstract— This paper reports the planned implementation for a NSF sponsored study that is being undertaken to examine whether effective use of instructional technology, specifically slate enabled technology, has an impact on the innovative thinking skills among engineering undergraduates enrolled in large lecture classes. The methodology used in this study a quasi-experimental mixed method approach utilizing a control and treatment group. Findings from the planned study can be used to improve innovative thinking skills through effective pedagogical approaches which may include employment of various forms of slate enabled instructional technology.

Keywords—innovative thinking; pedagogy; faculty development

I. INTRODUCTION

Innovative thinking skill development among engineering undergraduates is of critical importance to the global economy. The ability to transform creative ideas into useful products and services through problem-solving that requires applying known information to unknown situations, finding new information and assessing its value or worth, and collaborating synergistically to develop ideas can be developed through pedagogical approaches that create engaging and active learning environments. Instructional technology, when used effectively, has been shown to enhance educational environments facilitating active and engaging learning strategies such as providing access to information, ideas, and collaborative exchanges focused on generating innovative solutions. Recent advancements in slate enabled laptop computers and smaller slate hand-held devices (e.g., Tablet PCs, iPads, HP Slate 500s), a form of instructional technology, and their impact on innovative thinking skills have been relatively unexamined.

II. BACKGROUND

Innovative thinking has been defined as a “complex thinking process that is used to transform creative ideas into useful products and services [1].” In the context of educating undergraduate science, technology, engineering and math (STEM) majors, included in the definition is the assumption that an innovative individual has the skills necessary to accept change, can carefully select tools employed in the thinking and design process, the ability to problem-solve by applying known information to unknown situations, the ability to find unknown information and assess its value or worth, and the ability to collaborate to synergistically develop new ideas [1,2,3,4].

Literature has attempted to highlight skills that innovative engineering undergraduates would demonstrate. Using TRIZ theory (e.g., a theoretical model for inventive problem solving), problem-solving methodologies, and a variety of corporate based literature as references, engineering educators suggest that students would be able to set goals for their own learning and identify when they need to seek new knowledge to solve problems. Innovative thinkers should be able to give and receive feedback on new ideas as well as possess the ability to represent those ideas visually and contextually. Students should also be able to think critically so that they can assess the value of their prior knowledge and elaborate, translate, and summarize known and new information [3,4,5]. Documented attempts to develop and assess these skills among engineering undergraduates have been limited to senior capstone design courses and an approach that includes additional classes or a new curriculum coupled with workshops and training for both faculty and students that introduces students to the concept of innovative thinking [2,3,4].

While these efforts show some promising results relative to the development of innovative thinking there is little literature that discusses how these skills can be developed among first and second year engineering students, many of whom are enrolled in large lecture courses where delivery of core engineering content is a priority. However, a wealth of knowledge based in cognitive psychology identifies pedagogical approaches that can be used to facilitate more collaborative, active and engaging learning environments even in large lecture-based courses. This paradigm and the body of research associated with it suggests that instructional technology, if it is employed effectively, can serve as a means to engage students and promote active learning; facilitating educational environments that are related to the development of innovative thinking among undergraduates [6,7,8]. For instance, the ability to acquire knowledge can be developed through activities that employ seamless integration of instructional technology that has students repeat concepts in new and different contexts. This can include online instructional modules that provide students with immediate feedback [9]. Scaling of ideas and information, a key skill for innovative thinking, can be facilitated by software such as OneNote that allows students to outline and organize information and then easily share it with others. Students' skills in this area as well as overall achievement increases when the ability to manipulate and add graphics is present in the educational software utilized [6, 10, 11, 12]. The ability to elaborate by paraphrasing and summarizing known information either visually or contextually through note-taking can be assisted by e-inking features that allow students to build upon instructor delivered content [6, 11, 12]. Critical thinking is also a key skill in innovative thinking and can be developed through collaborative activities and problem solving that asks students to generate new ideas and bring knowledge that is applied to new and different situations [13]. Individuals need to have the ability to identify their own comprehension and explore new solutions. Instructional technology such as instructor provided online resources or polling features that use clickers allow students to check their own comprehension and can facilitate innovative thinking skills as students build upon pre-existing knowledge [6, 14,15]. Collaborative activities that use a group of peers to generate new ideas can be further enhanced through instructional technology such as course management software that allows for discussion boards. These online forums allow students to ask questions of one another and pose new solutions; activities which are linked to the development of innovative thinking skills [6]. Finally, instructional technology can provide enhanced presentation opportunities that allow an audience to review new ideas and provide input facilitating the development of entrepreneurialism, a key component of innovative thinking [6, 7].

New and different teaching approaches that can include recent advancements in slate enabled technologies that include iPads and smaller hand held devices such as the HP Slate 500 have been identified as an attractive form of instructional technology for use among engineering undergraduates [16].

For instance, Tablet PCs have been identified as one form of slate enabled instructional technology that can facilitate learning among engineering undergraduates since this medium allows for drawing on the computer screen. This educational activity is a valuable way for students to annotate prepared lesson documents, replicate graphs and other visual content, and take and share notes that include diagrams [17]. While there is a lack of research about how slate enabled technology can be used to facilitate innovative thinking among engineering undergraduates, social constructivist learning theory provides a conceptual framework to begin to understand more clearly how this form of instructional technology can have an impact on innovative thinking skills. Constructivist learning theory posits that active learning strategies that encourage interactions between learners as well as with the instructor can aid in cognitive development [18]. Explorative research has examined how this form of instructional technology can be used among engineering undergraduates to encourage innovative thinking. For instance, critical thinking skills, interaction with peers and instructors, and active processing of engineering course content which are inherently tied to innovative thinking have been shown to be enabled by using slate enabled features such as inking features, polling, and software such as OneNote and Dyknow [19]. In addition, frequent use of slate technology and associated features such as e-inking capabilities by engineering students is correlated with an increase in learning behaviors linked to innovative thinking [20]. Other studies have shown that Tablet PCs provide opportunities for collaborative note-taking, interactive exercises, and real time assessment which can create more opportunities for active learning among students [17]. Paired with teaching strategies that encourage cooperative learning, the Tablet PC and related functionality have been shown to increase interaction between instructors and students and have encouraged more self-initiated exploration among students [21]. While primarily descriptive in nature, other studies focusing on engineering undergraduates have shown that the capabilities associated with the Tablet can serve as a means to facilitate a variety of pedagogical approaches and invite student participation and collaboration with one another [22] as well as with the instructor [23]. It is believed that the capabilities associated with the Tablet can assist engineering undergraduates who are enrolled in courses that cover material that is often mathematically and graphically intensive [24]. Surveys conducted at one university reveal that students report an increase in their confidence related to applying concepts learned in class when using the relatively easy note sharing capabilities associated with the Tablet PC [25]. Other studies examining the Tablets' role in the understanding and attitudes towards conceptual design are inconclusive [25].

The goal of our NSF sponsored TUES project is to examine whether effective use of instructional technology, specifically slate enabled technology, has an impact on the innovative thinking skills among engineering undergraduates enrolled in large lecture classes.

III. STUDY IMPLEMENTATION

An in-depth case study will examine the pedagogy in relation to how innovative thinking is taught and developed among students, including faculty use of and motivations for employing slate enabled instructional technology (e.g., Inking, DyKnow, OneNote) to develop innovative thinking skills. The methodology is a quasi-experimental mixed method approach utilizing a control and treatment group and will study how students enrolled in specific courses use slate enabled computing features and whether there is a relationship between that use and development of innovative thinking skills and student learning as measured by course GPA. Student survey data, observation of faculty teaching, observation of student engagement with course content, individual interviews with faculty, and focus groups among students enrolled in the courses being used in this study will provide these data. In addition, we will examine the technological infrastructure at the college and university including the degree to which the wireless network can actively support the use of instructional technology in large lecture courses and the amount of technological support provided to faculty and students through training sessions. Since 2006 the Virginia Tech College of Engineering has required all engineering undergraduates to have a form of slate enabled technology by requiring all entering students to purchase the Tablet PC. In order to assess the impact that these approaches have on students' innovative thinking it is necessary to have a control group of students. This control group, while exposed to slate enabled instructional technology as a result of the student Tablet PC requirement, are not in a course section where the instructor is intentionally using this form of technology to develop innovative thinking skills. The sample for the study will include among 1) entering freshmen enrolled in a first-year course and 2) upper-level students, primarily comprised of second year undergraduates, enrolled in a Statics course.

A. Data Collection

Student survey data will provide one measure of the impact of slate enabled technology on development of innovative thinking skills. Changes in students' innovating thinking skills will be measured by an online pre- and post-test administration of the Modified Strategies for Learning Questionnaire (MSLQ) (refer to Table 1). The MSLQ is a valid and reliable survey that provides a measure of the skills identified in the literature as linked to innovating thinking. This instrument has items that ask students how often they utilize the following skills including: knowledge acquisition (e.g., repetition of words or concepts), scaling (e.g., outlining, organizing information), elaboration (e.g., paraphrasing, summarizing), critical thinking (e.g., application of new knowledge to situations, generation of new ideas), self-initiated exploration (e.g., self-directed learning, setting goals, monitoring one's own comprehension), and peer collaboration (e.g., using a study group or friends to help learn and generate new ideas) [7] through the creation of scales from multiple

items. Our previous assessment efforts indicate that the scales indicate a high degree of reliability ($\alpha < .60$) based on Chronbach's alpha scores.

A more complete picture about how to effectively develop innovative thinking skills among students enrolled in a large lecture course and whether effective use of slate enabled technology facilitates that development, will be provided by direct observation of students and faculty members in class. In addition to having an observer sit in on the class, these class sessions will be videotaped for more complete analysis. Among faculty, we will examine the pedagogical approach used by the faculty member by using a rubric. The rubric will identify the frequency of use of key strategies identified in the literature that can be employed by an instructor to facilitate innovative thinking skills through active and engaging learning strategies as well as how often slate enabled technology is used in relation to those methods [6, 2,3,4].

TABLE 1. MEASUREMENT OF INNOVATIVE THINKING

| Innovative Thinking Skill | MSLQ Related Survey Questions Used to Measure Innovative Thinking Skill "How often do you do the following with your Tablet PC/Slate device?" |
|---|---|
| <i>Knowledge Acquisition</i> (Identifying new words and concepts, use of rehearsal strategies to memorize information) | -I studied by reading my notes over and over again. -I make lists of important items for this course and memorize the lists. -I memorized key words to remind me of important concepts from this class. |
| <i>Scaling</i> (Organizing information and concepts so that they can be integrated into designing of new ideas and information) | -I made simple charts, diagrams, or tables to organize course material. -To study, I reviewed my notes and made an outline of important concepts. -When I studied the readings for my courses, I outlined the material to help me organize my thoughts. |
| <i>Elaboration</i> (Summarizing known information; ability to reframe content) | -I make connections between readings and lecture notes. -I try to apply ideas from web-based sources to other class activities such as lecture and discussion. -When I studied for this course, I pull together information from lecture, readings, and discussions. |
| <i>Critical Thinking</i> (Application of previous knowledge to unknown, ill-defined and/or new situations; generation of new ideas) | -I often questioned things I heard or read in the course to see if I found them convincing. -I reread my course materials as a starting point and tried to develop my own ideas about it. -Whenever I read or heard an assertion or conclusion in class, I thought about possible alternatives. |
| <i>Self-Initiated Exploration</i> (Ability to question ideas and information being presented) | -I tried to change the way I studied in order to fit the course requirements and the instructor's teaching style. -When studying for the class I tried to determine which concepts I didn't understand well. -When I was confused taking notes |

| | |
|---|--|
| | in class, I made sure I sorted it out afterwards. |
| <i>Collaboration</i> (Ability to seek and entertain new ideas from peers and instructors; ability to utilize peers as a means to check new ideas and concepts) | -When studying for my courses, I tried to explain the material to a classmate or friend. -I tried to work with other students from this class to complete the course assignments. |
| <i>Entrepreneurialism</i> (Use of team members to determine what creative ideas can become valuable innovations; effective presentation of new ideas to others) | -I solicited input from others on new ideas. -I collaborated with peers or others outside of class to generate new ideas or concepts. |

In addition, we will conduct individual interviews with participating faculty to determine what motivated them to utilize active and engaging learning strategies, including slate enabled technology, and their perception of what impact the use of these strategies has on students' development of innovative thinking.

Student engagement in relation to strategies designed to teach innovative thinking will also be examined during classroom observations. This will also be done by using a rubric that measures how frequently students utilize strategies and learning behaviors that are linked to the development of innovative thinking as well as how often those strategies involve slate enabled technology [6,2,3,4]. Students in all course sections will be asked to participate in focus groups that will explore the degree to which students perceive different instructional strategies have helped them develop innovative thinking strategies. Focus groups with students will help identify what pedagogical approaches were most useful for helping them learn and whether slate enabled technology facilitated that learning.

Information about the infrastructure will be collected by identifying the number of wireless issues encountered during a given class. We will also document the amount of training or technology support sought by students and faculty in each participating course section. This information is provided by a card swipe feature that enacted as a sign-in feature through the Software Assistance Triage (SWAT) team that provides technology support to the College of Engineering. Given the fact this study focuses on the use of slate enabled technology and related features, several of which rely on wireless capabilities, the infrastructure is an important variable that can influence how often faculty use this form of technology as well as the success in which that technology is employed.

B. Data Analysis

In terms of the quantitative data, having students grouped by treatment and control groups will allow us to examine the impact that slate enabled technology and active learning strategies that employ this technology has on student learning and the development of innovative thinking skills. This will be done by comparing the growth in student learning (e.g., GPA) and innovative thinking skills in each skill area after creating the scales (i.e., knowledge acquisition, critical thinking, scaling, collaboration, entrepreneurialism, self-initiated exploration) as measured by the MSLQ, between and

among students enrolled in the different sections using a Factorial ANOVA. The MSLQ will be administered online to all of the students enrolled in the participating four course sections two weeks into the fall semester. Changes in students' innovative thinking skills will be measured by an online post-administration at the end of the fall semester. This will allow us to determine the differences in growth among and between students by grouping them by control and treatment groups as well as by class year (i.e., first year students, second year and upper-class students). In addition, Pearson's correlations will be used to determine whether the frequency of usage of this instructional technology by faculty and students as measured by items on the survey that gauge student perceptions about how frequently both groups use this technology and related slate enabled features in a semester has a significant relationship with student learning as measured by GPA and different innovative thinking skill areas (i.e., knowledge acquisition, critical thinking, scaling, collaboration, entrepreneurialism, self-initiated exploration) as measured by the MSLQ scales.

Observational data collected from faculty and students using the rubric will be tallied. In terms of the faculty observations, the frequency of use of different pedagogical strategies, including those using slate enabled technology, designed to develop innovative thinking will be compared using chi-square to determine if there is a difference by faculty member. Among students the frequency of use of different skills associated with innovative thinking and how often those skills are employed in conjunction with use of slate enabled technology as well as without the use of slate technology will be conducted using chi-square to determine if there is a difference in the frequency by the course students are enrolled in.

C. Model Development

Following data collection in the fall semester our analysis during the spring semester will allow us to determine the degree to which innovative thinking skills have developed over a semester, and the extent to which that was impacted by use of slate enabled technology and related features through intentional instructional strategies as well as student employment of these technologies in their classes. The mixed-method concurrent strategy being used in this study will allow for the integration of the qualitative and quantitative data. As these data are interpreted we will use the information gathered to create a model.

Following development of the model we will then use the summer to train two faculty members that did not previously receive training on how to create active and engaging learning environments through use of slate enabled technology and other methods. One faculty member will be teaching a Statics course while the other will be teaching the same entry-level engineering education course. During this phase of the implementation, the training will focus on the pedagogical approaches using slate enabled technology that impact innovative thinking skills among engineering undergraduates

enrolled in large lecture courses as determined by our first phase of data collection. The fall semester, following this training, we will use all four faculty members (both the ones that participated in the initial data collection and those that participated in the training of the model) and their four respective course sections to employ a similar research design as outlined above to validate our model. We hypothesize that after training on how to effectively use slate enabled technology and other methods to develop innovative thinking skills among students enrolled in large lecture courses that students will develop innovative thinking skills in the same manner across groups after exposure to an educational environment that maximizes use of active and engaging learning strategies that employ slate enabled instructional technology in an effective pedagogical manner. The pilot implementation during the fall semester of 2013 will allow us to determine the effectiveness of the model we developed. As the pilot model is implemented we intend to conduct similar comparisons in terms of pre- and post- assessment as well as direct observation among the new cohort that would enroll in the classes during the pilot implementation. We will also be able to track the cohort that participated in the fall 2012 collection of data. Among the first year students who have progressed to the second year of study, many of these students elect to take Statics in their second year. We will be able to group these students by who taught their first year engineering course in order to examine longitudinal differences and determine whether or not having an initial exposure to pedagogical approaches that use slate enabled technology during their first year has any residual effect on development of their innovative thinking skills as they progress through their course of study.

After the pilot implementation of the model, the data collected during the pilot phase will be examined and the information will then be used to further refine the model we have created. Following this refinement we will be able to distribute and share our results among interested stakeholders at our university as well as to a national audience through conferences and publications.

Data from the focus groups and individual interviews with faculty members will be transcribed. Following transcription, the focus group interviews will be coded using the constant comparative method to determine what themes emerge from the data in relation to students' perceptions about whether slate enabled technology and related features or other pedagogical methods assisted in encouraging innovative thinking. The faculty interviews will also be coded using the constant comparative method to evaluate what motivated faculty members to use this technology as well as how they felt different approaches they employed facilitated innovative thinking among students.

IV. CONCLUSION

Findings from this project will advance the understanding of how students learn to be innovative in the form of measurable and identifiable learning outcomes. In addition, information about how best to teach innovative thinking skills among undergraduates in an active and engaging educational environment using slate enabled instructional technology will be provided in the form of a model. The model considers faculty motivation for employing active and engaging learning strategies that utilize instructional technology in developing innovative thinking, the infrastructure (e.g., wireless capabilities, student requirements, technology support) that is necessary to facilitate such a model, and how to assess the extent to which the employment of the model has been effective. The broader impact of this project is in its ability to develop an exemplary model that can be used to develop a cadre of faculty who effectively employ instructional technology within large lecture classes in a manner shown to develop and enhance the innovative thinking skills among engineering undergraduates. We have targeted first and second year large lecture courses that are fundamental components of the engineering curriculum at our university. As this model is implemented the initial focus will be on developing innovative thinking skills among our engineering undergraduates at critical points in their course of study. As the model is refined the implementation can reach students at upper levels in their undergraduate career. We will seek to examine differences by gender and race in measurable changes in innovative thinking skills to determine whether the model is applicable across the undergraduate student population to the same degree. While certain pedagogical approaches, such as collaborative learning strategies, have been shown to have a positive impact among both male and female retention in engineering degree programs, the degree to which those approaches utilize instructional technology as a component in facilitating collaboration is largely unexplored. Our research will add to this body of literature by examining the degree to which collaborative learning strategies using instructional technology impacts attainment of innovative thinking among undergraduates by gender and racial/ethnic status.

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Work in Progress: The Effects of Mobile Learning on Inquiry-Based Instruction

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Abstract— Recently, inquiry-based learning has been used to enable students to ask scientific questions and come to objective conclusions based on observation and experimentation. Within this context, we have been exploring the impact of mobile devices upon different modes of learning including inquiry-based instruction. While much attention has been on the acquisition of mobile devices for the classroom, mobile learning has the ability to facilitate education beyond the confines of the brick and mortar to improve information retention and student engagement. This paper describes research being performed at Miami University which explores best practices in engaging students in inquiry-based learning experiences using a suite of technological tools (including a mobile app) being developed to support citizen science and research data collection.

Keywords- *Mobile learning, inquiry-based instruction, citizen science*

I. INTRODUCTION

With more than 50% of US mobile subscribers owning a smartphone [1], it is no wonder why educators and researchers are trying to tap into the learning potential that smartphones possess. In particular, the ongoing cost of updating traditional textbooks combined with the diminution of educational funding has motivated several schools across the US to invest in tablets and other mobile technologies. Despite the hype surrounding mobile devices and their applications in education, the lack of literature and underdeveloped m-learning pedagogies has made it difficult to know the true educational effectiveness of various mobile learning solutions. At Miami University, we are investigating the effects of mobile devices on inquiry-based instruction, a particular model of learning where the fundamental focus is on “learning by doing”. Specifically, we want to know (a) how learning is affected when students are not actively engaged in the entire process of some scientific investigation and (b) whether or not there is something we can do with mobile devices that improve information retention in these types of environments. In performing this research we will be able to develop a methodology highlighting best practices of mobile devices in inquiry-based learning environments. Considering the overall lack of research on mobile learning effectiveness for specific models of learning and limitations of current apps supporting inquiry-based learning, the products of this research are a valuable contribution to both education and computer science fields.

II. BACKGROUND AND APPROACH

With mobile learning being a relatively new field, there have been several competing definitions. One of the more widely cited definitions is by Quinn who defines m-learning as simply “elearning through mobile computational devices” such as Palms and Windows CE machines [2]. Clearly, mobile devices have come a long way in terms of functionality and computing power since the advent of PDAs. As such, mobile devices are now in a better position to influence how people augment their learning experience.

Inquiry-based instruction is defined as the creation of a classroom environment where students are engaged in open-ended, student-centered, and hands-on activities [3]. With regards to science education, Banchi et al. suggest that there are four models of inquiry: confirmation inquiry, structured inquiry, guided inquiry, and open inquiry [4]. For this research, we are focusing on how well mobile devices can facilitate structured inquiry, a type of inquiry where students are given the research question and the experimental procedure, but are expected to draw their own conclusions based on the results from their experimentation.

According to an article in BioScience the term “citizen scientists” refers to volunteers who participate as field assistants in scientific studies [5]. The article goes on to say that citizen scientists (a) are not paid, (b) are often amateurs, and (c) strictly gather data and are not involved in the process of analyzing data or authoring scientific papers. On some wide-scale research projects, it may be beneficial for researchers to have assistants whose sole purpose is to perform experiments and collect data (potentially using a mobile device to gather data). In doing this, however, the assistants are potentially disengaged from core aspects of inquiry-based learning, thus affecting their ability to acquire new knowledge about the research topic.

III. APPROACH

We are studying the effects of mobile devices on inquiry-based instruction. In our study, we are randomly dividing our participants into four different groups (based on a combination of level of participation and use of a mobile device), having them gather data for a simple experiment, and then evaluating the perceived engagement, learning, and attitudes towards mobile devices through surveys administered to the

individuals in each group. The remainder of this section describes the users in each of the four groups and the expected performance of each group.

Depending on the size, a given research project could be comprised of at least two different types of people, each having a distinct participatory role. The first type would be the lead researchers; people who have specific research goals in mind and are therefore following the scientific method (or some similar model) in its entirety. If the research requires an exhaustive collection of data, lead researchers may harness the power of citizen science by having masses of volunteers (with or without formal training) collect various pieces of data and report their observations to the lead researchers. These volunteers are potentially disengaged from the scientific method (or some other inquiry-based procedure) and therefore do not fully understand the purpose of the data they are collecting or the goals of the research project. For the purpose of this research, this type of engagement will be called *limited participation*. Lead researchers, on the other hand, are cognizant of every detail of a research project and therefore have *full participation* in the scientific process that is guiding their study.

The inquiry-based model we will focus on in this research involves the scientific method, a common process researchers follow in order to properly define research problems and acquire new knowledge based on the results of experiments and observations. Specifically, the model we follow has five basic steps (define research problem, make observations, formulate the hypothesis, experiment, draw conclusion). For data collection, a mobile device would be most effective in the “Experiment” step of this particular model. This implies that users of mobile devices would not necessarily have to be engaged in any of the other steps in the scientific method. Given this implication, we would like to delve into the effects of *full participation* in the scientific method on learning with and without the use of mobile devices to gather experimentation data.

In our experiment design, we have randomly divided participants into four groups. Group one represents users who have *full participation* in the scientific method (i.e., users are following all 5 steps of the scientific method) and are using a mobile device to gather experimentation data. In group two, users still have full participation, but are NOT using a mobile device to gather experimental data. Group three represents users who have *limited participation* in the scientific method (i.e., users are strictly gathering data) and are using a mobile device to collect their data. Finally, in group four, users still have limited participation, but are gathering data without a mobile device. Data will be gathered individually (i.e., not as a group). After the experiment, participants will be asked to complete a survey gauging their perceived engagement and learning in performing the experiment.

We expect *full participation* in the scientific method with use of a mobile device would yield the most favorable outlook on perceived learning and engagement, followed by *full participation* in the scientific method without the use of a

mobile device, then *limited participation* with a mobile device and finally ending with *limited participation* without use of a mobile device yielding the least favorable outlook. However, it may be possible that the outcome from group two matches the outcome in group three. This depends on what is more important to the learner; having access to a mobile device or understanding the context of a particular research question. In addition, the outcomes may be affected by interest in the experiment and overall intellect.

In partitioning the types of participants into these groups, we will hopefully be able to gain a better understanding of the effect of mobile devices on different levels of participation in inquiry-based environments.

IV. CONCLUSIONS AND FUTURE WORK

In performing this study, we are developing a suite of technological tools (including a mobile app) designed to help instructors, students, and/or researchers collect, aggregate, and analyze different types of experimentation data for both small and large scale research projects. Specifically, these tools are dedicated to (a) establishing and assigning research tasks and objectives, (b) collecting an array of different types of experimentation data via mobile devices, and (c) extrapolating trends and verifying statistics based on the data collected. Our participants in the study described above will use these tools.

Mobile devices in inquiry-based learning environments have the potential to impact researchers from several different disciplines ranging from STEM fields such as physics and statistics to business fields such as marketing. By providing a suite of standard data documentation tools in the palm of one’s hand, mobile devices allow researchers to gather data quickly and efficiently, thus streamlining the research process. In streamlining the research process, learners are able to focus more on the research itself and less on irrelevant details often accompanying field research. The increased focus will allow users to gain more from their research and reach objective conclusions faster.

The results of our experiment may be influenced by how interested our participants are in the research question regardless of mobile device use. In addition, positive results stemming from the use of the mobile device may be due to the novelty of using the device to collect data. Also, mobile devices can be used to gather different types of experimentation data in an array of domains. Therefore, what we find to be true for one particular domain may not be true for another.

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Will Texting Help Student Learning?

A case study of using mobile devices in university classrooms

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Abstract— The use of Student Response Systems (SRS) has been shown to increase student attendance, participation, and learning. Prevailing systems at universities are typically SRS that require installation of software by the university and purchasing of “clickers”. Thus, the adoption of SRS usually requires a sizable initial investment. Given the diffusion of mobile phones and wide-spread use of mobile technology by students, the possibility of using them as a cost-effective alternative to clickers is attracting more attention. The emergence of audience response systems hosted in the cloud instead of being physically connected to a computer triggered WPI faculty and staff to explore the use of mobile technology as a response tool through Poll Everywhere.

First, we present our motivations for adopting this technology (limited clicker supply, desire for open-ended response option, etc.). Second, using our experience in the classroom and findings from extant literature, we make suggestions related to course design to enable faculty to take full advantage of cloud-based SRS. We evaluate whether students concur with our perceived benefits of Poll Everywhere in terms of ease of use and facilitation of learning. We close with discussion and suggestions for future research.

Keywords—*Student response systems; mobile devices; clickers; feedback; mobile learning*

I. INTRODUCTION

Regardless of the discipline taught, instructors strive to help students learn and must make numerous pedagogical choices. One such choice has been consistently found to be effective: Providing immediate and frequent feedback to students accompanied with peer discussion has been shown to be associated with improved student performance and learning [1, 2]. A traditional way to provide this feedback to undergraduate students is to implement instant assessment of learning by means of flashcards [3] and, more recently, clickers (transmitters used to wirelessly send individual students’ answers to receiver and software) [4, 5]. We examine a new Student Response System (SRS), Poll Everywhere. This SRS is enabled by mobile technology instead of wireless transmitters and stores information in the cloud. We argue that this technology is less intrusive, but as effective as flashcards or clickers.

Academia has provided widespread evidence of the perceived benefits of clickers. They engage students, create a

more interactive environment [6], and help faculty identify and correct misconceptions, thus facilitate understanding [7]. Although the effect of clickers on learning does not appear superior to flashcards, clickers are especially helpful in large classroom [8] as they facilitate aggregation of the students’ answers and encourage attendance as well as participation [4]. Yet, clickers require an investment in technology and do not take advantage of the mobile technology students have and are comfortable with (students belong to the millennial generation; 94% of millennials own a cell phone and 87% own a laptop [9, 10]).

Taking advantage of the positive attitude students have towards technology (74% believe technology makes their life easier [9]), of technology they are familiar with, and of their preference for receiving information quickly and for active learning [11], we examine a new use of Poll Everywhere as a SRS that relies on mobile technology. Poll Everywhere not only uses technology already in the hands of students (e.g., laptops, cell phones), it also provides an easy and familiar platform for instructors to interact with students at a deeper level by using, for instance, open-ended questions, and makes student responses web-accessible to faculty as well as students. This paper builds on extant research on benefits and challenges of traditional SRS such as clickers and flashcards and shares the experience of two faculty members as well as students perceptions of Poll Everywhere. This technology was applied in different disciplines (engineering and business) and various implementation methods were tested. We find that Poll Everywhere, like clickers, not only is associated with positive perceptions of students in terms of ease of use and improved learning, but also addresses several of the challenges typically associated with clickers.

We first present a review of the SRS literature. Second, we describe Poll Everywhere and the implementation choices we made. Third, we evaluate this technology and present students’ perceptions. We close with discussion and suggestions for future research.

II. LITERATURE REVIEW

Of concern of pedagogical scholarship is not technology per se, but how technology can be used to facilitate learning [12].

Technology such as clickers enables faculty to assess and encourage different levels of learning [13].

As such, clickers have been widely used in several disciplines where they have been associated with pedagogical benefits as well as concerns. First and foremost, research finds that clickers seem to improve learning as they help instructors become aware of how well students understand the concepts they teach [7] and address misconceptions [5]. Although most articles assess the perceived effectiveness of clickers and infer that improved learning will result from improved understanding [e.g., , 14, 15, 16], Preszler and his colleagues [17] show that exam performance actually improved in the classes that used clickers. Additional benefits in the form of increased attendance and participation seem to add to the positive perception that students and faculty have of this technology and of the environment it creates [4-7, 18].

Still, it is not always clear whether those benefits are direct benefits of clickers or a byproduct (e.g., it might be the fact that students are more active in the classroom or the provision of participation incentives rendered possible by clickers that helps improve participation and attendance). Moreover, clickers seem to pose technological challenges as students forget them or they malfunction [5, 18]. They are costly (to students or the university) and instructors can incur logistical difficulties as they will likely need to distribute and account for the clickers and activate the receiver and software they rely on at the beginning of each class period [7, 18]. In addition to these challenges, most clickers are limited in the type of questions one can ask (multiple choice or true/false¹) and, accordingly, require faculty to rethink the exercises they use in the classroom [16, 18].

We argue that these challenges can be addressed by replacing clickers with technology that the student population is already comfortable with (i.e., mobile technology in the form of laptops, tablet computers, or cell phones). Although the use of mobile technology is widespread [9], mobile learning in the classroom via SRS is in its infancy. Chen et al. [1] conducted initial tests of PDAs and proprietary software as SRS and suggest that PDAs provide similar benefits as clickers. New types of SRS using mobile technology such as Poll Everywhere, iClicker and Turning Point take advantage of the accessibility and of the students' familiarity with mobile technology.² We present our application and assessment of the former, Poll Everywhere.

¹ While some clicker models allow for open-ended question, typing is cumbersome (e.g., hit 3 twice for an "e").

² After a comprehensive review of SRS and other educational learning software, we determined that there was not, at the time of selection, another viable system with synchronous response capability that does not require an internet connection. Other systems, such as Socrative (<http://www.socrative.com/>) and Learning Catalytics (<https://learningcatalytics.com>) have since appeared on the market, but do require a web-enabled device.

III. IMPLEMENTATION OF POLL EVERYWHERE

A shortage of clickers motivated us to find a technology that was easy to use for both faculty and students and that had the same benefits as clickers, but fewer drawbacks.

A. SRS Description

Our selection was guided by WPI's Academic Technology Center. Poll Everywhere is an audience response system available to higher education instructors at a low monthly cost that depends on class size.³ In order to provide participation incentives, faculty need to be able to identify the students who participate and, accordingly, need to invite student to register by email. As with clickers, the instructor initiates questions and it is necessary for the instructor to provide probing questions. These questions come in the form of polls, multiple choice (concept or skill questions), or open-ended questions. Once the faculty has generated questions, they can be incorporated in a PowerPoint presentation. These PowerPoint slides can be used in classroom without the burden of utilizing any sort of user interface. Students answer these questions in class with the mobile devices selected by the instructor (cell phones, laptops, or tablet computers) by twittering, texting, or through the Poll Everywhere website. They receive confirmation once their answer has been received by the system. Aggregated answers can be shared with the class at the discretion of the instructor by simply clicking on a built-in function button on each PowerPoint slide. Poll Everywhere also provides individual feedback that can be downloaded by faculty to assess participation or reviewed by students online.

B. Implementation Choices

We tested this technology in introductory engineering, ES 2001 Introduction to Materials Science and Engineering with 100-130 students and business, ACC 2060 Financial Statements for Decision Making with about 50 students. Before the implementation of Poll Everywhere in our classrooms, a survey was conducted to determine the students' access to mobile phones or laptops. It turned out that 100% of the students surveyed had a mobile phone or a laptop. Our application of Poll Everywhere differed on several dimensions as detailed in Table 1. Those differences were motivated by personal preferences more so than driven by our respective disciplines.

For instance, both instructors included participation incentives in the class grade. Prof. Liang chose to grade participation based on whether students answered the questions posed in randomly selected class periods because, in ES 2001, grading each question asked via Poll Everywhere would have been too time-consuming. Prof. Miller took a different approach by grading every question asked and giving full credit only to the questions answered correctly. This choice was motivated by the weight given to participation in the class grade and faculty's concern that it would be difficult to select class

³ Alternatively, students can purchase access to Poll Everywhere for an annual charge.

periods that would be representative of typical student attendance and participation.

TABLE 1. IMPLEMENTATION DECISIONS

| <i>Implementation decisions</i> | <i>Discipline</i> | <i>Choice</i> | <i>Rationale</i> |
|---|---------------------------------|---|---|
| <i>Mobile technology allowed</i> | Engineering | All Personal Devices | Increased flexibility, free answers |
| | Business | Cell phones (texting only) | Limiting distraction |
| <i>Question type</i> | Engineering | Multiple choice questions | Testing of student knowledge |
| | Business | Multiple choice & open-ended questions | Testing of student knowledge; end of class review, quiz at beginning of class, voting on team presentations |
| <i>Frequency of questions</i> | Engineering and Business | Every 10-15 minutes | Frequency seem optimal to maintain engagement |
| <i>Number of answers allowed</i> | Engineering and Business | One | Answering questions followed discussion with peers |
| <i>Display of aggregated answers</i> | Engineering and Business | Dependent on questions and proportion of correct answers | Stimulating class discussion |
| <i>Peer discussion subsequent to initial answer</i> | Engineering and Business | Dependent on questions and proportion of correct answers | Investigating challenging questions |
| <i>Participation incentives</i> | Engineering (5% of class grade) | Answers chosen at random; full credit given for any answer | Increasing attendance and participation while minimizing grading |
| | Business (10% of class grade) | All answers included; full credit for correct answer, partial credit for incorrect answer | Increasing attendance and participation |

Everywhere ahead of class and no equipment or software needs to be activated at the beginning of each class. Registration is initiated by faculty who send an email that provides a URL to invite students to register; thus, making the registration process simple for students. Furthermore, since students could use their personal mobile technology, there was no need to distribute equipment, account for it, and collect it at the end of class. Technological challenges were also rare because students did not forget their phones or laptops, did not risk bringing the wrong clicker to the wrong class, and were very familiar with how to operate their own equipment. Interestingly, students were also able to help each other when technical questions arose such as how to send answers by texting. Finally, we also noted that students' responses were transmitted quickly and reliably.⁴ In other words, using mobile technology in combination with Poll Everywhere to help students learn and encourage student participation makes preparing for and providing immediate feedback a smooth and effective process.

Despite the benefits associated with Poll Everywhere, a few new concerns arose. These concerns and the cost and benefits of their potential solutions should be evaluated before deciding how to implement Poll Everywhere. They are presented in Table 2 below.

As detailed in Table 2, requiring students to bring mobile technology to class might increase distraction as students access the internet, check their email, etc. Accordingly, faculty might want to apply the techniques they typically use when students use laptops in the classroom or limit the kind of technology they can use to answer questions. Still, we felt that the benefits associated with helping students become active learners were far greater than the challenges discussed in Table 2.

IV. EVALUATION OF POLL EVERYWHERE

First, we present our perspective and, second, describe the students' perceptions captured through surveys.

A. Faculty Perspective

Our individual experience with clickers echoes the evidence presented by the literature discussed above in terms of improved attendance, participation, engagement, and identification of misconceptions. We observed similar benefits when students used mobile technology to answer the questions we created with Poll Everywhere. Additionally, we found that Poll Everywhere helped resolve many of the challenges often associated with clickers. Logistics problems disappeared as questions are incorporated in PowerPoint slides via Poll

⁴ Because Poll Everywhere uses SMS technology, the communication occurs in one direction: from the student's device to the Poll Everywhere server. Other existing virtual clicker systems rely on two-way communication: an instructor posts a question which is sent to a student's device, at which point the student is able to answer the question. This two-way communication can slow down the speed of the responses.

TABLE 2. POLL EVERYWHERE CHALLENGES

| <i>Challenge</i> | <i>Proposed Solution</i> |
|---|--|
| <i>Student distraction: Students bring laptops to class and need to have them available to answer questions</i> | <i>Restricting participation to texting via cell phones.</i> |
| <i>Cost of texting: Some students do not have unlimited texting</i> | <ul style="list-style-type: none"> - <i>Surveying students at the beginning of the semester to evaluate the extent of this concern,</i> - <i>Allowing other medium such as laptops,</i> - <i>Asking students to work in teams and take turns to answer questions.</i> |
| <i>Texting limited to 160 characters, thus limiting the length of answers to open ended questions</i> | <ul style="list-style-type: none"> - <i>Allowing other medium such as laptops,</i> - <i>Tailoring questions accordingly.</i> |
| <i>There is currently no integration between Poll Everywhere and Learning Management Systems. Therefore, rosters and grades must be transferred manually.</i> | <ul style="list-style-type: none"> - <i>This may be a feature to look for from Poll Everywhere in the future.</i> |
| <i>Security: Students' cell phone numbers and responses are stored by Poll Everywhere.</i> | <ul style="list-style-type: none"> - <i>Students register themselves for the system, and no student identification numbers are shared. Additionally, although Poll Everywhere does offer a gradebook feature, assessment is probably best kept in a more secure environment.</i> |

B. Student Perceptions

We administered surveys (1 to 5 likert scale) anonymously to our students to gauge whether students perceived that Poll Everywhere helped them learn, was easy to use, and compared favorably with clickers. We obtained a total of 162⁵ usable responses.

- 1) *Perceived Learning Outcomes:* Students' perceptions of Poll Everywhere benefits confirmed our own evaluation. 68.2% and 70.6% of the engineering and accounting students, respectively, believed that using Poll Everywhere improved their understanding of the concept learned. 60.7% of the engineering students perceived that Poll Everywhere increased their interaction with the instructor while 82.4% of the accounting students indicated that using Poll Everywhere helped them become more engaged in the class. 80.9% of the accounting

students felt that seeing the aggregated answers was informative.

- 2) *Ease of Use:* Students had little or no difficulty registering at the beginning of the term (82% of the accounting students found this process easy) and found answering questions with this SRS easy (73.5% of the accounting students agreed or strongly agreed with this statement and 83% of engineering students reported no difficulty of registering or using the technology).
- 3) *Comparison with Clickers:* Mobile technology combined with Poll Everywhere was preferred to clickers by most students (81.3% and 84.5% of the engineering and accounting students, respectively). Finally, 84.5% of the accounting students believed they were less likely to forget their cell phone than a clicker and very few indicated that they ran into technical problems (i.e., low battery) during the term.

In sum, students perceived that Poll Everywhere learning benefits are very similar to those of clickers, but seem to prefer this technology to clickers as they run into fewer technical challenges and are more comfortable with the equipment used. Combined with our own observation of increased attendance, participation, engagement, and identification of misconceptions, the students' perceptions suggest instructors can derive the same benefits from Poll Everywhere as from clickers and confirm that this technology is less intrusive, less costly, and associated with fewer challenges than clickers.

V. CONCLUSION

In conclusion, our experience with mobile technology as an alternative SRS was very encouraging from both the faculty and students' perspective. In addition to the familiarity and widespread adoption of mobile technology by students, flexibility and the low cost of mobile technology make it particularly attractive to faculty and campus with constraints associated with cost and resources such as technical support. However, similar to other SRS systems, the actual learning outcomes largely depend on not only adoption of technology, but also on how the technology is adapted into the learning experience. For example, in our initial experiments, dialog has always been initiated by faculty using the SRS. It is expected that more benefits will result if we can close the loop and add an interactive loop with students initiating dialog/questions into the learning process [19]. Our research did not include formal assessment of learning. Future projects could test learning actually improves by comparing learning in a class using Poll Everywhere to learning in a similar class that does not use this SRS. Even though our intuition suggests that, everything else being equal, the actual learning outcomes of adopting Poll Everywhere might be similar to other SRS, a future research project is planned to assess this hypothesis.

⁵ Four different classes (two introductory material science and engineering and two introductory accounting classes) participated. Questions varied between the various classes.

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Enhancing Curiosity Using Interactive Simulations Combined with Real-Time Formative Assessment Facilitated by Open-Format Questions on Tablet Computers

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Abstract— Students' curiosity often seems nearly nonexistent in a lecture setting; we discuss a variety of possible reasons for this, but it is the instructor who typically poses questions while only a few students, usually the better ones, respond.

As we have developed and implemented the use of InkSurvey to collect real-time formative assessment, we have discovered that it can serve in an unanticipated role: to promote curiosity in engineering physics undergraduates. Curiosity often motivates creative, innovative people. To encourage such curiosity, we solicit questions submitted real-time via InkSurvey and pen-enabled mobile devices (Tablet PCs) in response to interactive simulations (applets) run either before or in class. This provides students with practice in asking questions, increases metacognition, and serves as a rich springboard from which to introduce content and/or address misconceptions.

We describe the procedure for measuring curiosity and results from applying this method in a junior level electromagnetics engineering physics course. We conclude that students are indeed more curious than they appear in class, and students participate even without extrinsic motivation. This method of enhancing curiosity using interactive simulations coupled with real-time formative assessment in response to open-format questions could be implemented in a wide variety of engineering courses as well as elsewhere.

Keywords- *curiosity, real-time formative assessment, InkSurvey, interactive simulations, open-format questions*

I. INTRODUCTION

Most people would probably agree that good engineers and scientists are curious. An emerging operational definition of curiosity is "the threshold of desired uncertainty in the environment that leads to exploratory behavior" [1]. In spite of recent advances in cognitive science and learning theory [2], many engineering educators find themselves teaching in a lecture setting, where students' curiosity and intellectual exploration is rarely displayed. This lack of evidence of students having crossed the threshold of curiosity might have

several possible contributing factors; our experiences suggest these factors may include:

(a) Students may be embarrassed to ask questions (either in the presence of their peers or in a one-on-one setting with the instructor during office hours);

(b) Students may not want to make a genuine effort to understand the material by asking probing questions;

(c) Students' past experiences may have trained them to expect to absorb content rather than generate questions;

(d) Students may feel so lost and confused that no question comes to mind;

(e) Students may feel confident that they understand everything, and therefore have no need to ask questions; and

(f) Students may be accustomed to not asking questions, as this is not a skill generally nurtured or valued in the educational system.

However, curiosity often motivates creative, innovative scientists and engineers (and others) [3-5]. It is also seen as an important factor in student learning [6, 7]. Practical methods for encouraging curiosity have been discussed [6, 8-10]. Lowenstein [11] points out that "curiosity is influenced by cognitive variables such as the state of one's knowledge structures but may, in turn, be one of the most important motives for encouraging their formation in the first place. Positioned at the junction of motivation and cognition, the investigation of curiosity has the potential to bridge the historical gulf between the two paradigms."

This paper describes results when students in a junior-year undergraduate electromagnetics class were asked to report their questions as they explored interactive simulations related to course content. The goal was to motivate learning by enhancing student curiosity. To better understand the role curiosity plays in engineering education, a categorization scheme for questions was devised and applied as a simple measurement tool.

II. NURTURING AND MEASURING CREATIVITY

Efforts to improve student motivation have been linked with curiosity. In particular, the ARCS (Attention, Relevance, Confidence, and Satisfaction) model of motivation provides insight on how to nurture curiosity [10]. Some instruments to measure motivation have curiosity subscales [12], reflecting the contribution curiosity may make to motivation. However, curiosity is not a simple attribute to measure. Loewenstein provides a comprehensive review of instruments which use teacher evaluations, peer evaluations, and self-evaluations to measure curiosity, while he questions the validity of some of these instruments [11].

Trying to understand the underlying cause of creativity has led to theories focused around drive (curiosity results from biological/psychological drives similar to thirst, hunger, or sex), incongruity (curiosity results when an observation violates a model or heuristic rule of how the world works), competence motive (curiosity results from feelings of a lack of competence), and a gap in information (curiosity results from a discrepancy between what one perceives and what one expected to perceive) [11,13].

Rather than focus on a comprehensive study of the underlying causes of curiosity, we attempt to extract information about a student's curiosity only in terms of the questions the student asks about an observation, problem, simulation, or object presented in a STEM context.

In theories of curiosity described in the literature, the types of questions students might ask are not categorized. For example, in an incongruity-based theory, such as that developed independently by Hebb [14], Hunt [15], and Piaget [16], any question reflecting curiosity would, by construction of the theory, be defined as incongruous.

None of these theories about curiosity has emerged as the most widely accepted, but perhaps there are insights to be gained from all of them. An example, in the context of Newton's Laws, illustrates that student questions do not always conform with a single theory. A student who does not believe the rule that an object moves in uniform motion until an external force acts would ask a question such as "What object moves without slowing down?" This aligns with the incongruous theory of curiosity (above), since it indicates that uniform motion is incongruous with the student's model of how the world works. Another student question might be "How do I calculate the external force on a car coasting?" illustrating curiosity about how to apply the rule rather than about a violation of the rule. For convenience, this could be described as a question reflecting congruous curiosity.

Based on this theoretical framework, the question categories used in this study to assess curiosity are as follows. Although this list of categories may not be exhaustive for consideration of curiosity in all disciplines or even all topics within engineering disciplines, they are adequate for this study.

INCONGRUOUS: violating a model or heuristic rule of how the world functions.

Example: Doesn't this violate conservation of energy?

CONGRUOUS: understanding of or gathering information about how a model or rule is applied (typically one just presented in class).

Examples: How do I apply this in a different situation? How do I calculate the effect shown in the simulation? What examples are found in the real world?

MODIFYING: probing what happens when the assumptions, parts, application, or parameters of the model or rule are changed.

Example: What happens if the temperature is not assumed to be constant?

GENERALIZING/ANALOGY: comparing one model with another.

Example: When an earthquake occurs, do the plates slip when pressure generates melting at an interface, like a skate on ice?

CAUSAL/CREATIVE: attempt to generate a new model, improve on an existing one, or search for novel patterns.

Example: How does this simulation of classical physics change if quantum mechanics is applied?

INFORMATIONAL: finding information simply for its intrinsic interest or for diagnostic purposes.

Example: How does the platypus relate to its environment?

When the student responses are collected as students explore interactive simulations, we categorize the question responses and discuss in class these classifications with the students. Using this procedure, along with having the students become aware of questions asked by both peers and the instructor, we hope to nurture the transformation of specific state curiosity (a condition that can be manipulated) into the more general trait curiosity (a personality feature) in STEM fields, as suggested by Loewenstein [11].

III. DESCRIPTION OF TEACHING MODEL

Students used the web-based software *InkSurvey* [17] to compose and submit their responses to questions about free, interactive simulations they accessed online. There are a variety of tools that could be used for this (*DyKnow*, *Classroom/Ubiquitous Presenter*, etc.); we chose *InkSurvey* because it is free and is robust in classes exceeding sixty students. The preparation, collection, and receiving of responses was facilitated by pen-enabled mobile computing devices (in this case tablet computers) in the hands of both instructor and students. Other pen-enabled mobile computing devices (iPads, smart phones, etc.) could also be used in a similar manner. However, without facilitation by some form of technology, it is difficult for the instructor to collect and respond to meaningful formative assessments quickly.

The real-time assessment gathered with *InkSurvey* is particularly authentic since it is seamlessly integrated with the activity [18], in this case not only temporally, but physically as well, with a single tool used for both exploring simulations and using *InkSurvey*. An additional advantage of this coupling is

that students can engage in further manipulation of the simulations as they construct their responses, allowing them to explore facets they may have initially ignored. A single student is able to submit multiple responses to a question posed by the instructor. Even though student identity is concealed from their peers (see I.a), the instructor could access this, thus allowing us to track how many and which responses were submitted by a particular individual.

The student responses provide a rich springboard from which to introduce content and/or address misconceptions. Having the students document their questions and understanding in this manner facilitates both student motivation to understand and metacognition.

In this method of enhancing curiosity, comments and questions were solicited using *InkSurvey*, with open-format questions such as:

- (1) What did you learn from or observe in the simulation?
- (2) What does this simulation illustrate?
- (3) What are you curious about after running the simulation?

The students enrolled in the class were engineering physics second semester juniors having three semesters each of physics and calculus, along with courses in differential equations, linear algebra, intermediate mechanics, thermodynamics, analog and digital electronics, and a summer session in vacuum systems, optics, machine shop, computer interfacing, and electronics.

IV. RESULTS

Student responses from four interactive simulations, along with categorizations and instructor comments, are presented next. To make trends more visible, similar responses are reported together, but unique responses are also reported to show the level and breadth of curiosity within the class. However, student submissions do not represent all categories for every simulation. Every student present at the time of each simulation submitted at least one response.

A. Induced charge simulation

Students ran the simulation on electrostatic induction found here:

<http://www.cegep-ste-foy.qc.ca/freesite/fileadmin/users/29/NYB/Theorie/contactdiff.swf>.

Question 3 above (“What are you curious about after running the simulation?”) elicited 68 questions from the 40 students present. These questions fall into five of the possible six categories.

INCONGRUOUS. Two responses are in this category:

“Does this actually happen as shown?”

“Why don’t the charges move after the conductors stop moving?”

CONGRUOUS. Twenty-four student questions (35% of total) involve how the charge distributed over the conductors, as

shown in the simulation. Sixteen student responses (24% of total) involve how much charge was shared between conductors. Another eight student questions (12% of total) are related to how the charge distribution, electric fields, or forces could be calculated. Unique responses in the CONGRUOUS category are:

“How do the charges of opposite sign eliminate each other?”

“What is the charge transfer a function of?”

MODIFYING. Six of the student questions (9% of total) involve what happens if the “tear shaped” conductor is turned around or two such conductors are used. Additionally, there are three unique responses in the MODIFYING category:

“How does the shape of the conductor affect the charge distribution?”

“How would insulators effect the simulation?”

“What happens if the conductors are brought together a second time?”

CAUSAL/CREATIVE. There are no questions in this category that were submitted multiple times, but these unique questions were received:

“How much time does it really take for the charges to distribute themselves over the conductor?”

“How does this simulation differ if quantum mechanics is applied?”

“Can electrons jump between the conductors or do the conductors need to touch?”

INFORMATIONAL. Four responses (7% of total) are questions about clarification, such as “Is there charge missing on the right conductor initially?” Another student questioned, “Where do the charges come from?”

Comments: While the majority of questions focus on what happens in the simulation, some students were curious about how to calculate what happens. A major objective of the course is for students to learn how to perform such calculations. The simulation thus provided motivation for the mathematical content of the course.

The students were concurrently taking a quantum physics class. A few were curious about how the content in both classes related. The quantum and classical models of charged conductors interacting are not often discussed at the junior level. By coupling the two topics, the breadth of understanding increases, thereby enhancing capability to both construct models and understand the limitations of the models. This simulation can also be used as a springboard to discuss quantum tunneling.

Some students were also curious about how quickly the charges distributed over the conductors. While this is not a question which can be adequately addressed using the electrostatic model presented, the instructor can use this as a catalyst to question the limitations of the electrostatic model, and launch a discussion of what governs the dynamics of this process and how one would construct a more realistic model.

B. Moving charge simulation

Students ran the simulation on electric fields from a moving charge found here:

<http://www.cco.caltech.edu/~phys1/java/phys1/MovingCharge/MovingCharge.html>.

Subsequently asking the students, “What are you curious about after running the simulation?” elicited 53 questions from the 31 students present. These student questions fall into five of the possible six categories.

INCONGRUOUS. Six responses (11% of total) deal with how the magnetic field (not shown in the simulation) is generated. Four student responses (8% of total) question how it is that field lines can cross (shown when running the saw-tooth motion option). Unique responses are:

- “When the charge is moving fast why doesn’t E continue in front of the charge?”
- “Why is the charge able to outrun the E field when traveling at the speed of light?”
- “Why are there kinks in the field lines when the charge accelerates?”
- “Won’t the waves always move faster than the particle?”
- “Why does acceleration cause ripples?”
- “What makes the electric field E behave like a wave?”
- “Why does the electric field seem to get stronger towards the front as the charge goes faster?”
- “Why is there an asymmetry in the field between the front and back of the moving charge?”
- “What happens when the particle crosses a bending E field?”
- “How can the field lines cross over each other when selecting the saw-tooth motion?”
- “What is the mechanism behind the field distortions when the particle speed changes?”

CONGRUOUS. Seven responses (13% of total) deal with “compression” of the field lines when the charge moves at high constant speed. Unique questions generated by the students are:

- “How is energy shown?”
- “How can you calculate the kinks in the field?”
- “Do the distorted field lines create magnetic fields?”
- “How can we calculate the fields given the particle motion?”
- “Is the superposition principle used to calculate the effect?”
- “How does the field propagate when the charge undergoes simple harmonic motion?”
- “Is there any change in the amplitude or frequency of the electromagnetic waves produced as they propagate away from the source?”
- “How do we account for the force based on the speed of the moving wave?”

MODIFYING. Six student questions (11% of total) are concerned about what happened when the charge moved at or near the speed of light. Additional unique student questions received are:

- “How does this simulation change in a gravitational field?”
- “What happens when two particles accelerate?”
- “What are the relativistic effects?”

- “How does the magnetic field affect motion of the particle?”
- “How does the magnetic field arise?”
- “Are there kinks in the magnetic field when the charge accelerates?”
- “How does this moving particle interact with other particles during acceleration?”

GENERALIZING/ANALOGY: There are three unique questions that fall in this category:

- “When the charge moves faster than the speed of light, is this similar to a bow wave when an aircraft moves faster than sound?”
- “How does this simulation apply to light?”
- “Are there shock waves generated?”

CAUSAL/CREATIVE. A single student question is classified in this category:

- “Do multiple charges create an interference pattern?”

Comments: Some students noticed that under certain conditions the simulation generates crossing field lines. They correctly suspected that this cannot happen physically. Bringing this to the attention of the class facilitates a discussion of critical thinking skills about what methods can be used to verify models (or how the model is simplified to generate the simulation).

Questions about the interference pattern illustrate the ability to make connections between different physical phenomena. The analogy with shockwaves can be a springboard to generate more questions about what is similar or different between the two situations. The connection between acoustics and electromagnetic waves can be discussed in terms of the similarity between the partial differential equations used in each model.

C. Inductance calculator

Students ran the inductance calculator found here:

<http://emclab.mst.edu/inductance/index.html>.

The question “What did you learn in using the calculator?” elicited 35 comments from the 35 students present; 100% of the responses submitted fall into the CONGRUOUS category. Seventy-eight percent (78%) mention the relationship between geometry and inductance while seven percent (7%) relate this to the induced electromotive force changing as a function of geometry. A typical comment is “Different shapes make the calculations way harder. It is cool that we know how to calculate this.” Curiosity is apparent in the following two comments: “I didn’t realize that for the two loop configuration that the inductance would increase with the separation distance,” and “The N^2 relationship was unexpected. However when we look closer at the math I understand.”

Comments: Somewhat surprisingly, students found this calculator interesting. They demonstrated curiosity in exploring how inductance varied in different geometries. The limited number of geometries available provided an opportunity to discuss the scarcity of closed form solutions for inductance.

D. Quantum harmonic oscillator simulation

Students ran the simulation found here:

<http://web.ift.uib.no/AMOS/MOV/HO/>.

The prompt “What are you curious about after running the simulation?” elicited 32 questions from the 31 students present.

INCONGRUOUS. Ten responses (30% of total) deal with “Why are we studying this problem in a electromagnetism class?” Additional unique student questions that fall into this category include:

“Why don’t we see evidence of this non-classical behavior on a macroscopic scale?”

“Can we make such a state?”

“Why does the oscillator look more classical with a greater number of energy levels?”

CONGRUOUS. Unique student questions in this category are:

“Why are coherent states so important?”

“What gives them a stable shape?”

“What does it mean when the shape of the wavefunction splits and recombines?”

“Does this correspond to a transition to a higher energy level?”

“Can we use the superposition principle?”

“Why did the wave always move to the right?”

“How accurate is the simulation?”

“What are the limitations of the simulation?”

“What is represented by non-coherent states?”

“Why is the Glauber state important?”

“What impact do energy levels not excited have on the state?”

“How do you produce just even or odd wavefunctions?”

“Why do so many amplitudes have to exist to get a standard wavepacket?”

“Is this an example of multiple electrons or single electrons?”

MODIFYING. Two student questions belong to this category:

“What simplifications went into making the simulation?”

“How would this behave if the oscillator were damped or experienced an external force?”

GENERALIZING/ANALOGY: There are two student questions in this category:

“Is this how lasers work?”

“Are there any real world electromagnetic examples of these states?”

Comments: Students explored this simulation after having studied the separation of variables solution to Laplace's equation. The harmonic oscillator simulation is a quantum example of separation of variables applied to the Schrödinger equation. This topic was being studied by most of the members of the electromagnetics class in a concurrent quantum physics class. Some students did not see the mathematical connection between the electrostatic and quantum problems. They

therefore asked why quantum content was being covered in an electromagnetics class.

Many questions were focused on making connections between the simulation and real world applications. Answering these questions allowed the instructor to further stimulate curiosity and make connections to other physical phenomena. How a laser generates ultra short optical pulses in a manner similar to that demonstrated in the simulation is such an example.

Table I summarizes the results of categorizing the questions submitted as student responses for each of the four simulations described.

V. DISCUSSION

The use of pen-enabled mobile technology to collect student responses allows the instructor to receive student input in real-time and use it to guide students as they construct deeper understanding. This novel method of assessing and nurturing curiosity when exploring interactive simulations could be used effectively in many settings. Further explorations in contexts beyond those of using computer simulations are warranted by these results.

The results from classifying student responses, shown in Table I, are heavily predominated by curiosity associated with the students constructing an explanation of the simulation based on their understanding of the model presented in class (CONGRUOUS). The next largest contribution is associated with aspects of the simulation which do not match the student's expectations (INCONGRUOUS). Few students show curiosity about generalizing or modifying the model.

It is expected that students struggling to understand a model would have more congruous questions, focused on the details of calculating the consequences of the model, while those with a more mature understanding of the model would be curious about applications, analogies, modifying, or generating new models. Also, we suggest that the concepts and content illustrated by various simulations could influence the particular categories of curiosity they stimulate.

In this study, we have not addressed the issue of the “quality” of the questions and have considered all student responses to be equal in the level of curiosity and insight they reflect.

TABLE I. SUMMARY OF CATEGORIZATION OF STUDENT QUESTIONS SUBMITTED, FOR EACH OF 4 SIMULATIONS

| | Sim #1 | Sim #2 | Sim #3 | Sim #4 |
|-----------------------|--------|--------|--------|--------|
| INCONGRUOUS | 3% | 40% | 0% | 40% |
| CONGRUOUS | 74% | 28% | 100% | 44% |
| MODIFYING | 12% | 25% | 0% | 6% |
| GENERALIZING /ANALOGY | 0% | 5% | 0% | 6% |
| CAUSAL /CREATIVE | 4% | 2% | 0% | 0% |
| INFORMA-TIONAL | 7% | 0% | 0% | 0% |

The questions generated in these exercises are remarkable for their quantity, quality, and diversity, especially in light of the fact that students were given no external incentives for their responses. This is consistent with curiosity being an intrinsic motivational factor. Furthermore, none of the exams or homework exercises involved nurturing or assessing curiosity. From the students' questions and comments, it was apparent that they were genuinely interested in engaging with the material at a level not apparent prior to the real-time formative assessments.

The responses revealed an aspect of student thinking not often measured or even exposed in a lecture-based classroom. Many provided springboards for making connections between physical phenomena, discussing critical thinking skills, and enhancing curiosity.

Disadvantages of categorizing the types of curiosity include the non-uniqueness of the sorting categories and the potential confusion due to the redefinition of terms by which to sort.

One advantage of categorizing the questions is that students become aware of the many ways that they might be curious. This awareness can lead to a process which stimulates their curiosity. Consider a heuristic rule from a statics class that structures built in triangles are less likely to collapse. When asked what they are curious about, the students might apply the "Modifying" category to ask how the skull of a reptile exhibits this rule. A student's curiosity could expand from state to trait as they are exposed to multiple examples in class. Facilitated by technology such as *InkSurvey*, this process can be demonstrated by both the student's peers and the instructor. Hopefully, if this process is implemented often enough, students would become fluent in generating questions reflecting all categories of curiosity.

Additionally, the development of the method presented here to measure curiosity, if both valid and reliable, may lead to improved curricula. Categorization allows different levels and types of curiosity to be studied.

Other advantages of this teaching model are: (1) it reinforces the congruent category of curiosity, which aligns directly with the content STEM students are generally considered to be in class to learn about (they should be curious about how to calculate the consequences of a model they are studying, for example), (2) it encourages students to communicate what they think is incongruent so instruction can be modified to address such issues, and (3) it affords students practice in metacognition as they construct questions about which they are curious.

VI. CONCLUSIONS

When students were provided with an opportunity to submit questions they generated while exploring interactive computer

simulations, it was revealed that they are indeed more curious than they appear in a lecture-based class. They were willing to actively engage with the material they were studying, even without extrinsic motivation. Furthermore, the questions generated by individuals in the class provided relevant and worthwhile springboards for subsequent class discussions involving higher level thinking skills, as well as stimulating student curiosity to further explore the simulations. The process and classification scheme described here may prove valuable in nurturing and measuring curiosity.

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Work in Progress: Real World Relevant Security Labware for Mobile Threat Analysis and Protection Experience

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Abstract—To address the need for innovative mobile security learning materials and for promoting mobile security education, this paper presents our work-in-progress effort on developing a real-world relevant security labware to provide students with mobile threat analysis and protection experience. A preliminary evaluation has been conducted on the pilot labs and positive feedback has been received.

Keywords—Labware, Mobile Security, Real World Relevant

I. INTRODUCTION

The computing landscape is shifting towards mobile devices [1]. The smartphones and tablets are permeating into nearly all aspects of our information society and many students have considered them as computers [2]. Unfortunately, security threats to mobile devices and applications are also growing explosively. Traditional security threats, e.g., malware or social engineering, are evolving in this new environment; more importantly, new components (e.g., Global Positioning System and Subscriber Identity Module) and services (e.g., call, message, and location services) in mobile devices introduce new sources of security risks. Recent security reports [3, 4] have described the rapidly growing number and sophistication of mobile threats. However, the rapid growth of mobile threats has not been accompanied by sufficient educational activities in the area of mobile security. To our best knowledge, very few courses have been initiated for teaching mobile security and there is a lack of well-prepared learning materials to provide students with the state-of-the-art mobile security knowledge and hands-on experience. This calls for innovations in educational activities and learning materials to promote the exposure of students to this emerging and important security area and to prepare them for the growing industry needs.

To address the above needs and challenges, this paper presents our work-in-progress effort on developing a real world relevant labware to provide students with mobile threat analysis and protection experience. The labware employs a novel learning approach that couples the in-depth threat analysis with the detail hands-on implementation of corresponding protection mechanisms. In addition, the labware aims at providing real world relevant learning, which means that the labware will

reflect the up-to-date mobile threats and protections, provide materials close to students' everyday lives, and instruct students implementing protection apps that are workable in practice.

II. LABWARE DESIGN

To design the labware, we collected and analyzed a number of recent mobile security reports from both academy research and security companies, e.g., Lookout, McAfee, and Symantec. Table 1 lists the ten labs that we will design in the labware. It covers important threats in multiple aspects of mobile security. Each lab focuses on one type of mobile threats and develops multiple forms of learning materials for the threat analysis and protection, including lecture, case study, demonstration, and hands-on mobile app development. Instead of implementing a comprehensive mobile security resource center, the labware is intended to create real world relevant learning materials and to provide students with hands-on mobile security experience.

III. EXAMPLE LAB

This section demonstrates the labware using *Lab 7: Mobile Messaging Threats*. Mobile messaging service, including Short Message Service (SMS) and Multimedia Messaging Service (MMS), is one of the most important functions in mobile devices; however, its convenience and popularity have also made it become a lucrative playground for various attacks and frauds such as spamming, phishing, and spoofing [5]. These threats are unique to the mobile computing systems and are seldom applicable to other information systems. The *Lab 7: Mobile Messaging Threats* aims at providing students with mobile messaging threat analysis and protection experience. In the threat analysis part, this lab first introduces the mobile messaging service and analyzes important threats to the service; then it provides a mobile app to demonstrate an SMS attack instance. Fig. 1 shows two screenshots of this demonstration app. In this demonstration, an attacker installs a malicious SMS broadcast listener on the victim's mobile phone, then he sends a malicious SMS to the victim and steal victim's contact (subfigure on the right of Fig.1), and the victim has no information about the attacker's malicious SMS activities (subfigure on the left of Fig. 1).

TABLE I. LAB LIST

| Lab | Mobile Threat Analysis & Protection | Security Aspect |
|-----|--|---|
| 1 | Threats of Lost or Stolen Mobile Devices | Mobile Device Security & Privacy |
| 2 | Unauthorized Mobile Resource Access | |
| 3 | Mobile Privacy Threat | |
| 4 | Mobile Malware | Mobile App Security |
| 5 | Mobile Spyware | |
| 6 | Secure Mobile App Development | |
| 7 | Mobile Messaging Threats | Mobile Network & Communication Security |
| 8 | Mobile Banking Threats | |
| 9 | Mobile Phishing Threats | |
| 10 | Mobile Network Threats | |

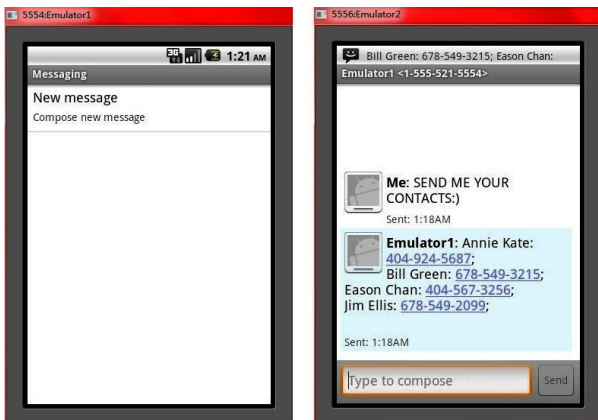


Fig. 1. Screenshots of a Mobile SMS Attack Demo.

In the protection part, the lab first gives an overview of the protection mechanisms, e.g., using white list or black list to block or filter messages. To defend the attack demonstrated in the threat analysis part, the lab instructs students implementing a protection mobile app using SMS filtering. Fig. 2 shows two screenshots of the mobile SMS protection app. In this protection app, the students implement a filter to block suspicious SMS messages (subfigure on the left of Fig. 2) from unknown users (subfigure on the right of Fig. 2). The app is workable in practice. Students can easily install their developed apps in their own devices such that they can obtain an instant gratification and confidence from the hands-on practice and they can be encouraged to create new apps.

IV. PRELIMINARY EVALUATION

Pilot labs have been presented to 28 undergraduate students in the course "Wireless Security" for preliminary evaluation. Table II shows the evaluation question and students' feedback. On average, about 90% of students gave non-negative feedback on all evaluation questions, and about 70% agreed with our design objectives of the labware. In particular, we are pleased and encouraged to see that about 65% students felt that the labs were easy to follow and practice, since none of the 28 students had previous mobile development experience.

V. CONCLUSION

This paper presents our work-in-progress effort on developing a real world relevant labware to provide students with mobile threat analysis and protection experience. A preliminary evaluation has been conducted on the pilot labs and positive feedback has been received. In the future work, we will continue to improve the design of the labware, complete the labware development, and conduct extensive evaluations.

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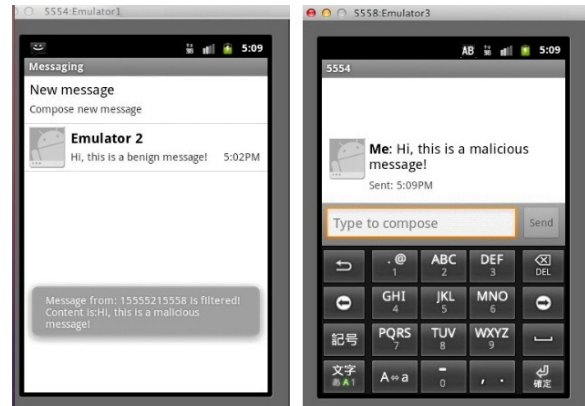


Fig. 2. Screenshot of a Mobile SMS Protection App.

TABLE II. PRELIMINARY EVALUATION

| Evaluation Question | Feedback ^a |
|--|-----------------------|
| 1) The labware helps me understand better about the mobile security concepts in the project. | 71.43 / 21.43 / 7.14 |
| 2) The labware provides me with more hands-on experience on learning mobile security. | 71.43 / 28.57 / 0 |
| 3) The labware is easy to follow and practice. | 64.29 / 7.14 / 28.57 |
| 4) The labware promotes my interest and engagement in security. | 71.43 / 21.43 / 7.14 |
| 5) The labware promotes my interest and engagement in mobile app development. | 57.14 / 28.57 / 14.29 |
| 6) I gained real world security experience from the real world relevant hands-on mobile labs | 71.43 / 21.43 / 7.14 |

a. the format of feedback data is Agree / Neutral / Disagree, e.g., the feedback to question 1 is 71.43% agree, 21.43% neutral, and 7.14% disagree

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Work in progress: Entrepreneurial Skills for Computing Graduates

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Abstract— Preliminary experience with a final year activity focusing on Entrepreneurship & Enterprise is presented. The curriculum is described and its suitability for Computing students evaluated. Persuading technical students to participate in a non-technical course is a considerable challenge. The University has recently organized an annual business competition, with prizes, to encourage students to pursue their ideas and develop commercial products and services. This has been incorporated into the assessed course with some success.

Keyword - enterprise; entrepreneurship; professional development; graduate training;

I. NEED FOR NEW ENTERPRISES

Graduates from UWE with bachelor degrees in Engineering and Computing are very likely to find employment with established firms who are currently experiencing great difficulty in finding new staff with the correct set of technical skills [1][2]. Although it is quite unusual for young UK graduates to want to launch their own enterprises and start developing services and products, it is from these new start-ups that much of our future economic growth is anticipated. To prepare technical graduates to be entrepreneurs is a great challenge for universities. Such a situation is not true for all disciplines. In Arts & Media courses, graduates are already prepared for self-employment or sole-trading because that is the more common job environment for them, and students will require business skills and a canny market awareness from their first day at work.

II. ENTREPRENEURSHIP

This course originally started in September 2009 to satisfy the requirements of a newly introduced university-wide Graduate Development Program. (GDP) [3]. Each year of the GDP program has assumed a distinct, designated mission. Year 1 GDP generally focuses on group socialization, student retention, and individual study skills. With 4 year sandwich degrees, GDP2 deals almost exclusively with preparation for the approaching third year industrial Placement/Internship. When deciding how best to exploit GDP3 sessions in year 4, we decided that a course which exposes students to skills and understanding of Entrepreneurship and Enterprise would be eminently suitable in preparing them for their future careers.

The curriculum was titled "Entrepreneurship for Computing" [4], and was only intended for senior students following the BSc Computer Systems Engineering degree (CSE). It was

broadly based on a well proven course running at University College London (UCL) given by Philip Treleaven [5]. The scheme involves groups of students working together throughout the year to bring a virtual product to market. It was primarily intended to stimulate interest in business innovation and product development amongst students on computing-based awards. So students are led progressively through the process of starting their first business, with discussions relating to technical, marketing, financial and personnel issues. Its aim is to stimulate interest, increase self-confidence and ease the pathway for emergent enterprises. Thus students are encouraged to acquire skills and knowledge for the time when they feel ready to exploit some innovative idea through a start-up business venture. Each student group must identify a new service or product which could then become the focus of the group's attention throughout the year. They must also locate and appoint a Commercial Mentor who will offer support, advice and criticism when appropriate. A Commercial Mentor may come from a Placement experience, part-time job or personal contact. The course Alumni Lists will be very useful in obtaining well qualified assistance.

On completion of this module a student will typically be able to show a detailed knowledge and understanding of the activities required at each step in launching a new product or service. This will include an understanding of the different models available for financing a new start-up and how to create a business model and a business action plan. Marketing will be an important part of this plan, requiring a high level strategy with the deployment of a website, publicity material and direct presentations. All new start-ups run an increased risk of failure, with only 50% surviving through the first four years. This stark statistic has to be factored into all real-world plans!

III. CURRICULUM DELIVERY

One important decision taken early on was to bring in a true Entrepreneur to present the course. It is unlikely that an average academic would be able to muster the experience and credibility to convince students of the wisdom of his/her words. Luckily, Jeff Graham (CEO XOR Systems) agreed not only to lead the course, but also to become closely involved in its initial development. He agreed that all teaching materials should be selected with technical students in mind, in order to gain their attention and win engagement. The module that emerged has many interesting features.

When Entrepreneurial Skills for Computing was offered as voluntary GDP3 activity it became apparent that it would be

difficult to sustain engagement beyond Christmas due to competing pressures of the final year of study. Considering this experience, it was decided to validate the activity as an academic, 10 credit module (still only contributing 8.3% of their final year), and offer it as an option on the BSc CSE degree. In addition, participation with the UWE theBizIdea start-up competition [6] was then formally incorporated into the activity and assessment schedule. This was done after discussions with the organizer, Jill Burnett, who welcomed the involvement of CSE students who previously had not been encouraged to participate.

The first year of this scheme was much more successful than had been anticipated. The benefits for CSE students are clear. TheBizIdea competition serves to introduce technically oriented students, who often have a narrow view of their work focusing on the academic challenges and merits of their work, to engage and consider the wider business aspects, such as budget planning and marketing.

Although engagement with theBizIdea has been limited in the past, it is now recognized as potentially providing a very important and beneficial role for students. This could readily be extended to other technical programs in the department.

The tasks that students have to complete for theBizIdea aid their preparation and understanding of commerce and industry. Additionally our view is that theBizIdea activities map directly onto the GDP3 targets, having an employability focus and that the external input/feedback that the students receive adds a weight and credibility over and above academic feedback – even if they do say the same thing!

Students' draft business plans are submitted to theBizIdea external assessor panels who grade the work and provide feedback. Students often found this shockingly tough and unexpectedly frank in its criticisms.

IV. COURSE CURRICULUM & ASSESSMENT

The full curriculum is obtainable on-line [4] but the significant aspects are group work, product identification, business plan development, marketing plan development, presentation of plans to external assessors and responding to the resultant critical appraisal. Assessment deals with both individual and group work by written reports and oral presentations.

V. EXPERIENCE SO FAR

A major difficulty is generating a viable business idea for each group. It's hard to develop a business concept in a short period when you've never had to do this before and it needs to be done early in the academic year, while teaching is still underway, so the students haven't fully benefited from the course. The idea needs to be sufficiently strong to sustain interest over the year and robust enough to survive competitive, even ruthless scrutiny.

This was solved in a number of ways. All the students were undertaking a final year personal project which can involve quite sophisticated concepts, potentially offering a rich source of product ideas. Staff also had a number of specific ideas and product areas prepared; smart phone apps being currently suitable for CS students. Such generic suggestions are

extremely useful in providing students with a lead towards a novel business idea.

The students then developed the idea further, to personalize it and make it their own. It is advisable to talk with students who are planning to take the module, perhaps before the summer recess, to allow them to at least explore what areas interest them before the module starts.

We had to be cautious when exploiting theBizIdea competition as part of teaching. The competition was set up separately to encourage any student who thinks they already have a viable business idea and want to pursue the idea with passion and commitment. We rather needed to co-opt the process for our own ends. Our purpose was to use it as a teaching vehicle, gaining invaluable feedback from experienced business people, and as a measurement tool to evaluate what the students had learned on the module. This is a slight distortion of theBizIdea competition. We wanted students to invent an idea and then submit it, against a time-line driven by the needs of the module.

When it came to assessment of the students' work, the intrinsic quality of their idea became an issue. Should we overlook the weaker ideas, and concentrate on the bid process and business model? In general, the ideas adopted do tend to be strong enough in their own right and it was easy to judge how well they would fare in the market place. But for the weaker ideas, the judgment was based on how well the idea was developed by the team.

It was important that the students should re-submit their work, and aim for a minimum of two attempts at theBizIdea, so that they would improve their proposal, based on the feedback they received. This encouraged a process of refinement, improved their use of business language, highlighted areas that needed further development and created some dialogue with the assessors. The marking scheme for the module therefore could reward their second attempt with an improved mark.

IP ownership has been discussed within some groups where a particularly strong idea has been proposed by a member of that group. Non-disclosure agreements could be used, involving all academic staff and external assessors as well as the students. An alternative is for those involved to acknowledge IP ownership at the outset and so avoid any later disputes.

Several new degree programs have now adopted the Entrepreneurship module for their students. The future looks bright!

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Differentiating Undergraduates from Graduate Student and Faculty Inventors

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Abstract — Undergraduate students are increasingly engaged in developing products and technologies that are commercially viable outside of the university through their involvement in courses and experiential programs focused on entrepreneurship and product design. It is hypothesized that this trend is increasing activity between undergraduates and university technology transfer offices, leading to questions of how best to align student interests with institutional policies and practices related to intellectual property (IP). Since most undergraduate students are not employed by their universities as are faculty and many graduate students, this raises interesting questions related to the ownership of intellectual property developed as part of a course or experiential program. This paper summarizes the preliminary results of a survey designed to examine the level and nature of undergraduate involvement in creating intellectual property as well as institutional policies and practices in response to these trends. The survey was administered to intellectual property professionals in technology transfer offices at universities in the United States with strong emphases in engineering, science, and technology and/or entrepreneurship.

Keywords — *intellectual property; undergraduate; entrepreneurship; engineering education; product design; innovation*

I. INTRODUCTION

In recent years, there has been a significant increase in the quantity and diversity of students participating in entrepreneurship education and activities focused on developing products, technologies, and services that are commercially viable. This trend has been driven by a number of factors, including: (1) a generation of students who are

aware of the financial and personal benefits of entrepreneurship; (2) a need to prepare students for a new economy where smaller companies are increasingly a source of jobs; (3) accreditation and other requirements that drive the integration of more “real world” experiences into educational programs; (4) and a general trend towards creating more entrepreneurial universities able to generate revenues by engaging with the private sector [1]. In response, institutions are developing entrepreneurship courses and experiential learning programs for students. They are also creating entrepreneurship centers, stepping up technology commercialization efforts, and expanding business incubators and technology parks.

For many years, entrepreneurship education programs existed primarily in schools of business. More recently, there is a movement to equip students in a wider range of disciplines such as engineering and the arts with entrepreneurship education so that they are able to generate value from their knowledge in more entrepreneurial ways [2]. These efforts are based on the belief that students who are involved in developing products, technologies, processes, and services will be able to generate more value from their knowledge if they understand customer needs, markets, competition, business models, and are able to advocate for their ideas. This movement is likely to continue given initiatives such as the National Science Foundation’s award of a \$10 million grant over five years to launch a national STEP Center based at Stanford University for teaching innovation and entrepreneurship in engineering [3].

The increased access to entrepreneurship education and emphasis on “real world” product design is likely to lead to more involvement by students in generating intellectual property and/or creating businesses that are viable outside of the walls of the university. Since most undergraduates are not employed by the university, unlike faculty and many graduate students, this poses interesting questions such as: Who owns

the IP developed by a student as part of a course project or experiential program? How is the contribution of a student versus that of the university defined? And, who should students turn to for assistance with intellectual property protection issues?

I. BACKGROUND

A. *Management of intellectual property at universities*

The passage of the Bayh-Dole Act is the principal factor in explaining the increase in patenting and licensing activities by academic institutions in the United States [4]. This legislation gave U.S. universities, small businesses and non-profits control of their inventions and intellectual property that resulted from federal government-funded research. Revenue generation opportunities provide considerable incentive for universities to pursue commercialization of their intellectual property, particularly in light of reductions in federal or state funding for education [5]. A summary of patent and licensing revenue data from the Association of University Technology Managers (AUTM) in 2010 revealed research-related income of \$2.4 billion generated by 155 universities and 27 hospitals and research institutes surveyed [6].

In order to manage the opportunities and challenges introduced by increased IP commercialization activity, many universities created administrative units commonly referred to as technology transfer offices (TTOs). The main function of a TTO is to act as the intermediary between the IP creators (i.e., inventors) and partners who aid in the commercialization process (e.g., entrepreneurs, industry, attorneys). As such they are responsible for putting in place policies, processes and practices which: 1) support IP creation, 2) provide clear ownership determination of IP, 3) encourage IP commercialization opportunities for the institution, and 4) align with long-term IP management strategies. Given the number of stakeholders involved in the IP management process at universities, a desired outcome is balancing the interests of all involved parties. While the alignment of the incentives are typically intended to be beneficial to all stakeholders, there are often trade-offs between participants in the process.

B. *Undergraduate students and intellectual property*

Until recently, little has been published about the topic of university intellectual property policy specifically as it relates to undergraduates. This suggests that the level of involvement by undergraduates in IP protection has not warranted much attention and/or that many entrepreneurship or product development courses were created with limited consideration of institutional IP policy. There appear to be three main contexts in which undergraduates can potentially confront issues related to the ownership of intellectual property: 1) entrepreneurship programs, 2) industry-sponsored engineering or product design courses, and 3) undergraduate research. Nordheden and Hoefflich [7] addressed the issue of ownership

of IP within the context of the increasing involvement in research by undergraduates. They pointed out that because students typically do research for credit and not money, they do not have an employment contract with the university and are not covered under what is referred to as the "workplace doctrine" and could be in a position to challenge a university for a share of the rights. They suggested the need to get students to sign away their rights before conducting research, but point out that this could conflict with university policies toward students.

An IP Policy Primer prepared by the National Collegiate Inventors and Innovators Association, an organization that works closely with student inventors, stated that a good IP policy removes gray areas, and spells out each player's stake, rights, and responsibilities [8]. Similarly, in an article describing IP issues faced by universities seeking to commercialize student innovation at all levels, Evans [5] indicated the need to create understandable IP policy and provide educational materials suited to each constituent. However, an accurate understanding of IP ownership rights and policy appears may be the exception more than the rule at many institutions. A study conducted by the University of North Dakota indicated that the perception of IP ownership related to work involving students is viewed quite differently by the students and the university faculty. Students consistently assigned more ownership to students than to faculty and attributed less ownership to faculty when industry sponsors were involved [9].

Preliminary interviews and pilot survey data collected from university technology transfer professionals prior to conducting this study suggested that there were few institutions with explicit policies directed at undergraduates [10]. Instead, most governed under the general IP policies of the institution where undergraduates operated in a gray area and where, as one interviewee stated, technology transfer offices "turn a blind eye." Cases where undergraduate IP policy appeared to be relatively straightforward were situations where students were being paid for work which resulted in the generation of IP and when students were involved in a product design or similar course that was sponsored by a company. However, this was described as leading to other complexities. One institution reported that students had to be given the opportunity to opt out of industry-sponsored engineering courses, which meant comparable curricular alternatives had to be available.

Another gray area identified in pilot survey data was the definition of "significant use of university resources" in relation to the development of IP. This referred to the use of libraries, computers, software, space, hardware, and materials owned or provided by a university. Some institutions made distinctions such as "expensive, core, specialized equipment," or "facilities not available to the public." Universities varied as to whether they included IP developed as part of classes or class assignments. Other issues included the degree to which faculty should be involved in enforcing IP policy and whether technology transfer offices have the resources to devote to student intellectual property.

The experience of the authors has been that when faculty are unable to clearly articulate intellectual property policy to students and/or when it is perceived by students to be in favor of the institution, it can inhibit innovation and prevent students from obtaining the feedback and assistance that could help advance their innovations or ventures. In some cases, students resort to working on projects that simply meet the minimal requirements of the course, while keeping their “real” projects to themselves for fear that the university will claim ownership. While these fears are unfounded in many cases, they highlight the need to communicate IP policy to students in a way that encourages them to innovate and ultimately create goodwill. This was the goal of North Carolina State University, which found that “requiring disclosure and possibly asserting university ownership of inventions created by undergraduate students as a result of their coursework was antithetical to the fundamental nature and purpose of the university, and would have a negative impact on student perceptions and alumni philanthropy.” The university has since updated their patent policy to clarify the students’ rights, allowing them to own the IP generated through their normal coursework [11].

II. PURPOSE AND RESEARCH QUESTIONS

The purpose of this study was to examine trends in the level and nature of undergraduate involvement in creating intellectual property and institutional policies and practices in relation to them. The research questions were:

- What is the extent and nature of undergraduate involvement with technology transfer offices?
- What are universities’ specific policies related to undergraduate IP?
- What are general (unofficial) attitudes and practices related to IP involving undergraduate students?

III. METHOD

A new survey instrument was developed to capture data necessary to answer the research questions. Survey items were created based on a literature review as well as pilot data collected via interviews with technology transfer professionals prior to conducting the study. It was comprised of both objective and subjective questions in order to understand trends related to and attitudes toward the management of intellectual property generated by undergraduates. The survey was reviewed by faculty, technology transfer professionals, intellectual property attorneys, and educational assessment experts.

Directors of TTOs at approximately 50 colleges and universities in the United States were asked to complete the survey. These institutions were selected because they had a strong emphasis in the STEM disciplines and/or entrepreneurship and were likely to have active involvement in technology transfer activities which may involve undergraduates. Appropriate contacts at each institution were verified by via web searchers and telephone calls prior to

administering the survey. Contacts were sent an email explaining the purpose of the study and a link to the online survey. Over the course of several weeks, email reminder messages were sent and telephone calls were made to encourage contacts to participate. This paper reports on preliminary survey data collected from 32 institutions.

IV. RESULTS

Question 1: What is the extent and nature of undergraduate involvement with technology transfer offices?

Survey respondents were asked a number of questions related to the frequency of their interactions with undergraduates within the previous year, the disciplines from which they came, and the factors driving growth in IP activity among undergraduates. There was great variation the number of undergraduate with which TTOs reported to be interacting. Of those surveyed 6% reported that they had interacted with no undergraduates; 25% less than five; 31% 5-10; 16% 11-20; and 16% 21-50 and 6% more than 50. When asked whether the number of undergraduates they see was growing, 22% responded “yes, at a faster rate than for other inventor groups (e.g. faculty and graduate students); 28% “yes, but at a rate similar to other inventor groups”; and 50% “no, staying about the same.” Fifty-three percent agreed that undergraduate involvement favored certain academic departments versus 31% who did not. Top areas were engineering, followed by science, chemistry, and computer science. Growth was attributed to a number of factors. Respondents agreed most strongly that growth was driven by entrepreneurial competitions, a general increased emphasis on entrepreneurship on their campuses, and engineering design courses and to a slightly lesser degree due to undergraduate participation in research or university success stories related to technology commercialization (Table I).

TTO professionals were also asked several questions about the frequency with which students came to their offices seeking particular types of advice. Students were reported to be most frequently seeking advice about internship opportunities, understanding their personal rights related to IP, or guidance related to a specific invention (Table II).

Question 2: What are universities’ specific policies related to undergraduate IP?

A number of questions related to the extent to which TTOs addressed undergraduates specifically in their IP policies, how these differed from those directed at faculty and graduate student inventors, and whether they anticipated any changes to their policies. In response to whether institutions had instituted any programmatic changes to accommodate undergraduates, 25% said yes, 13% said they were in progress, and 63% said no. One third of those surveyed reported to have a specific policy for intellectual property developed by undergraduates, while 66% did not. Respondents were asked whether they actively tracked undergraduate student involvement in IP generation. Of the 32 respondents 94%

reported that they did not track undergraduate student involvement in IP generation specifically. However, in a follow-up question related to how the tracking process differs from that of other inventor groups, 16% of respondents indicated that they track undergraduates as they do any other inventor. When asked whether their university's policies and practices vis-à-vis undergrads were likely to change, 3% reported it was very likely, 8% likely, 59% unlikely, and 13% very unlikely.

Seventy-five percent of respondents considered the "use of significant university resources" when assigning IP ownership to undergraduates. University resources that were taken into consideration most frequently were research labs; parts, components and supplies; and machine shop use. Taken into consideration to a lesser degree were library resources, internet access, and advice or mentoring from the TTO. The extent to which other resources were considered varied widely across institutions (Table III).

TABLE I. FACTORS DRIVING GROWTH IN IP ACTIVITY AMONG UNDERGRADUATES

| Factors | Disagree or strongly disagree | Agree | Strongly agree |
|--|-------------------------------|-------|----------------|
| Entrepreneurship or product innovation-related competitions | 9% | 38% | 53% |
| A general increased emphasis on entrepreneurship and technology commercialization on your campus | 6% | 47% | 47% |
| Engineering design/product development courses | 16% | 38% | 47% |
| Entrepreneurship courses offered on campus | 16% | 47% | 38% |
| Entrepreneurship-related clubs or student organizations | 16% | 50% | 34% |
| Seminars or workshops related to entrepreneurship and intellectual property (not semester-long) | 22% | 47% | 31% |
| More students pursuing entrepreneurial careers | 22% | 47% | 31% |
| Undergraduate participation in research | 34% | 38% | 28% |
| University intellectual-property success stories | 44% | 41% | 16% |

Question 3: What are general (unofficial) attitudes and practices related to IP involving undergraduate students?

Respondents were asked a number of more subjective questions designed to understand institutional attitudes toward undergrad IP. The first question asked respondents to characterize their degree of involvement with undergraduates. Over 50% stated they got involved with undergraduates primarily on a case-by case basis, with the remainder split between being passive and very active (Table IV).

When asked their opinions of the degree to which they should be involved with undergraduates, many agreed that they should be more involved in working with undergraduates but many also agreed that undergraduate IP yields very little return on investment of time or money (Table V).

TABLE II. FREQUENCY WITH WHICH STUDENT SEEK PARTICULAR TYPES OF ADVICE FROM TTOS

| Reasons | Rarely | Occasionally | Frequently |
|---|--------|--------------|------------|
| Opportunities for internships | 25% | 44% | 28% |
| An understanding of their personal rights in relation to university IP policies | 19% | 66% | 16% |
| Guidance related to a specific invention or technology | 13% | 72% | 16% |
| General entrepreneurship and business start-up questions | 31% | 50% | 13% |
| General knowledge about patents and the IP protection process | 34% | 53% | 13% |
| Financial benefits/obligations related to IP | 44% | 38% | 6% |

TABLE III. FREQUENCY WITH WHICH UNIVERSITY RESOURCES ARE CONSIDERED IN IP OWNERSHIP DECISIONS

| Resources | Never | Sometimes | Always |
|---|-------|-----------|--------|
| Research labs | 22% | 38% | 41% |
| Parts/components/supplies (e.g., electronic components, metal, chemicals, etc.) | 28% | 47% | 25% |
| Advice or mentoring from professors – (direct input to solve problem or generate ideas) | 47% | 28% | 25% |
| Machine/fabrication shop | 34% | 44% | 22% |
| Class assignments | 69% | 19% | 13% |
| Computer servers | 53% | 41% | 6% |
| Software provided by the university | 50% | 47% | 3% |
| Computer labs | 56% | 41% | 3% |
| Office space | 66% | 31% | 3% |
| Advice/mentoring from technology commercialization office | 78% | 19% | 3% |
| Internet access/networks provided by the university | 72% | 28% | 0% |
| Library resources/databases | 78% | 22% | 0% |

TABLE IV. STATEMENTS THAT BEST DESCRIBE INSTITUTIONS' SURVEYED PRACTICES TOWARD UNDERGRADUATE IP

| Statements | n | percent |
|---|----|---------|
| Somewhat involved – we get involved on a case-by-case basis | 18 | 56% |
| Passive – we tend to ignore it or look the other way | 7 | 22% |
| Actively involved – we play an active role in activities that can generate undergraduate IP | 7 | 22% |

TABLE V. ATTITUDES TOWARD UNDERGRADUATE IP

| Attitudes | Disagree or strongly disagree | agree | Strongly agree |
|---|-------------------------------|-------|----------------|
| We should be more involved in working with undergraduates | 41% | 59% | 0% |
| We don't have the resources to meet the needs of undergraduates | 50% | 31% | 19% |
| Undergraduate IP yields very little return on investment of time or money | 38% | 56% | 6% |
| Undergraduate students are primarily generating IP that is not within the scope of the university IP policy | 28% | 53% | 19% |

Respondents were asked whether they felt their policies were understood by students. Only 6% felt that their policies were well understood, 59% felt they were somewhat understood, and 34% felt they were not understood at all. In response to whether faculty should be more involved in handling IP topics and issues related to undergraduates; 38% indicated yes, 34% said no, and 28% were unsure. Respondents were also asked about the frequency with which they were consulted when new courses that involved entrepreneurship and innovation were developed; 28% said frequently, 47% said occasionally, and 25% said never.

V. DISCUSSION

The preliminary findings of this study indicate that undergraduate involvement in intellectual property is growing at approximately half of the institutions surveyed and remaining constant at the remainder. Growth appears to be driven by an increased emphasis on entrepreneurship and "real world" product design via coursework and experiential learning opportunities, particularly in disciplines such as engineering, chemistry, and computer science. The types of IP-related advice students are most frequently seeking from TTOs are an understanding of their personal rights in relation to policy and guidance related to a specific invention or technology.

In response to these trends, 38% of institutions indicated that they had or were in the process of instituting

programmatic changes to accommodate undergraduates and one third had specific policies for undergraduates. Interestingly, when asked whether their institution policies and practices related to undergraduates were likely to change, only 11% reported this was the case, suggesting that most institutions that intended to address undergraduates had already taken steps to do so.

The extent to which the "use of significant university resources" plays a role in assigning IP ownership appeared to vary greatly. When asked about the frequency with which specific resources were considered, there were a significant amount of "sometimes" responses as opposed to "never" and "always." This finding suggests that there is considerable gray area or subjectivity when attempting to assign ownership based on the use of these resources. Additional research is necessary to understand whether this is the case and exactly how TTOs navigate through these issues.

Only 22% of universities surveyed reported to be actively involved in activities that could generate undergraduate IP but 59% felt that they should be more involved in working with undergraduates. For half of those surveyed a barrier to doing so was not having sufficient resources to meet the needs of undergraduates and 62% felt that undergraduate IP yielded very little return on investment of time or money. This suggests for many institutions, investing more in servicing undergraduates lacks a compelling return.

These findings suggest that there may be opportunities to better address IP issues at the courses or program level. However, doing so would require a better understanding among students and faculty of institutional policies and practices. The results of the study indicated that policies were not well understood by students and respondents felt that faculty could be more involved in handling related issues. It is possible that better communication of policies and practices to students and faculty, may improve a TTOs ability to intervene on those undergraduate IP activities that have a greater likelihood of providing a return to the institution.

CONCLUSION

The emphasis on entrepreneurship and real-world product design is likely to grow as institutions seek to better prepare students to create value in this increasingly competitive, global economy. Given these trends, the results of the preliminary data collected as part of this study suggest that it may be beneficial to institutions to clarify policies as they related to undergraduate generation of intellectual property and find ways to communicate them to both students and faculty. This is likely to reduce ambiguity and provide a better return on investment to TTOs in terms of time, money, and goodwill to the institution.

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Work in Progress: Integrating Entrepreneurship into Undergraduate Engineering Education

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Abstract—As government and industry leaders place increased importance on entrepreneurship and innovation within science, technology, and engineering (STEM) in higher education, courses, programs, and centers are being developed to enhance students’ learning and development in these areas. Despite this growth in programming and the extensive entrepreneurship research in the literature, little research has been completed regarding ways in which students in STEM disciplines value, identify with, and are willing to participate in entrepreneurship activities. This paper presents work in progress to develop a survey and run focus groups to better understand STEM students’ perceptions of entrepreneurship and entrepreneurship educational opportunities. The results can be used by educators to better understand the knowledge, beliefs, and practices of students being served by entrepreneurship and innovation programming, and to identify approaches to engaging more students in this critical area.

Keywords- *entrepreneurship; STEM; undergraduate education; identification; willingness; future career, program development*

I. INTRODUCTION

A 2008 Kauffman Foundation report states, nearly 50% of U.S. startup founders hold science, technology, engineering, and mathematics (STEM) degrees. Moreover, the majority of startup founders were above the age of thirty-five when they began their ventures, not 20-somethings as might be the perception of some Americans [1]. In recent years, some M.B.A. programs have shifted their focus to emphasize entrepreneurship and schools such as Harvard Business School and MIT are developing cross-disciplinary entrepreneurial atmospheres that promote innovation, creativity, and the creation of successful technology-based startups. Additionally entrepreneurship courses and programs outside of business schools are being developed and some are calling for entrepreneurship and innovation to be addressed at an institutional level [2].

At the same time, industry and government leaders are calling for an increased emphasis on innovation and entrepreneurship in STEM education [3]. Major STEM innovation centers, including the \$10M Stanford Epicenter (Engineering Pathways to Innovation) Program (<http://epicenter.stanford.edu/>), seek to satisfy this call. Yet even as programs and research centers develop, critical questions regarding engineering students’ perceptions and beliefs about entrepreneurship remain. How do STEM students, who have been found to implement entrepreneurial concepts after graduation, identify with entrepreneurial courses and

beliefs? What is their willingness to take courses, often beyond their required course load, which promote knowledge gains in entrepreneurship, innovation, and new venture creation? Furthermore, how might these entrepreneurial-minded STEM college students view engagement in interdisciplinary training and experiences that encourage startup practices prior to and upon graduation? This paper addresses questions such as these by reporting on the development of an entrepreneurship survey and focus groups targeting science and engineering undergraduate students.

II. RESEARCH METHODS

A. Overview

To better understand STEM students’ beliefs and values associated with entrepreneurship, we draw on prior research in motivation and engineering student pathways to develop a research instrument designed to measure constructs such as expectancy-value, interest, identification, and future possible selves as they pertain to entrepreneurship. Since little data regarding STEM students in this area exists, we employ an intersection of theoretical constructs here to better identify those most salient to both students and program development. In addition to measuring core constructs, the survey will also seek to supply logistical knowledge needed by engineering educators and entrepreneurship program developers (e.g. the number of entrepreneurial courses students are willing to take). The following sections provide details on the survey population and examples of the survey items under development.

B. Population

The initial population chosen for this survey is all undergraduate students in the Colleges of Science and Engineering at a large R1 university. Including students from all levels of their undergraduate education will allow for the analysis of differences in students’ perceptions as they progress through their undergraduate education. It will also provide course and program developers the information needed to develop entrepreneurship education opportunities at the various levels of undergraduate education.

C. Survey Item Examples

The survey is currently in the pilot phase. The survey items have been developed based on existing validated survey items where possible. When applicable, we have provided the original validated survey reference.

To address willingness and logistics we seek to find the extent that students are willing to commit limited resources to

entrepreneurship activities. Questions such as the one below also provide course and program developers with important information directly from students. The following is an example of a survey item addressing willingness and logistics:

How many extra courses would you be willing to take to learn about entrepreneurship?

To address students' interest in entrepreneurship and their future career as an entrepreneur, we called on the University of Washington's Center for the Advancement of Engineering Education (CAEE) Pathway of Engineering Alumni Research Survey (PEARS) administered as part of the Engineering Pathways Study [4].

Regarding students' interest in entrepreneurship, we provide the following example:

How interested are you in doing each of the following activities? (Rated on a 5-point Likert-type scale from "Not Interested" to "Extremely Interested").

- *Reading articles or books about entrepreneurship*

Regarding students' future career as entrepreneur, we provide the following example:

Looking ahead, how likely is it that you will do each of the following? (Rated on a 5-point Likert-type scale from "Definitely Not" to "Definitely Yes" with the inclusion of a "Not Applicable" category.)

- *Start a company/organization in the near future*

To address the identification with entrepreneurship we called on survey items employed by Jones, Paretti, Hein, and Knott to measure motivational constructs among first-year engineering students [5]; the items in that survey were drawn from validated motivation instruments. The following is an example survey item adapted from the above study:

Please rate your level of agreement with the following statements: (Rated on a 7-point Likert-type scale from "Strongly disagree" to "Strongly agree").

- *Being good at entrepreneurship is an important part of who I am.*

III. RESULTS

The results of this survey will reveal insights about undergraduate science and engineering students' identification with entrepreneurship, their desire to commit already limited resources, and the potential barriers to pursuing a better understanding of entrepreneurship and innovation. Also, a focus group protocol will be developed based on the survey findings and established literature in entrepreneurship research. Findings from this research will not only assist entrepreneurship program development from within STEM disciplines, but it also serves to inform business schools as they partner to create interdisciplinary course offerings targeting STEM students.

IV. FUTURE WORK

This survey is the first step in a larger research-to-practice cycle. Future survey work includes pilot analysis, revision, and

administration of the revised survey with science and engineering undergraduates. Upon completion, we will analyze and disseminate the findings as well as develop and administer entrepreneurship-centered focus groups to obtain a more detailed view of science and engineering students' perceptions of entrepreneurship and entrepreneurship education. Survey participants will have the opportunity to sign up to participate in a focus group session providing an in-depth view of their perceptions regarding entrepreneurship and entrepreneurship education. Finally, the findings of both the survey and focus groups will be reported and used to develop and promote entrepreneurship education activities within the college of engineering and will be disseminated to key course and program developers within the university.

V. IMPLICATIONS AND CONCLUSIONS

This paper adds to the body of entrepreneurship literature, specifically addressing engineering students' entrepreneurial beliefs and desires to gain knowledge in entrepreneurship. Performing and disseminating research to understand students' values, interests, willingness, and identification with entrepreneurship is a critical step toward enhancing the nature in which we implement entrepreneurship education. Additionally, this paper reaches beyond the entrepreneurship community and into the fields of business, science, and engineering education as well as university administration, addressing the broader issue of developing curricula that meet the needs of both STEM students and our nation.

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Work in Progress: Developing an Innovation Self-Efficacy Survey

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Abstract—Innovation is critical to our economic and social prosperity. We rely on industry, university, and government employees to develop, modify, and implement innovative ideas while navigating ambiguous problem contexts, overcoming setbacks, and persisting in competition with courses of action. Research has shown that self-efficacy, or an individual's belief in their ability, influences the pursuit of and persistence in challenging work. This suggests that self-efficacy is critical for innovation. Despite resource-intensive efforts to foster innovation in organizations, we inadequately understand how to measure the impact of these interventions on individuals' judgment of their own innovation ability. We present the initial development and validation of the first survey measure for Innovation Self-efficacy (ISE), or the belief in one's ability to innovate.

Keywords – self-efficacy; innovation; assessment

I. INTRODUCTION

Government, academia, and industry are continuously called upon to create innovative solutions to societal challenges. To innovate is to intentionally implement novel and useful processes, products, or procedures to a new domain [1]. Contemporary examples include electric vehicles, crowd funding, and modular carpeting. The work of innovating can be unpredictable, controversial, and in competition with current courses of action despite the benefits. Innovators must develop, modify, and implement ideas while navigating ambiguous problem contexts, overcoming setbacks, and persisting through uncertainty [2].

Self-efficacy is defined as an individual's judgment of their capability to organize and execute courses of action for a given task [3]. Research has shown that being efficacious toward a task is an important factor in an individual's ability to attempt and subsequently perform the task successfully by influencing intrinsic motivation, engagement in specific behaviors, and the ability to pursue certain tasks [3]. This suggests that individuals may not

engage or persist in innovative efforts if they do not believe in their ability to do so successfully.

While resource-intensive efforts to foster innovation in organizations are plentiful, we inadequately understand how to measure the impact of these interventions on an individual's judgment of their own innovation capabilities. In this paper, we present initial steps undertaken in the development and validation of an Innovation Self-efficacy (ISE) measure.

A. Innovation Self-efficacy

Innovation self-efficacy refers to an individual's belief in his or her ability to accomplish tasks necessary for innovating [4, 5]. Researchers increasingly recognize the critical role of self-efficacy in innovation [6], which demands a high level of persistence and creativity to overcome setbacks. Positive self-efficacy beliefs lead to persistence, creative performance, learning from failure, and the tendency to expend effort [7, 8, 9].

B. Specific Abilities Necessary for Innovation

Our understanding and identification of innovation is understandably complex; however research in engineering, design, management, psychology, and education agree on a number of important components of innovative work including transferring knowledge from one domain to another [10], developing novel and useful ideas [1], experimentation with ideas [10], and learning from experimentation [11]. We synthesize these models of innovation from these different fields mimicking the past processes undertaken to develop surveys to assess self-efficacy of creativity [12], engineering design [13], modeling [14], tinkering [15], and entrepreneurship [16]. We aim to develop the first

integrated measure that relates to a collection of tasks associated specifically with innovation.

II. METHODS OF RESEARCH

Our early stage work included four components: (1) Conducting a literature review of self-efficacy and tasks associated with innovation in engineering, design, management, psychology, and education; (2) Surveying practitioners and academics in innovation-related fields; (3) Developing a preliminary model of innovation self-efficacy by clustering and mapping indicators into schemata based on existing beliefs; and (4) Piloting a preliminary set of survey items.

III. RESULTS

Our literature review and interview data suggested 38 indicators (task-related skills, behaviors or attitudes) of innovation self-efficacy that could be learned or cultivated in an innovator. To conceptualize our integrated model, we grouped the indicators into nine clusters: *communication*, *creativity*, *exploration*, *flexibility*, *resourcefulness*, *implementation*, *iteration*, *synthesis*, and *vision*.

The survey conducted with experienced practitioners and academics (N=22) afforded participants to rate each of the 38 indicators from 1 (not at all important) to 5 (extremely important). Results from this exploratory survey allowed us to see the indicators our sample of participants believed were most crucial to innovation and what indicators we want to continue to measure. A pilot survey was then created from the 25 indicators that the majority of participants found most important.

The pilot survey was subsequently administered to engineering students at a large state university (N=62). The survey asked students to rate their degree of confidence in their ability to do each of the 79 tasks (3-4 task-specific self efficacy statements mapped onto each indicator) on a 10-point Likert scale ranging from zero (cannot do this at all) to 100 (highly certain can do) [17]. A factor analysis was conducted on statements within each cluster (our sample size was not large enough to factor analyze the entire survey) and refined the groupings of statements into 13 indicators (Table 1); each with three task-specific self-efficacy items. A test of reliability using Cronbach's alpha was conducted for each 3-item scale to ensure values greater than 0.70 [18]. The alpha values ranged between 0.761-0.837.

TABLE I. INDICATORS OF INNOVATION SELF-EFFICACY

| Clusters | Indicators | Description |
|------------------------|--------------------------------------|--|
| <i>Vision</i> | Vision | Identify new opportunities |
| <i>Exploration</i> | Awareness/Empathy | Pay attention to what is around and adopt others' viewpoints |
| | Observation | Imagine and understand how things work |
| <i>Synthesis</i> | Information processing | Make connections |
| <i>Creativity</i> | Creativity | Have original and unique ideas |
| <i>Iteration</i> | Idea testing | Assess ideas for viability, feasibility and desirability |
| <i>Resourcefulness</i> | Collaboration | Work with others |
| | Knowledge building | Utilize people, tools, and other resources |
| | Persistence | Continue to approach problems despite setbacks |
| <i>Implementation</i> | Decision making | Set goals and choose how to proceed |
| | Risk-taking | Go against what is expected or safe if necessary |
| <i>Communication</i> | Oral and written communication | Craft and share information through written and oral means |
| | Visual and data driven communication | Translate ideas into visualizations |

IV. FUTURE WORK AND IMPLICATIONS

This preliminary investigation describes a pathway for studying innovation self-efficacy. Future research intends to refine and retrace these steps with larger and more diverse sample sizes to obtain more robust validity determinations. The planned extensions include: (1) administering the survey of indicator importance to an expanded network of engineering and design experts to determine focal indicators, and (2) administering a refined pilot survey of self-efficacy with a sample of 400 students and practitioners of engineering to run more powerful factor analyses on the entire measure. We also plan to examine what the resulting survey is capable of measuring by comparing results to external measures of innovation such as number of patents, project work and assessments, or employer/collaborator ratings [12]. We hope that our findings will allow us to extend our analysis of innovation self-efficacy with respect to elements like domain expertise, work experience, job design, motivation, and work place conditions that can influence self-efficacy.

Organizations spend millions of dollars on interventions to foster innovation every year. A validated instrument of innovation self-efficacy is needed to evaluate the efficacy of these interventions

and more broadly inform the design and development of such innovations and programs.

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Work in Progress: Entrepreneurship in Education: Faculty Beliefs, Teaching Practices, and Student Learning

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Abstract—This work will present preliminary results from a study of entrepreneurship programs serving undergraduate engineering students. The purpose of the study is to examine questions relating to students' perceptions and understanding of entrepreneurship education. In addition, the study addresses faculty members' perceptions of entrepreneurship education including the critical skills and concepts that should be taught. To address these questions, we developed a study to better understand the faculty and students who are engaged in engineering entrepreneurship teaching and learning. Entrepreneurship program directors were asked to identify program faculty who were teaching in spring 2012. Faculty completed a comprehensive questionnaire about their beliefs and practices regarding entrepreneurship education, focusing on a specific course they were teaching in the spring 2012 semester. They were also asked to invite their students in this course to complete a questionnaire that asked students about their prior entrepreneurship experiences, familiarity with technology entrepreneurship concepts, and attitudes towards entrepreneurship. In addition, students were asked to indicate entrepreneurship resources they had used on their campuses. This study will provide systematic data from a variety of institutions about faculty who teach entrepreneurship and the students they teach. We expect that this knowledge will provide an important baseline against which future improvements in the field can be identified and assessed.

Keywords— *entrepreneurship education; technology entrepreneurship; engineering education*

I. INTRODUCTION

While many case examples have been written describing specific courses and programs of study [e.g. 1], we know little about what faculty believe and how undergraduate engineers are taught entrepreneurship on an aggregate level. Likewise, we know little about the engineering students who enroll in entrepreneurship courses and programs. What are their prior experiences related to entrepreneurship and familiarity with key concepts of the technology based entrepreneurship? What

attitudes do they hold in the context of their majors and career aspirations? To address these gaps, we developed a study to better understand the faculty and students who are engaged in engineering entrepreneurship teaching and learning.

II. RESEARCH QUESTIONS

This project addresses four research questions:

- 1) What are students' reported familiarity with engineering entrepreneurship terms and concepts?
- 2) What are faculty members' perceptions of engineering entrepreneurship education?
- 3) What do instructors state are the critical skills and concepts that are taught in entrepreneurship courses?
- 4) Is there a relationship between faculty beliefs of entrepreneurship education and students' beliefs?

III. METHODS

A. Recruitment of faculty participants

In the spring of 2011, a review of course catalogs at 345 ASEE schools in the U.S. was conducted to identify entrepreneurship programs of study that were accessible to undergraduate engineering majors. Based on a cluster analysis, we identified engineering programs that focused their entrepreneurship programs around certain course attributes. The project team identified more than one hundred entrepreneurship programs that served undergraduate engineering students, 40 of which were administered solely or jointly by schools and colleges of engineering.

Program directors from these schools were contacted by NCIIA, and were asked to identify at least one faculty member who was teaching a product development or venture development in their entrepreneurship program. Interested program directors forwarded study information to the relevant faculty members. Faculty members were offered a stipend of \$500 to complete three research tasks: a) complete an online survey about their views of entrepreneurship education in engineering and about the content used in one of their entrepreneurship courses; b) administer an online survey to

students in that course about their entrepreneurship experiences and knowledge; c) provide details about entrepreneurship opportunities available to students at the institution. The faculty and student surveys are described further below. The estimated amount of time required of participants to complete the entire research study was two hours. Participating faculty members will also receive aggregated results of their student data with comparisons to peer programs, provided that the sample sizes for their particular course were high enough.

B. Student Survey

Faculty were asked to administer the Entrepreneurship Knowledge Inventory (EKI) to their students in the product development or venture development course they were teaching in spring 2012. The EKI is an inventory consisting of 103 items intended to measure students' familiarity with entrepreneurial terms in five areas: 1) Becoming and Being an Entrepreneur, 2) Finance and Accounting, 3) People and Human Resources, 4) Sales and Marketing, and 5) Product Ideation and Development. In each category, students were asked to rate their familiarity with a set of terms using a 5-point rating scale [2]. The anchors on the scale follow:

- None (Never Heard of it)
- Low (Heard of it but not sure what it means)
- Moderate (Can explain it partially)
- High (Can explain in depth but not sure how to apply it)
- Very High (Can explain in depth and can apply it)

As explained in Besterfield-Sacre, et al. (2012) [2], the instrument has been piloted with a large number of students. Significant differences in scores have been found between freshmen and senior engineering students. Participating faculty were encouraged to offer extra credit, but were not required.

C. Faculty Survey

Faculty were asked to complete an online survey consisting of two distinct parts. The first part, entitled the *Entrepreneurship Faculty Beliefs Survey*, was developed in fall of 2009. The survey was constructed based on the results of a qualitative study 26 faculty interviews at three large research universities. The results of the qualitative study are available in Hochstedt, Zappe, and Kisenwether (2010) [3] and Zappe, Hochstedt, and Kisenwether (2012) [4].

The survey is intended to address the following questions:

- How do instructors define entrepreneurial mindset, or the characteristics necessary to be an entrepreneur?
- Do instructors feel the mindset is innate? Or do they feel it can be developed with training?
- What teaching methods do instructors use to teach entrepreneurship to engineers?
- Is there a relationship between faculty beliefs and teaching methods?

The second part of the online instrument consisted of a faculty version of the EKI. The faculty survey included the

same items as the student version of the EKI but participants were asked to indicate the degree to which the terms were emphasized in their course. The rating scale was changed to the following anchors:

- None (Term is not used in the course)
- Low (Term is used in the course, but the students are not expected to understand it)
- Moderate (Term is used in the course and the students are expected to understand it partially)
- High (Term is used in the course and the students are expected to understand it in-depth)
- Very High (Term is used in the course and the students are expected to understand it in-depth and can apply it)

IV. DATA COLLECTION AND PROGRESS TO DATE

Data collection commenced in March 2012. Forty-six program directors were contacted. Of these, 17 faculty members were identified from 16 different colleges and universities; one school had more than one faculty member who participated. As of the end of April 2012, all participants had completed the faculty survey, and 16 had launched the student survey in their course. One faculty member surveyed two courses that fit the project criteria.

The survey officially closed at the end of May 2012 and was completed by 327 students. For three of the student courses, sample sizes were quite low, ranging from 2 to 8 student participants. For the remaining 11 courses, sample sizes ranged from 11 to 63.

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Work in Progress: A Pilot Project to Assess the Added Value of Engineering and Student Affairs Collaboration on Student Cognitive and Affective Development

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Abstract—This Work-In-Progress paper describes a pilot project at Western Michigan University to assess the added value of academic and student affairs collaboration on student cognitive and affective development. The academic performance in first-year science, technology, engineering and mathematics (STEM) courses as well as retention to STEM are used as measures of cognitive development, and the students' experience in co-curricular activities as captured in their written summaries is used as a measure of their affective development. While there is no statistically significant difference in individual course performance, first-year Engineering House (EH) students have a statistically significant higher GPA than non-EH in fall 2010, and they have a statistically significant higher fall-to-spring retention to engineering and applied sciences than non-EH students.

Keywords—cognitive and affective development, academic and student affairs collaboration

I. INTRODUCTION

At Western Michigan University (WMU), the College of Engineering and Applied Sciences (CEAS) and the Office and Residence Life (ORL) have increasingly worked together since 2006 to support student success. The collaboration between CEAS and Student Affairs (SA) has since been extended to other SA units, e.g., Career and Student Employment Services. At WMU, first-time first-year engineering and applied sciences students are placed in STEP (STEM Talent Expansion Program) cohorts during Summer Orientation where they are enrolled in the same 3-to-5 courses in the Fall semester and the same 2-to-4 courses in the Spring semester. Details on how the STEP cohorts are constructed for WMU-CEAS first-year students can be found elsewhere [1].

Many CEAS first-year students choose to live in the Engineering House (EH), a special-interest residence program created by ORL with significant CEAS input. In this Work-in-Progress paper, we will describe a pilot project to assess the added value of academic and student affairs collaboration by evaluating the cognitive and affective development of CEAS first-year students who live in the EH versus the non-EH CEAS first-year students. The research methodology and assessment measures will be described with some preliminary results.

II. THEORETICAL BASES FOR PILOT PROJECT

Writing in the journal *Change*, T.W. Banta and G. Kuh [2] argue that “improving the quality of the undergraduate experience at any institution is so complex and multifaceted that it demands cooperation by the two groups on campus that

spend the most time with students: faculty members and student affairs professionals.” Additional studies that have included the effects of involving student affairs in the affective development efforts of first-year engineering students have occurred at Arizona State University in the late 1990's and The University of Southern California in the late 2000's [3,4].

III. PILOT PROJECT DESIGN

A. Engineering House (EH) vs. Non-EH

First-year CEAS students' participation in the EH increased from 88 in Fall 2006 to 173 in Fall 2010. In Fall 2011, 163 first-year, 49 sophomore, 112 junior, and three (3) senior CEAS students lived in the EH. In addition, there were 406 CEAS students who lived in other residence halls in Fall 2011. Therefore, there are sufficient numbers of first-year students living in the EH and the non-EH to allow us to compare the cognitive and affective development of the two populations. Furthermore, average ACT math scores were used to determine that both groups had similar or equal academic preparation before choosing their living accommodations. The EH students have an average ACT math score of 25.37, while the non-EH students average a 25.21.

The distinguishing features between EH vs. non-EH include the following: (1) the Residence-hall Assistants (RA's) in the EH are CEAS students while RA's in the non-EH are not CEAS students. (2) RA programming in the EH has an engineering focus or theme, while RA programming in the non-EH does not have such focus or theme.

B. How EH and Non-EH Students are Tracked

Since 2005, all CEAS first-year students who are placed in STEP cohorts during summer orientation are tagged using their Western Identity Number (WIN). Each semester, the WMU Office of Student Academics and Institutional Research run a report that shows the academic performance of the students, their majors, as well as whether they return to CEAS or WMU. This allows the researchers to monitor the academic performance, track retention, and make comparisons between the STEP students and the non-STEP students. Beginning in 2010, as the number of students living in EH increases, the researchers made a request to Institutional Research to add a field indicating the place of residence. This allows the researchers to compare the academic performance and retention of the EH students with the non-EH students.

Identify applicable sponsor/s here. (*sponsors*)

C. Measure of Cognitive Development

In this pilot project, performance in courses required in the CEAS curricula, as indicated in percent of students who successfully completed the course with a grade of C or better, is used as one measure of students' cognitive development. *Chi*-squared tests are performed with a significant level set at $\alpha < 0.05$. The courses monitored include mathematics (Algebra II, Pre-Calculus, Calculus I, and Calculus II, depending on the first-year students' MATH ACT score); General Chemistry I, University Physics I, Technical Communication, and Engineering Graphics. In addition, retention to the CEAS from Fall to Spring semester as well as second-year retention to CEAS are tracked and compared between the two student populations (EH vs. non EH), and between STEP students and historic baseline retention rates.

D. Measure of Affective Development

IME 1020, "Technical Communication," is a required course in the CEAS curricula. In IME 1020, students are given bonus points when they participate in out-of-class co-curricular activities and write a summary about their experience. Samples of 246 written summaries on the same 8 types of co-curricular activities are collected from the EH and the non-EH students.

A rubric based on Bloom's taxonomy in the cognitive and affective domains [5] has been previously developed by three authors of this WIP paper and later revised with the addition of three additional researchers to improve inter-rater reliability [6]. Figure 1 below illustrates the rubric used by two authors of this paper to holistically score the students' summaries to assess their cognitive and affective development.

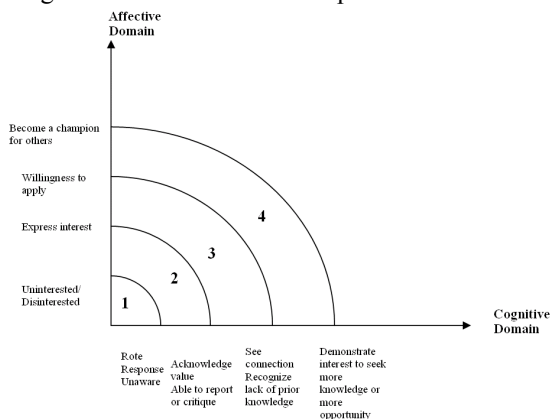


Figure 1. A 2-dimension evaluation rubric combining the Cognitive & Affective Domains

IV. SOME PRELIMINARY RESULTS

A. Cognitive Development

There is no statistically significant difference in the performance between EH students and non-EH students in individual courses in Fall 2010 and Spring 2011. However, first-year CEAS-EH students have a statistically significant mean Fall 2010 GPA (2.62) compared to first-year CEAS non-EH students (2.38). First-year EH students also have a statistically significant higher return rate to CEAS from Fall to

Spring semester than first-year non-EH students, but there is no statistically significant difference in the second year retention to CEAS. However, students in STEP cohorts have a significantly higher passing rate (course grade \geq C) than non-STEP students in Engineering Graphics, Pre-Calculus, and Calculus II.

B. Affective Development

A statistically significant difference is not apparent between EH and non-EH students in terms of where their written co-curricular responses registered on the rubric in Figure 1. The EH responses to activities categorized as cultural and hands-on averaged (by mean) a score of 2.03, whereas the non-EH students averaged a 2.41. For the activities categorized as social gatherings and student society meetings, the average scores are 2.69 (EH) and 2.41 (non-EH). EH students averaged a 2.33 on responses to activities categorized as academic lectures, and the non-EH students averaged a 2.26 on those activity types. Finally, EH responses to the Capstone Senior Design Project presentations averaged 2.11, and the non-EH responses to the same presentations averaged a score of 2.12.

V. FUTURE WORK

Statistical analysis of cognitive development indicators between EH and non-EH students will carry on at WMU, as will performance tracking of EH and non-EH students in individual courses to see if any trends arise. Differences in mean GPAs, Fall-to Spring return rates and retention will also be monitored, and any affective differences, based on Bloom's taxonomy in relation to co-curricular events, will be surveyed.

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Engineering and Computer Science Community College Transfers and Native Freshmen Students:

Relationships Among Participation in Extra-Curricular and Co-Curricular Activities, Connecting to the University Campus, and Academic Success

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Abstract— Research studies have shown the importance of the relationship between “a sense of belonging” and successfully adjusting to college life for undergraduate students. Few studies, however, have compared if native freshmen and transfer students connect to the campus in similar ways. The purpose of this study was to examine the relationships among participation in social and academic engagement activities, social integration, and academic success for students graduating with engineering or computer science Bachelor’s degrees at a large, public university. An additional area of interest was the role of undergraduate research experiences (UREs) in making friends on campus.

Using analysis of variance, 1,042 responses were analyzed from senior exit survey questions and cumulative GPA from student records. Students who reported higher levels of social integration on average had higher GPAs. Seven activities were found to be strongly associated with social integration for native freshmen, and three activities for transfer students. Three activities – organizations in their major, experiential learning, and intramural sports – were common to both groups. Surprisingly, given the cohort experience structure of UREs, no significant relationship was found for social integration in this study. This finding may be limited by the sample size or other factors such as self-selection bias.

Keywords- college adjustment; retention; persistence; academic success

I. BACKGROUND

This study was conducted at the University of Central Florida (UCF), a large, metropolitan university (Carnegie classification, RU/VH: Research Universities – very high research activity), and the second largest in the nation in terms of student enrollment. In 2005, the university established a higher education consortium in partnership with four of its area feeder community colleges. Through this agreement, the DirectConnect program was created which guarantees entry to the university for students who obtain an Associate of Arts (AA) or Associate of Science (AS) degree at one of these four community colleges.

Consortium transfer students at the university now represent 32% of new undergraduates in the College of Engineering & Computer Science (between 2002-2005, prior to DirectConnect, that percentage was 23%). Further analysis of

student data for seven years (2001-2008) showed that 78% of native freshmen students had graduated within 4 years after reaching junior status, 15% were still enrolled or had dropped out, and 7% had changed to a major outside the college (total sample size in the cohorts was 3,057). However, the graduation rate for those students who had entered as community college transfers was substantially lower: 54% had graduated within 4 years, 39% were still enrolled or had dropped out, and 7% had changed to a major outside the college (cohort sample size 2,951). These statistics indicate the importance of understanding the factors leading to persistence for community college transfer students on our campus, and if these factors are similar or different for native freshmen students. The results of our study can inform program coordinators, professional advisors, and campus administrators which extra- or co-curricular activities best serve the needs of both groups of students in terms of connecting to the campus.

II. UNDERGRADUATE RESEARCH EXPERIENCES

In this study, we examined associations among academic and social integration into campus life (known factors that have been identified by researchers as contributing to persistence) through participation in extra-curricular and co-curricular activities during the undergraduate career of engineering and computer science students. An additional area of interest was the role of undergraduate research experiences (UREs) in making friends on campus. A benefit of participation in UREs is the quality and frequency of interaction with faculty and URE peers through a cohort experience.

Four authors of this paper are program staff for the YES (Young Entrepreneur and Scholar) Scholarship program. YES is an S-STEM (Scholarships in Science, Technology, Engineering, and Mathematics) program funded by the National Science Foundation. YES offers eligible STEM junior and senior students the choice of two pathways: the Research Path (paired with a faculty mentor) or the Entrepreneurship Path (paired with an industry mentor). As of Fall 2011, 124 people had participated in the YES program: 49 STEM students, 41 faculty mentors, 8 industry mentors, 15 External Advisory Board members, and 11 program staff. Most students (84%) selected the Research Path, 8% the Entrepreneurship Path, and the remaining 8% switched

between Paths. The demographic profile of the YES students showed a diverse representation of 41% women, 33% Hispanic, 14% African American, 8% Asian, 2% Multiracial, 43% White, and 51% first generation college students. All students ($n=10/10$) who completed the YES program through Summer 2011 continued on to advanced studies at the university or found employment in their field upon graduation, whereas for non-completers, it was 18% ($n=2/11$). (The next group of YES students is due to graduate Spring 2012.)

In focus groups conducted for the past two years, YES students have reported that one of the benefits of the program was forming friendships with other YES students. YES students described that working in the similar environment was beneficial and they learned through interacting with each other; friendships were strengthened when friends had classes together; they liked being able to interact with graduate students in labs; and overall, they had positive relationships with their mentors. An outcome of the focus groups was that they requested additional social opportunities to interact with each other. Due to the limitations of the small sample size of the focus group ($n=10-14$), we were unable to determine if the experience of making friends was unique to the YES program or representative of research experiences for STEM students at the university. It is for this reason that participation in UREs was an additional area of interest in this study which utilized a larger sample size. Our hypothesis in this study was that a statistically significant relationship would be found between participation in UREs and making friends on campus.

III. LITERATURE REVIEW

The theoretical framework for this study is based on Tinto's model of student departure which emphasizes the importance of academic and social integration on student persistence [1], and Astin's theory of student involvement and its role in student development (e.g., highly involved students study a lot, spend a lot of time on campus, participate actively in student organizations, and interact frequently with faculty members and other students) [2]. New students entering a university are often transitioning between support systems and acclimating to a new environment. This transition to college life can be compared to the grieving process – shock followed by eventual recovery and integration for most people [3]. Many of these students suffer from what Paul and Brier [4] refer to as “friendsickness.” Coping with the loss of their support system is a traumatic event that can delay a healthy adjustment to college life for many students [4].

Additional studies have contributed to understanding the role that social integration plays in students' adjustment to college life. These findings provide the conceptual framework for this study. Bean [5] suggested that men and women college freshmen dropout for different reasons and recommended a different course of action to retain each population: for women, encourage them to join campus organizations, emphasize the usefulness of the degree in securing employment, and maintain an active and effective placement program; for men, offer educational programs to develop personal, intellectual, creative, and interpersonal skills, and offer a flexible schedule during the first semester. Aspinwall and Taylor [6] found that social support as a mediating variable

predicted better adjustment to college. Walton and Cohen [7] conducted a three-year longitudinal study of college freshmen who were asked to read a report based on the survey of senior students about difficulties they experienced in transitioning during their first-year as freshmen. They found that reading the report about the common challenges experienced by senior students had a positive impact on freshmen sense of belonging and physical health and well-being, and most significantly on African American students. Other studies on under-represented students indicate similar patterns of the importance of social experiences on adjustment to college life. Latino students rated academic adjustment and social relationships as the most difficult aspects of their first-year college experiences, and college peers (boy/girlfriend, roommates, and other students) and family as the individuals who provided the most support during their first year [8]. Eimers and Pike [9] found that satisfaction with academic and social experiences had a significant effect on intent to persist for minority freshmen students, while Nora and Cabrera [10] found that they exerted an indirect effect on persistence. First-generation freshmen students achieved better adjustment to college life through intellectual activities, whereas second-generation freshmen achieved better adjustment through the support of on-campus college friends [11].

The term “transfer shock” appeared in a study by Hills [12] and referred to a drop in grades experienced by students transferring from a junior college (now known as community colleges) to a university. Cejda [13] found that community college transfer students majoring in business, mathematics, or the sciences were more likely to experience greater transfer shock and suffer declines in grade point averages compared with education, fine arts and humanities, and social sciences majors. More recent studies on community college transfers have expanded to include other factors that impact successful adjustment to a university campus. The mechanisms by which transfer students achieve social integration into campus have been one such focus. Rhine, Milligan, and Nelson [14] suggested that academic and social factors (other than a drop in grades) contributed to transfer student attrition. Flaga [15] identified four dimensions of transfer students' transition from community college to the university: Learning Resources, Connecting, Familiarity, Negotiating, and Integrating. Transfer students reported native university students as the most frequently used resource for negotiating the academic, social, and physical environment of the campus, and participation in campus involvement through academic clubs, student organizations, and sporting events to connect to the campus [15]. Laanan [16] proposed establishing a peer mentorship program sponsored by student affairs or student organizations to ease the difficulties associated with acculturating to university life for transfer students. Difficulty in making friends was cited as one barrier to social integration into campus life – transfer students reported finding it easier to make friends at the community college than at the university [17]. Community college transfers are not similar to freshmen students, for one, they tend to be older [18] and may be less inclined to participate in social activities on campus [19]. Therefore, in our study, we hypothesized that participation patterns in extra-curricular and co-curricular campus activities for community college transfer students would be different

from those of native freshmen students; and native freshmen students would be more likely to form friendships with other students and on average have higher GPAs. Understanding these differences will be useful in determining which campus-sponsored programs can provide the most benefit to these populations in terms of connecting to the campus.

IV. METHODOLOGY

Data were collected from the university-administered 2009-10 and 2010-11 senior exit survey (completed one semester prior to graduation) for engineering and computer science students (n=1,117) at the University of Central Florida (UCF). Sixty-two percent (n=693) of respondents had entered as native freshmen, 31% (n=349) as transfers with an AA or AS degree and 7% (n=75) without an AA or AS degree. For the purpose of this study, only 1,042 students were used in the analysis – native freshmen and transfer students with AA or AS degrees. The demographic characteristics of under-represented groups for native freshmen students were 14% (n = 99) women, 11% (n = 77) Hispanics, and 5% (n = 37) African Americans. For transfer students, the profile was 17% (n = 58) women, 14% Hispanics (n = 47), and 4% African Americans (n =14). In terms of age (at the time of completing the survey), 80% of native freshmen were <24 years old (30% for transfers); and 20% were 24 years or older (70% for transfers).

Ten questions from the graduating senior exit survey were used in this study which asked students about participation in various engagement activities during their undergraduate career. These activities were categorized as academic (undergraduate research experiences, student organizations related to major, student leadership programs, experiential learning opportunities, and honor societies) and social (sororities and fraternities, community service and involvement, spiritual/religious activities, intramural sports, and other clubs). Survey respondents could select participation in more than one activity. As the options provided on the survey was not exhaustive, an “Other club” option was provided for students to report any club affiliation not listed.

Two items from the survey were considered as a measure for social integration: a) “To what extent would you say you developed close personal friendships at UCF?” where an endorsement of “almost all or most of my friends are from this institution” defined that they had; and b) “How would you rate your social experience at UCF?”, where a rating of “excellent, very good or good” by the student suggested a positive social experience.

Responses from the survey, in conjunction with cumulative GPA from student records, were used to determine associations among participation in social and academic engagement activities, social integration, and academic success. To evaluate associations between social integration and academic success of graduates, analysis of variance (ANOVA) was used to identify statistically significant differences in mean cumulative GPA for various levels of social integration. Additionally, comparisons were made between native freshmen and transfer students with respect to their social integration and participation in co-curricular and

extra-curricular activities. These comparisons were made using difference of proportion tests of hypothesis. A less restrictive significance level ($\alpha = 0.1$) was used in this analysis as this study was exploratory in nature.

V. RESULTS

A. Participation in Co-curricular and Extra-curricular Engagement Activities

As was expected, native freshmen and transfer students participated in very different co-curricular and extra-curricular activities during their undergraduate careers. As shown in Table I, native freshmen had a higher participation rate compared to transfer students for most of the activities. The one exception was participation in experiential learning activities, although the difference was very small. The activity with the largest difference in participation was intramural sports, with transfer students at 15% and native freshmen at an overwhelming 41%.

TABLE I
EXTRA-CURRICULAR AND CO-CURRICULAR
ENGAGEMENT ACTIVITY PARTICIPATION RATES
FOR NATIVE FRESHMEN AND TRANSFER STUDENTS

| | | Freshmen | Transfer |
|---------------------|--|----------|----------|
| Academic Activities | Undergraduate research experiences | 19% | 7% |
| | Student organizations related to major | 33% | 19% |
| | Student leadership programs | 11% | 3% |
| | Experiential learning opportunities | 41% | 42% |
| | Honors societies | 12% | 9% |
| Social Activities | Sororities and fraternities | 13% | 1% |
| | Community service and involvement | 16% | 11% |
| | Spiritual/religious activities | 14% | 8% |
| | Intramural sports | 41% | 15% |
| | Other clubs | 37% | 22% |

B. How Social Integration Is Defined In This Study

Table II summarizes endorsements by native freshmen and transfer students for the two questions pertaining to social integration.

TABLE II
POSITIVE RESPONSES FOR MEASURES OF SOCIAL INTEGRATION
FOR NATIVE FRESHMEN AND TRANSFER STUDENTS

| | % Positive Response | |
|---|---------------------|----------|
| | Freshmen | Transfer |
| To what extent would you say you developed close personal friendships at UCF? | 55% | 29% |
| How would you rate your social experience at UCF? | 93% | 90% |

“To what extent would you say you developed close personal friendships at UCF?” is a more direct way of asking about student connections to the campus than “How would you rate your social experience at UCF?” The response options for the close personal friendships question (almost all of my closest friends are from UCF, most of my closest friends are from UCF, ... , almost all of my closest friends are from elsewhere) quantify how much integration a student has made on campus. The survey item pertaining to social experience is simply a rating of their social experience (excellent, very good, good, fair, poor). Lastly, developing close personal friendships was more discriminatory between native freshmen and transfer student groups; therefore, for this study it was used to define social integration during the students’ undergraduate career.

C. The Relationship Between Social Integration and GPA

Table III summarizes the impact of social integration on cumulative GPA for native freshmen and transfer students. Using ANOVA, the mean cumulative GPA of 3.16 for the 485 students who reported higher levels of social integration was statistically higher than 3.11 for the 556 students who reported lower levels of social integration. The mean cumulative GPA was higher for native freshmen students ($n=384$, mean GPA = 3.17) who reported high levels of social integration when compared with transfer students ($n=101$, mean GPA = 3.14), but it was not statistically significant. The largest differences existed between female native freshmen who reported higher levels of social integration ($n=57$; mean GPA = 3.30) and those who did not ($n=42$; mean GPA = 3.18). A similar

pattern was found among female transfer students; however, the small sample size limited our ability to test for statistical differences endorsing high levels of social integration. No statistical differences in mean cumulative GPA were detected for male native freshmen or male transfer students with respect to social integration.

D. Co-curricular and Extra-curricular Engagement Activities Associated with High Social Integration

Using difference of proportion tests of hypothesis, we compared rates of high social integration for participants and non-participants for each engagement activity. Table IV summarizes rates of high social integration by participation in various co-curricular and extra-curricular activities for native freshmen and transfer students. For instance, 67% of the 110 native freshmen participants in community service and involvement reported high levels of social integration whereas only 53% of the non-participants ($n=583$) reported high levels of social integration. For native freshmen, activities that were strongly associated with social integration were: organizations in their major, sororities and fraternities, intramural sports, student leadership programs, experiential learning, honors societies, community service, and other clubs (data on the specific clubs in this group were not collected). For transfer students, participating in organizations in their major, experiential learning, intramural sports, and other clubs were significant. The engagement activities with the largest difference in rates of high social integration were sororities and fraternities and intramural sports for native freshmen and transfer students, respectively. Participation in UREs and spiritual/religious activities was not significant with social integration for either native freshmen or transfer students.

TABLE III

MEAN CUMULATIVE GPA BY SOCIAL INTEGRATION AND GENDER FOR NATIVE FRESHMEN AND TRANSFER STUDENTS

| | | Social Integration | | Total |
|------------------------------|-----------------|----------------------------------|----------------------------------|-----------------------|
| | | No | Yes | |
| Freshmen | Male | 3.11 ($n=267$) | 3.14 ($n=327$) | 3.13 ($n=594$) |
| | Female | 3.18 ^a ($n=42$) | 3.30 ^a ($n=57$) | 3.25 ($n=99$) |
| | Total Freshmen | 3.12 ($n=309$) | 3.17 ($n=384$) | 3.15 ($n=693$) |
| Transfers | Male | 3.10 ($n=203$) | 3.10 ($n=87$) | 3.10 ($n=290$) |
| | Female | 3.12 ($n=44$) | 3.37 ^c ($n=14$) | 3.18 ($n=58$) |
| | Total Transfers | 3.11 ($n=247$) | 3.14 ($n=101$) | 3.12 ($n=348$) |
| Total Freshmen and Transfers | | 3.11 ^b ($n=556$) | 3.16 ^b ($n=485$) | 3.14 ($n=1,041$) |

a. difference in mean GPA for female native freshmen is statistically significant at $\alpha=0.1$

b. difference in mean GPA for aggregate native freshmen and transfers is statistically significant at $\alpha=0.1$

c. hypothesis testing not performed due to insufficient sample size

VI. CONCLUSION

In this study, we found different rates of participation in co-curricular and extra-curricular activities for native freshmen and transfer students. Native freshmen students had higher participation rates across all engagement activities compared with transfer students, with the exception of experiential learning (Table I). Both groups were as equally likely to participate in experiential learning, and this activity was found to be statistically significant in terms of social integration (Table IV). Although native freshmen and transfer students rated their social experiences similarly (Table II), the native freshmen rate (55%) was almost twice that of transfer students (29%) for developing close personal friendships on campus. At least one in five native freshmen had participated in student organizations related to their major or intramural sports. These findings confirm our hypothesis and previous research that native freshmen students are more likely to connect to the campus through extra- and co-curricular activities more frequently than transfer students.

TABLE IV
RATES OF HIGH SOCIAL INTEGRATION BY ENGAGEMENT ACTIVITY PARTICIPATION
FOR NATIVE FRESHMEN AND TRANSFER STUDENTS

| Engagement Activity | Freshmen | | Significant Differences Found | Transfers | | Significant Differences Found |
|--|--|------------------|-------------------------------|--|------------------|-------------------------------|
| | % reporting high social integration among... | | | % reporting high social integration among... | | |
| | Participants | Non-participants | | Participants | Non-participants | |
| Undergraduate research experiences | 57% (n = 124) | 56% (n = 532) | .4200 | 10% ^a (n = 21) | 29% (n = 296) | |
| Student organizations related to major | 63% (n = 229) | 52% (n = 464) | .0016* | 39% (n = 66) | 27% (n = 282) | .0196* |
| Student leadership programs | 71% (n = 77) | 53% (n = 598) | .0012* | 55% ^a (n = 11) | 28% (n = 320) | |
| Experiential learning opportunities | 59% (n = 275) | 53% (n = 399) | .0441* | 33% (n = 138) | 23% (n = 192) | .0236* |
| Honors societies | 61% (n = 83) | 54% (n = 610) | .0297* | 40% ^a (n = 30) | 28% (n = 318) | |
| Sororities and fraternities | 75% (n = 91) | 53% (n = 602) | .00003* | 60% ^a (n = 5) | 29% (n = 343) | |
| Community service and involvement | 67% (n = 110) | 53% (n = 583) | .0320* | 27% (n = 37) | 29% (n = 311) | .6114 |
| Spiritual/religious activities | 57% (n = 95) | 55% (n = 598) | .3813 | 35% ^a (n = 29) | 29% (n = 319) | |
| Intramural sports | 61% (n = 282) | 52% (n = 411) | .0109* | 41% (n = 54) | 27% (n = 294) | .0195* |
| Other clubs | 63% (n = 256) | 51% (n = 437) | .0012* | 41% (n = 76) | 26% (n = 272) | .0053* |

* indicates that participants of the activity reported higher instances of social integration (developed close personal friendships during their undergraduate career) compared to non-participants. Differences are statistically significant at $\alpha = 0.1$ using one-tailed difference of proportion hypothesis tests.

a. hypothesis testing not performed due to insufficient sample size

Students who reported higher levels of social integration were inclined to have higher cumulative GPAs near the time of graduation (Table III). This relationship between social integration and GPA was significant among female native freshmen students but not their male counterparts. A similar pattern was found among transfer students (though the small sample size for female transfer students limited our ability to test for statistical differences endorsing high levels of social integration). This finding suggests that social integration (defined in this study as making friends on campus) plays a larger role in the academic success of female students than male students. It also validates the results of the study conducted by Bean [5] that men and women college freshmen dropout for different reasons (i.e., retention factors may be different for each group).

Evaluating the interaction of social integration and student participation in co- and extra-curricular activities helped identify activities with potentially the greatest impact on student academic success. Seven activities were found to be strongly associated with social integration for native freshmen, and three activities for transfer students (Table IV). (Other clubs was also common to both groups; however, it was

excluded as a category because the description of these clubs was not collected in the data.) For native freshmen, activities that were strongly associated with social integration were: organizations in their major, sororities and fraternities, intramural sports, experiential learning, honors societies, student leadership programs, and community service. For transfer students, participating in organizations in their major, experiential learning, and intramural sports was significant. Three activities – participation in organizations in their major, experiential learning, and intramural sports – were common to both groups. These three activities seemed to benefit both native freshmen and transfer students of traditional and non-traditional ages in terms of social integration. For participation in organizations in their major, 86% of native freshmen were <24 years old (33% for transfers), and 14% were 24 years or older (67% for transfers). For experiential learning, 83% of native freshmen were <24 years (35% for transfers), and 17% were 24 years or older (65% for transfers). For intramural sports, 80% of native freshmen were < 24 years (48% for transfers), and 20% were 24 years or older (52% for transfers). These results suggest that an added benefit to promoting participation in experiential learning experiences,

organizations in their major, and intramural sports is their potential to connect native freshmen and transfer students of traditional and non-traditional ages to campus.

Participation in undergraduate research was of particular interest in this study given the quality and frequency of interaction of faculty and URE peers through a cohort experience. Our hypothesis was that a statistically significant relationship would be found between participation in UREs and making friends on campus. Native freshmen students were twice as likely to participate in UREs compared with transfer students. However, the relationship between participation in UREs and social integration was not statistically significant for either native freshmen or transfer students. This finding may be limited by the sample size or other factors such as self-selection bias or the structure of the URE program. Perhaps, students who chose to participate in a URE already had a support system of friends in place (students often begin a URE experience in the junior year) and were not necessarily looking to form more friendships. Also, the characteristics of various URE programs may be structured so that there is less interaction with faculty and students for some more than others. Some UREs may have a one semester duration (summer is a popular time period) or, like our NSF-funded, YES S-STEM program, a longer duration, fall and spring semesters (with summers optional) over a one- or two-year period.

Future research should include a longitudinal study following a cohort of students to further assess how participation in various activities affects student success. In particular, the study should focus on how participation affects female, under-represented minority, and community college transfer student groups' adjustment to college life. It may also be useful to look at student success at the course level rather than as an aggregate measure of cumulative GPA.

VII. LIMITATIONS OF THE STUDY

This study was conducted in the College of Engineering and Computer Science at a large, public institution. The findings may be specific to our college and not representative of other institutions. Another limitation of this study was the lack of a direct measure for social integration. Ideally, we would like to have a direct measure of our students' social integration and connection to campus rather than self-reported data. Future work on this topic would include identifying and collecting such a measure on social integration. Once a more direct measure is collected then analysis regarding the validity of our measure may be of interest. A third limitation of the study was the question of self-selection bias in participation in the various activities. Students who are more extroverted and sociable and have higher GPAs may be more likely to participate in extra- and co-curricular activities than those who do not have these characteristics. An empirical study that randomly assigns students to groups could investigate if participation in extra- and co-curricular campus activities is equally beneficial in terms of social integration and academic success to students with both low and high GPAs, under-represented groups, and extroverted and introverted students. If this hypothesis could be validated, then it would be important to understand which engagement activities would be more likely to attract these groups.

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Communities that Make a Difference:

The STEM Student Perspective

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Abstract - Responses from open-ended survey questions regarding undergraduate students' connections to community were collected from five different institutions, ranging from a large research institution in the Pacific Northwest to a small teaching college in the Northeast. Our results show that, regardless of institution or U.S. geographical location, STEM students felt connected to family more than any other community in their undergraduate experience. At institutions where faith plays a role in the institutional mission and culture, connections to religious organizations (especially church) were a close second in the strong connections to community that students reported in their lives. Across institutions, friends played a strong role in the communities in which students participated, and traditional extracurricular activities (non-academic clubs within the institution itself) also provided a significant source of connection for many students.

Index Terms— Community, Belonging, Extracurricular, Family, Friends, Sports, Church, STEM education

I. INTRODUCTION

A community is defined as a “social, religious, occupational or other group sharing common characteristics or interests and perceiving itself as distinct in some respect from the larger society within which it exists” [1]. STEM students participate in communities that are directly related to their academic endeavors such as class, lab, and study groups, but they also participate in a variety of non-academic communities, both on and off campus. This study looks at the communities in which STEM students participate and feel most connected. Communities, both non-academic and academic, serve an important purpose in the lives of these students, providing connections to others and fulfilling needs

not readily met in the STEM classroom. Understanding which communities are most important to students can allow educators to encourage and support participation in these communities from inside the classroom and thus improve the subsequent academic benefits.

The National Survey for Student Engagement [2,3], now conducted for more than a decade, provides a critical overview of the scope of collegiate participation in community. Results from the 2007 NSSE survey of more than 300,000 students at more than 500 institutions across the United States and parts of Canada revealed that more than 50% of collegiate students have frequent contact with close family members including parents and siblings [2]. The study also revealed that more than half of students surveyed spend at least one hour per seven-day week participating in co-curricular activities such as organizations, campus publications, student governments, fraternities, sororities and intercollegiate or intramural sports. Notably, more than 10% of students spend more than 10 hours per week engaged in these outside activities. These findings persisted through the 2010 NSSE [3], providing overwhelming evidence of the integration of outside activities with collegiate life. These activities, prevalent in students' lives, have also been shown to provide certain benefits, including improving educational outcomes as well as individual affective experience and outlook.

Given the high level of student participation in outside communities, the impacts of these activities on the quality of education and student outcomes have been the subject of numerous investigations. At the K-12 level, research has shown that participation in extracurricular activities leads to positive academic outcomes including increased engagement and test scores [4], higher SAT performance [5] as well as higher grades and better attendance [6]. Numerous studies at the undergraduate level have looked at how participation in outside communities improves the quality of education and outcomes. Studies have shown that much learning is socially

based; therefore, researchers argue that outside activities significantly impact undergraduate education [7,8]. Studies to test this hypothesis include one by Whitt et al. [9] which showed that non-classroom peer interaction significantly impacted self-reported gains in writing and thinking and composite scores for standardized measures of mathematics, reading, and critical thinking. An analysis of data from six of 23 institutions surveyed by the National Center for Postsecondary Teaching, Learning, and Assessment [10] found that participation in outside extracurricular activities had a significant positive impact on standardized measures of critical thinking skills. Another study of more than six thousand University of California students [11] found that time spent with family was associated with higher GPAs. Looking at broader educational outcomes, persistence in engineering careers has also been found to be connected to extracurricular service, as seen in the study of female engineering students by Wilson et al. [12].

The benefits of participation in community participation outside the classroom are clear. The types of communities students chose to connect to and the degree to which they participate are emphasized in this study and analysis.

II. RESEARCH METHODS

Participation of STEM students in various types of community at the undergraduate level was captured as part of a survey distributed to five very different institutions across the United States. These institutions are (a) a small minority-serving institution in the Southeast (HBCU); (b) a small faith-based private institution in the Northwest (Faith Based); (c) a large research institution in the Northwest (Research); (d) a moderate-size teaching institution in the Midwest (Teaching); and (e) a small women's college in the Northeast (Womens).

Over 900 students from engineering, computer science and other science-based majors from these five institutions were recruited at random to participate. The survey consisted of demographic questions, questions regarding participation in communities both in and outside of school, as well as Likert-scale items regarding students' feelings about the degree to which they do, or do not, belong in these communities. Students were either asked to complete the survey in or outside of class. At times, small incentives like gift cards or cash were used. Students were mostly white (Caucasian) and mostly male, although significant gender and ethnicity distribution differences were present within the Womens and HBCU institutions (Table I).

Survey participants were recruited during the Spring 2010, Fall 2010, or Spring 2011 quarter/semester. Participation in the study was voluntary and students' confidentiality was assured. Most subjects were recruited from core (major required) classes in each discipline, primarily at the sophomore and junior level (although some in targeted classes were seniors). Most participants were majoring in engineering disciplines, although non-engineering majors (mostly biology and chemistry) made up approximately 15% of the sample. All students in this study were asked to complete a paper survey, regardless of recruitment technique. The participation rate

(including consent to release results for research) in all classes was 90% or higher, with a completion rate of 95% or higher. All results were cross-sectional; no attempt was made to capture longitudinal responses from across quarters/semesters in the study. Response rates by e-mail recruitment were approximately 20%.

Two questions from the survey, in conjunction with demographic information were analyzed for this study:

1. To which communities in your life (such as family, religious organization, class, extracurricular organization) do you feel most connected?
2. On average, how many hours do you spend per week in extra-curricular activities (religious organization, book club, fraternity, professional societies, etc.)?

TABLE I. CHARACTERISTICS OF STUDY POPULATION

| Category | | N | % |
|-------------|-----------|-----|--------|
| Total | | 944 | 100% |
| Institution | Faith | 74 | 7.84% |
| | HBCU | 139 | 14.73% |
| | Research | 455 | 48.20% |
| | Teaching | 189 | 20.02% |
| | Womens | 87 | 9.22% |
| Gender | Male | 623 | 66.00% |
| | Female | 320 | 33.90% |
| Ethnicity | Asian | 179 | 18.96% |
| | Black | 149 | 15.78% |
| | Caucasian | 491 | 52.01% |
| | Hispanic | 17 | 1.80% |

1. Ethnicities not listed had populations less than 10
2. Gender may not add to 100% because of non-responses

In responding to the first question, students were free to list any number of different communities. Although examples of communities were provided, students did not limit themselves to these communities and listed many others. Typically one or two was listed, with an actual range of zero to six. Responses to this survey question were coded into the categories shown in Table II (next page).

Each community type was assigned a score of "1" when listed. For example, if a student reported that family, friends, and classes were the most important communities, then each community type was assigned a "1" for the frequency analyses. Note that the None category numbers are the sum of instances where the question was left blank (46/54) and those with the word "none" or the equivalent written in (8/54). Frequency analyses were broken down by gender and institution. In the second survey question, descriptive statistics were extracted from the responses and various groups were compared using standard ANOVA and independent samples t-tests with a significance level of 0.05.

TABLE II. COMMUNITIES TO WHICH STUDENTS FEEL MOST CONNECTED

| Community | Total | Institution | | | | |
|--------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | | Faith-Based | HBCU | Research | Teaching | Womens |
| Class & Lab | 13.2% | 18.9% | 10.8% | 12.8% | 13.8% | 13.8% |
| Extracurricular Clubs | 20.2% | 17.6% | 28.8% | 18.5% | 19.6% | 19.5% |
| Family | 71.7% | 75.7% | 71.2% | 70.8% | 71.4% | 74.7% |
| Friends | 23.1% | 28.4% | 12.2% | 30.1% | 15.3% | 16.1% |
| Living Area* | 6.7% | 14.9% | 0.7% | 10.3% | 1.6% | 1.2% |
| Local Academic (Major)** | 2.7% | 2.7% | -0- | 3.5% | 1.6% | 4.6% |
| Professors & Advisors | 0.1% | -0- | 0.72% | -0- | -0- | -0- |
| Religious Organizations | 16.5% | 29.7% | 28.1% | 14.7% | 10.6% | 9.2% |
| ROTC & Military | 0.64% | -0- | 0.7% | 0.7% | 1.1% | -0- |
| Volunteer Organizations | 0.7% | -0- | 0.7% | 1.1% | 0.53% | -0- |
| Work Community | 3.3% | 2.7% | 0.7% | 3.3% | 4.2% | 5.8% |
| None | 5.6% | 4.1% | 4.3% | 4.6% | 9.5% | 5.8% |
| Other | 0.8% | -0- | -0- | 1.0% | 1.1% | -0- |

Percentages may sum to over 100% because students may cite multiple communities in their responses

* Includes housemates, fraternities, dorm mates, etc.

**Includes research groups, design competition teams, and similar communities.

III. RESULTS

In analyzing all survey results (Table II), students reported by an overwhelming margin that they felt most connected to their families. At all institutions, over 70% of students felt most connected to their families, followed by friends a distant second at 23.1%. Students also frequently reported feeling most connected to extracurricular clubs (20.2%) and religious organizations (16.5%). Very few students (< 1%) reported strong connection to professors or to volunteer or service organizations. Class and Lab, although following behind religious organizations (13.24%), still are worth noting. Communities poorly represented in students' reports include work communities (3.3%) and local academic (major) communities (2.7%).

Table III reports hours per week spent in extracurricular communities. The overall average hours per week spent participating in these communities was 7.8 (with standard deviation of 8.9); some students spent no time at all in these outside communities while others participated 80 hours per week.

TABLE III.
HOURS SPENT IN EXTRACURRICULAR COMMUNITIES (PER WEEK)

| Institution | Hours: μ (σ) | |
|-------------|---------------------------|-------------|
| | Male | Female |
| Faith-Based | 9.6 (7.2) | 8.3 (7.5) |
| HBCU | 12.0 (10.7) | 11.3 (11.4) |
| Research | 6.8 (7.8) | 6.9 (7.1) |
| Teaching | 7.2 (10.6) | 7.5 (7.6) |
| Womens | -0- | 6.0 (7.9) |

Most students, however, spent five hours or less in extracurricular activity per week (Figure 1).

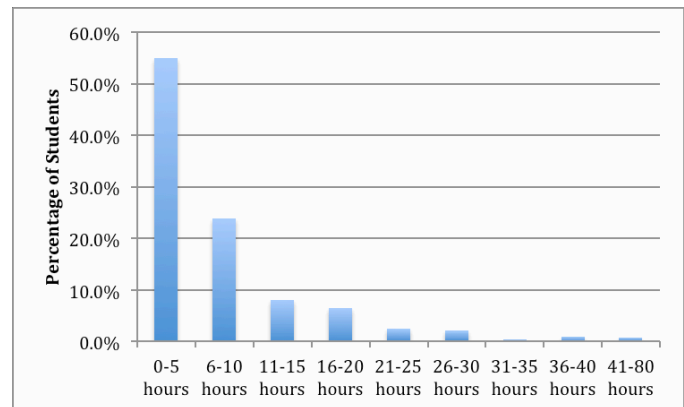


FIGURE 1:
DISTRIBUTION OF HOURS SPENT IN EXTRACURRICULAR ACTIVITIES

Differences across institutions: Despite strong similarities among institutions, some differences did emerge (Table II). Although family remained the dominant community for most students regardless of institution, the community that students reported with secondary frequency varied widely. Students at the HBCU and Faith-Based institution frequently reported strong connections to religious organizations. Others seemed to rely on religious organizations far less frequently (15% or less). At the Research institution, communities of friends seemed to take the place of religious organizations (30% of students reported being most connected to friends), although the Faith-Based institution students had nearly as high (28%). At the

Teaching and Women’s institutions, students did report strong connections to either friends or religious organizations, though not quite as often as at the three other institutions studied. Participation in extracurricular clubs was more uniform across institutions with less than 20% of students reporting they felt most connected here except at the HBCU where over 28% of students reported such a connection. About 5% of students at the Faith Based, Womens, HBCU, and Research institutions reported no strong connections to any community while at the Teaching institution, the percentage of students who had no such connections jumped to almost 10%. Students at the HBCU reported that they spent significantly more hours in community ($p < 0.05$) than any of the other institutions studied. No statistically significant differences in hours spent on extra-curricular activities were found among the Womens, Teaching, and Research institutions. The only other statistically significant difference in this data showed that students at the Faith-Based institution spent more hours in extracurricular activities than those students at the Womens and Research institutions but significantly fewer hours than students at the HBCU.

TABLE IV. GENDER DIFFERENCES IN COMMUNITY CONNECTIONS

| Community | Gender | |
|---|--------|--------|
| | Male | Female |
| Class & Lab | 12.84% | 14.06% |
| Extracurricular Clubs | 19.74% | 21.25% |
| Family | 69.80% | 78.43% |
| Friends | 22.00% | 25.31% |
| Living Area | 7.54% | 5.00% |
| Local Academic (Major) | 2.25% | 3.44% |
| Religious Organizations | 16.20% | 17.20% |
| Work Community | 2.25% | 5.31% |
| None | 6.42% | 4.63% |
| Percentages may not sum to 100% because not all communities cited are included in this table. | | |

Gender differences (Table IV): Men and women report connections to various types of community at surprisingly similar frequencies. The most notable difference among men and women appears to be in family connections where 78.4% of women report strong connections to family compared to men at 69.8%. Although not as distinct, women tend to report stronger connections to friends and to their work communities more frequently than men. In the remaining communities, men and women report strong connections with similar frequency. In terms of hours spent in outside community, no significant differences were found between men and women at any of the five institutions studied.

IV. DISCUSSION

Regardless of institution type, level in school, or major, most students cited *family* as a community to which they were most connected. Strong family connections that extend into adulthood can support mental health in adults, including

reducing fatigue, insomnia, and nervousness [13]. Strong family support is also frequently cited as a major factor in enabling women [14] and other under-represented minority groups [15] to succeed in engineering fields. The fact that STEM women, more than men, are showing strong family support in this study is encouraging for their continued persistence in rigorous programs. For other under-represented minorities, strong family ties can have the added advantage of counter-acting socioeconomic inhibitors that often affect immigrant families and minority populations in the United States [16]. Friends, while also playing an important role in students’ lives, make an expanded and slightly different contribution to the quality of students’ lives. Friendships provide social support that is more likely than family to be “received and interpreted in the spirit in which it is intended,” since it is provided by someone with whom the recipient shares a sense of voluntary social identity [17]. Haslam et al. [17] also tell us further that friends by giving “... sense of place, purpose, and belonging...give us a sense of grounding and imbue our lives with meaning. They make us feel distinctive and special, efficacious and successful” (p. 2-3). On average, over a quarter of students mention friends as an important community in their lives. While most students generalize friends regardless of how they met or where they live, some students specifically point to particular types of friends that make the most difference in their undergraduate experiences (Table V).

TABLE V. TYPES OF FRIENDS CITED BY STUDENTS

| Types of Friends | Male | Female |
|---|-------|--------|
| General | 78.4% | 75.3% |
| Hometown | 7.2% | 1.2% |
| Romantic | 1.4% | 1.2% |
| Hobby or Gaming | 2.9% | -0- |
| Peers | 10.1% | 22.2% |
| Percentages may sum to over 100% because some students report strong connections to multiple types of friends | | |

A notably higher percentage of students at the Teaching institution reported feeling strongly connected to no communities (9.5%) (‘None’) versus 4-6% for the remaining schools, with 5.6% overall. This may be attributed to the specific character of the average student. It appears that these students are more involved in outside work, so may not have sufficient extra time to feel as strongly connected even though they may be involved to some degree.

On a similar level to friends, connections to religious organizations are also frequently reported to be important communities. According to Saroglou and Cohen [18], religious community provides “a point of reference for what is normative, and provides validation for what is new”. Religious communities provide a connection to a community that has a “(glorious) past, present and eternal future,” thus joining the participant to a community with a long, shared, meaningful past [18]. In addition to these big picture benefits, connection to religious organizations has also been proven to have a number of educational benefits

including protection from behaviors that negatively impact educational performance, better grades, increased quality of time invested in academic pursuits, and improved sense of purpose and meaning [19]. Participation in church and other religious organizations seems to provide students with a sense of the ‘big picture’ that reduces stress and anxiety and provides a meaningful motivation for persisting in their studies.

Table VI.
EXTRACURRICULAR COMMUNITIES CITED BY STUDENTS

| Extracurricular Organization | Gender | |
|----------------------------------|--------|--------|
| | Male | Female |
| Student Government | 0.8% | -0- |
| Trade/Honor Societies(e.g. IEEE) | 10.6% | 8.8% |
| Sports | 36.6% | 19.1% |
| Music | 5.7% | 10.3% |
| Unspecified** | 35.8% | 30.9% |
| Other*** | 10.6% | 29.4% |
| International Groups | -0- | 1.5% |

Percentages may sum to over 100% because some students report strong connections to multiple extracurricular communities

**Students who simply stated “extracurricular club” or a similar generic response were grouped into the Unspecified category

***Responses that occurred less than two times were grouped into Other (e.g. 4H, ADPA, AnimeClub)

Participation in non-religious extra-curricular activities, while not necessarily providing the ‘big picture’ perspective of religious involvement, is also common among STEM students in our study. Students participate in a broad range of extracurricular clubs and organizations (Table VI). Participation in student government is rather poorly represented among STEM students, while men seem to integrate into sports communities far more frequently than women and women seem much more often to be strongly connected to music-based activities. The K-12 literature informs us that participation in clubs and sports provide students with opportunities to develop independence from their families as they “plan and arrange; make and correct errors; have real responses to real problems; and develop a sense of control” [20]. However, at the college level, while extracurricular activities have often been shown to positively impact academic outcomes [7-12], not all participation in extracurricular clubs has a uniform positive impact. In fact, contrary to the idea that social and academic integration enhance each other, some efforts to enhance social integration (through sports, for example) can compete with academic integration. Other factors, such as size of school and number of commuting students, also make it difficult to draw strong conclusions [21].

Gender Differences: Interestingly, women tend to more frequently (22.2%) cite peers as important friendships in their lives compared to men (10.1%), perhaps demonstrating the particular importance to them of belonging within their academic communities while in school. In these traditionally male-oriented disciplines, men likely need less peer affirmation. Although relatively low in percentage, the

difference between men and women with respect to hometown friends and hobby or gaming friends is also worth noting. Men named hometown friends at 7.2% and women at only 1.24%; this could reflect women’s incrementally greater emotional flexibility in making new personal ties. Men named hobby and gaming friends at 2.9% and women not at all; this may reflect a slight bias toward action activities for men versus a bias toward more personal relational ties for women.

Institutional Differences: The **Faith Based** institution tends to be characterized by a sense of community, especially within the STEM disciplines. Classes are small and access to professors is very good. Significant efforts are expended both inside and outside the majors to nurture students academically, socially, and spiritually. There tends to be high satisfaction among students with the programs. In addition, the character of the students who attend tends to be oriented and influenced by the Christian faith and values. Some of the results of the responses from the students seem to correlate well with cited research in this paper. Specifically, there appears to be an across-the-board elevation of community involvement among the various categories.

The **Teaching** institution is “typical” in that the strongest community connection identified by students is family. Its geographical location is known for strong family relationships and expected participation in family activities. Since the majority of students are from the local area, strong family involvement is logistically possible for many students and may reduce time spent with friends. Non-traditional students, a significant minority, have community with both their family of origin and immediate family. For some students, this fills all time not spent studying. Students also typically live on campus their first year but are usually living off-campus by sophomore year, reducing the impact of living area communities thereafter.

The **Research** and Teaching institutions are very similar overall, likely reflecting the predominant impact of student size on the ways that students choose and participate in communities. Interestingly, students at the Research institution report far more connections to friends than the Teaching institution which could reflect the fact that the Research institution has fewer students whose family home is local or it could reflect the dependence on friends to compensate for the impersonal nature of large classes and a demanding curriculum.

The uniqueness of the **HBCU** is that it connects students of an American ethnic minority. Similar to the other institutions, HBCU students’ strongest connection is to family but religious organizations and extracurricular clubs also emerge as important. The HBCU does not have a faith-based mission but studies show that African Americans are more religious than the United States population as a whole [22]. Thus, by concentrating African Americans, it seems that the values that are concentrated within the culture emerge independent of the mission of the university. The students also report spending more hours in extracurricular communities than the other institutions which plays a role in

student connectedness. Based on anecdotal evidence, this observation seems to be a result of the complex mixture of the culture of HBCU's, the culture of college-educated African Americans (>75% of mothers and >60% of fathers have attended college, including those who attended but did not graduate, based on demographic data in our survey) and the students' perception that participation in extracurricular organizations enhances employability.

Other than 'family', many of the distinctly mentioned community categories at other institutions are conflated at the **Womens** institution. Because the college is small, many students share living space and clubs with their friends. Of the four communities specifically mentioned in the survey prompt (family, religious, class, extracurricular), students at the Womens institution mentioned religious communities at the lowest frequency (9.2%). Although there are vibrant religious campus organizations, students may think of them as just another student group shared with friends. Notably, a higher percentage of students at the Womens college report a work community connection (5.8%). This may reflect this private college's limited financial aid resources versus other schools.

V. CONCLUSIONS

We can learn from the differences among our five institutions and work to leverage the best we find in each, but we also see that despite the differences, all people share the same needs when it comes to reaching their best potential as students, with family being the universal winner in terms of importance. In addition to expanding the number of participants to include more institutions or more majors within STEM, future work will also include understanding differences in community among disciplines and ethnicity (as well as among institutions and between genders as described in this paper) in the hope that such understanding can enable faculty and administrators to both create more effective community within an academic context and also to support and encourage participation by students in outside communities that meet essential needs for belonging and connection. Most students find meaningful community one way or another. However, a notable number apparently do not. It may behoove schools to respond to this by looking for ways to intentionally encourage more community engagement for those students.

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Why Do Some Engineering Students Study Alone?

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Abstract - This paper looks at undergraduate engineering students who have solitary study habits and do not frequently engage with classmates. These students, referred to as ‘academic solitaires,’ explicitly state that they do not interact or study much with their academic peers and may find a sense of belonging elsewhere. Using a mixed methods approach (including interviews with students and surveys), our data show that while some students are happy studying alone and do so by choice (‘preferred solitaires’), others universally express feeling like an outsider and study alone as a result (‘outsider solitaires’). We argue that many of these outsider solitaires may be at risk of dropping out or changing fields over short, moderate, or long-term time scales. As part of our mixed methods study, we have identified a unifying set of indicators that can be obtained by survey at much lower self-select bias than recruiting students for interviews. We found that this approach allows greater success in identifying outsider solitaires at potential risk of dropping out. In this pilot study, we show that using these affective indicators in survey form can potentially allow practitioners to identify students at risk of dropping out long before they reach the point of leaving.

Keywords – *belonging; community; engagement; isolation; solitude*

I. INTRODUCTION

Studies have shown that while studying in groups facilitates the learning of many students, students lacking community connection and feelings of belonging may be at risk of dropping out of STEM majors or professions. However, some students do study alone for a variety of reasons, and these reasons can be predictive of whether or not they will remain in their STEM field. This paper draws on data from a five-year study that examines how students’ feelings of connection to community and belonging influence both their study patterns and persistence in their major field, and seeks to understand how at-risk students may be easily identified.

II. BACKGROUND

The importance of working in groups compared to working alone has been demonstrated in a wide variety of K-12 studies. For example, in a study of sixth graders

randomly selected for inclusion in cooperative learning exercises, both high and low achieving students demonstrated better performance and attitude toward group learning than solitary peers [1]. In higher education, however, findings are mixed. Hansen [2] found that while some team learning experiences grow student motivation and achievement, others might be less than beneficial. For example, when undergraduate instructors place students in work ‘teams’ without first educating students on team skills and competencies, teams are more likely to lack leadership and development, providing little benefit to students. In contrast to team learning, studies which examine study habits show that some students may actually perform better when working alone [3]. Other studies in higher education have shown that students working in groups can be vulnerable to social loafing where individual responsibility is diffused into the group responsibility, allowing students to do less than they would do if working individually [4]. Thus, studying or working alone, while often viewed as a negative, clearly provides some individuals with stronger and more productive experiences.

Despite mixed findings regarding the impact of studying alone, it remains a concern because studies show that this behavior may be related to non-persistence in STEM majors or professions, as well as limiting students’ academic performance and individual fulfillment. The significance of community connections in regard to undergraduate academic retention is supported by Tinto’s model of social integration, in which student goals and commitments formed by pre-college attributes interact with their college experiences to indicate whether students are likely to complete an academic program [5]-[7]. This link between belonging and persistence is also consistent with studies that have shown isolation or lack of community as a primary reason why women leave engineering fields after graduation [8]-[9]. Fouad and Singh [10] also show that many women with an undergraduate degree in engineering either never enter the field or eventually drop out due to unfavorable workplace culture, amongst other factors.

These explanations of why students may drop out of STEM majors or professions are useful, but we are also interested in finding specific indicators that may help us identify these students early on in their STEM education in order to better facilitate their sense of community and belonging. In looking to prior research on indicators for STEM dropout or switching, indicators have been primarily focused on academic achievement, not necessarily

correlated with a student's sense of community or belonging. For example, in a study conducted at a Texas research university, Scott et al. [11] found a significant correlation between an undergraduate's high school rank, combined mathematics and reading SAT scores, and their retention in mathematics and science majors. Thompson and Bolin [12] implemented a 7-year cohort study with freshmen matriculating into STEM majors at a large public university in Texas. Their results confirmed Scott et al.'s findings that high school rank is correlated with whether or not a student would drop out of college, switch majors, or graduate. Though these indicators are helpful, they lack qualitative insights as to 'why' these actually matter and avoid the larger issues of isolation and community that other researchers [5]-[8] have identified as reasons why some students may leave STEM fields.

By digging deeper into why students study alone, we seek to find ways of easily identifying those within this group who really are at risk of leaving STEM majors and professions. If we can successfully identify these students, we can streamline interventions for them, reaching them more quickly and effectively than broader-based interventions with more generalized appeal.

III. RESEARCH METHODS

The present analysis was guided by the following questions:

- *What are the primary differences between engineering students who study alone by choice and those who do not study alone by choice?*
- *How can engineering students who study alone not by choice be easily identified?*

These questions were addressed using quantitative and qualitative methods, including a survey and follow-up interviews.

This paper draws on data from a larger, five-institution study; however, in order to limit contextual variables, data from only one institution figures into the present analysis. This institution is a large research university in the Pacific Northwest. This institution offers a wide range of engineering and computer science majors and is characterized by densely populated groups of students (class sizes of 30-500) who enter the program (competitively) during mid-sophomore year. Teaching assistants are common in core courses and complement limited faculty time per student. Instead of focusing on all STEM majors, this paper focuses only on the study habits of students in engineering fields.

Survey participants were recruited during the Spring 2010, Fall 2010 or Spring 2011 academic quarter. Participation in the study was voluntary and students were assured that their survey responses would be confidential. Most subjects were recruited from core major (required major) classes in each discipline, primarily at the sophomore

and junior level (although some seniors were also taking the target courses and were not explicitly excluded from the study). All students who were recruited from target core classes were asked to complete a survey (on paper) during each of these classes. The participation rate in all classes was 90% or higher, and almost all students who offered to participate completed almost all of the survey (95% completion or higher). All results were cross-sectional; no attempt was made to capture longitudinal responses from across quarters in the study.

Survey respondents were then recruited via email to participate in follow-up interviews (some conducted with individual students, other conducted with more than one student) in Spring and Fall 2011. The response rate by e-mail recruitment was approximately 20%. The characteristics of students at the research institution who completed surveys and those who participated in interviews are seen in Table I. Student interviews were audio recorded and transcribed, and students were assigned numeric codes to assure confidentiality. Interview questions covered a range of topics, including student participation in academic and nonacademic communities, student sense of belonging to their major, and student participation in class.

Interview transcripts were coded and analyzed using the constant comparison method [13]-[14] to identify emergent themes and trends. In analyzing the interview transcripts of participants at the research institution, it became apparent that a subset of 7 participants reported studying alone. This subset of students was characterized as 'academic solitaires.'

Within the academic solitaires group, there emerged major differences in the reasons students gave as to why they studied alone. In order to further explore these differences, the survey results of the 7 academic solitaires were compared to the full set of all survey results from participants at the research institution. From this comparison, four constructs were identified as differentiating the academic solitaires from the rest of the participants, and also differentiated two distinct sub-groups within the academic solitaires group: 'preferred solitaires' and 'outsider solitaires.' A construct was considered to be of interest only if all of the outsider solitaires' scores fell two or more standard deviations away from the mean for that particular construct. A total of four constructs were

| Data Collection Instrument | | Interview | Survey |
|----------------------------|----------------------------|-----------|----------|
| Total | | 38 | 435 |
| Gender | Males (%) | 28 (74) | 296 (68) |
| | Females (%) | 10 (26) | 139 (32) |
| Major | Electrical Engineering (%) | 12 (32) | 100 (23) |
| | | | |

TABLE I. CHARACTERISTICS OF STUDY POPULATION

identified in this way as being indicative of 'outside solitary' status.

After identifying these four constructs, we returned to the survey data and identified additional respondents whose survey results fit the 'outsider solitary' profile, meaning that they had scores two or more standard deviations away from the total mean (in the same direction as the original outsider students) for at least three of the four constructs of interest. We then contacted these newly identified students, using the original interview recruitment protocol. Individual interviews with these students were then conducted, using the same original interview questions and protocol.

IV. RESULTS

Of the 38 students who participated in interviews at the focus institution, the large majority (82%) reported that they regularly chose to study with peers, whether in formal lab groups or teams or in informal study groups. However, the responses of 7 students (18%) stood out in the data by reporting that they typically studied alone. These students fall into the category that we are calling 'academic solitaires.' In examining more closely the ways in which these academic solitaires talked about their study habits, differences in the reasons behind their choices emerged.

A. Research Question #1: What are the primary differences between students who study alone by choice and those who do not study alone by choice?

The existence of two distinct types of academic solitaires first emerged through analysis of the interview data. In the interviews, four of the seven academic solitaires asserted that they chose to study alone because they felt they worked better that way, or saw studying with peers as a hindrance to their learning. These students, who were all male, will henceforth be described as 'preferred solitaires.' Examples of explanations given by these preferred solitaires include:

"Study groups do not work out. ... The thing is, first of all people talk, people chat and that becomes a problem and eventually you are the ones that have to figure it out. ... So I think studying alone actually is a lot more efficient. ... When you spend too much time helping others, you don't have time for yourself to study."

"I'd rather trust in my ability to figure it out on my own with the assistance of the book than to go to a different student who I don't know how competent they are and get their help on it."

In contrast, the remaining three academic solitaires indicated in their interviews that although they currently studied alone, this was not necessarily their preference. It is notable that all three of these solitaires were women in the electrical engineering major. These students will henceforth be referred to as 'outsider solitaires.' These outsider solitaires reported that their solitary study habits were due to certain barriers in the academic environment that kept them

from participating in academic communities. Regardless of whether these barriers were perceived, self-imposed, or based on fact, these barriers made the students feel alone and outside of the realm of their peers, thus affecting how they studied and sought academic resources. For example, as one student related, a barrier to participation has been feeling (justified or not) academically inferior to her peers:

"For engineering classes, I don't talk at all. I'm one of those students who sits in the first row and don't talk at all. ... I feel a lot more reluctant to ask any questions because I feel like, 'Oh everyone already knows the answer.'"

Along similar lines, another student identifies her gender as a reason for feeling like an outsider in her major. She describes it as a barrier to engagement and belonging with her peers, recalling that:

"I didn't really ask too many questions in my group either because, part of the reason was probably that I was the only girl in my group and one of the kids in the group would every now and then say something about girls and, you know, how they couldn't really do engineering and stuff, so that made me feel like, if I was confused, I didn't want to ask for help to show that I was confused, and not understand. ... So I didn't really get help very much in the class."

The third student made a similar comment, indicating that although she appreciated getting help from other students, she felt like an outsider when trying to connect to her peers:

"I might need someone to...kind of show me what's going on and that helps majorly. And in that case, yeah, having people that I'm designated, that you are allowed to talk to these people, like a small lab group or something. Whereas in, like, a large class where you don't have...established people that you can talk to because there's just too many people, then it's difficult to keep that structured response under control. You feel really kind of alone."

She then talked at greater length about the dilemma of wanting to work with peers but being inhibited by large groups:

"I actually think labs would be better if it were only two people instead of three people, because ...if it's just three people, I tend to be the one left out of the two. ... I'm able to follow along, but it makes me feel really bad if I'm not contributing as much as I feel like I should or if it seems like they're doing everything, because I want to help, and I want to learn as much as they do. I just need a little more time."

As illustrated by these example quotes, all three of these outsider solitaires exhibited a desire to study with their peers, yet were hesitant to seek out groups for study or help. The three women attributed this to barriers such as self-identified intellectual ineptitude, a fear of being shunned by peers, and/or not knowing who they are 'allowed' to talk to

in academic communities. Additionally, though these women talked about academic resources being available to them (e.g. office hours), they referenced perceived barriers in seeking out those resources or comfortably accessing them.

To further understand the differences between the two types of academic solitaires, we looked at their survey responses. In doing this, consistent differences emerged between the two groups' responses along the four constructs described in Table II. The constructs 'Belonging Class Total' and 'Emotional Engagement Positive Class' were measured by four survey questions, while 'Emotional Engagement Negative' was measured by five survey questions, and 'Emotional Engagement Positive' by six survey questions. All questions were answered using a 5-point Likert scale.

TABLE II. CONSTRUCTS USED TO IDENTIFY OUTSIDER SOLITARIES

| Construct | Description |
|---|---|
| 1. <i>Belonging Class Total</i> | Refers to the student's sense of support, acceptance, comfort, and membership in a specific class in their major. <i>Example survey question:</i> "I feel that I am supported in this class." |
| 2. <i>Emotional Engagement Positive</i> | Refers to the level of a student's positive affect about learning and being in their major classes and lab/study groups. <i>Example survey question:</i> "I enjoy learning new things in my major classes." |
| 3. <i>Emotional Engagement Positive Class</i> | Refers to the level of a student's positive feelings about a class in their major. <i>Example survey question:</i> "When I'm in this class, I feel good." |
| 4. <i>Emotional Engagement Negative</i> | Refers to how often a student feels frustrated, angry, overworked, or insecure in their major. <i>Example survey question:</i> "When I'm in my lab/study group, I feel worried." |

Fig. 1 shows the mean survey scores for these four constructs for all survey respondents at the research institution, for the preferred solitaires, and for the outsider solitaires. While there is little difference in the mean scores between all survey respondents and the preferred solitaires across the four constructs, the outsider solitaires exhibit, on average, lower class belonging, lower overall positive emotional engagement, lower positive emotional engagement in their major classes, and higher negative overall emotional engagement. When compared to all survey respondents, outsider solitaires' responses were two or more standard deviations away from the mean on each of the four constructs.

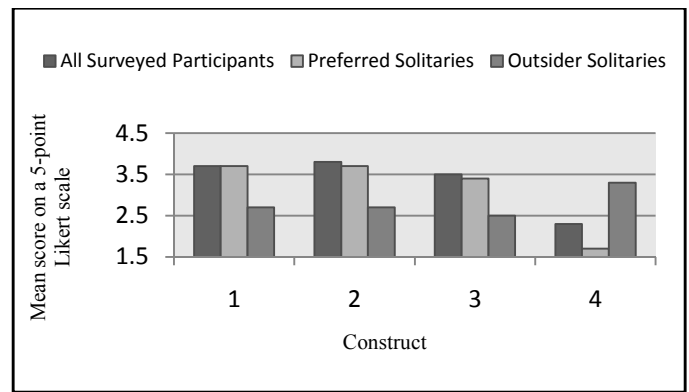


FIGURE 1. SURVEY RESPONSE MEANS BY GROUP

B. Research Question #2: How can students who study alone not by choice be easily identified?

Using these four constructs as possible indicators for identifying outsider solitaires, we returned to the full set of survey data and identified additional students whose scores fell two or more standard deviations away from the mean in at least three of these four constructs (in the same direction as the original outsider solitaires' scores). We then interviewed four of these identified students.

Similar to the three original outsider solitaires, the newly identified outsider solitaires discussed a variety of reasons why they were not (or had not been) engaging with their peers. Though all four of these newly identified students felt like outsiders in one way or another, three also showed a desire to work with other students and, based on the literature, seemed to be at risk of dropping out. One student interviewed had already switched out of her engineering major since taking the survey and commented on her new level of comfort and engagement:

"I think I belong better maybe than a year ago [when in previous engineering major]. Before, I didn't really go to lab because I didn't really know anyone there and would work home on my laptop. Now that I have friends the lab is like my second home and I feel pretty comfortable."

She further commented on her desire to connect meaningfully with other people, distinguishing her from preferred solitaires:

"People are the most valuable things in your life. If you don't have people around you, you'll feel lonely and life will become miserable."

Another newly identified outsider solitary indicated his perceived intellectual ineptitude as a barrier for approaching other students, mirroring the statements of the originally identified outsider solitaires. He stated:

"I like school much less than the average person. ... There are many times when I feel like I'm super lost and everyone else around me knows what's going on, and I'm the dumbest person in the class."

In reviewing the similarities in interviews and survey responses from these newly identified outsider solitary students in comparison to the original outsider solitary students, we conclude that we successfully identified new outsider students via the four survey constructs. Fig. 2 shows how these outsider solitaires were found through our mixed-methods approach and how they may be found only using surveys.

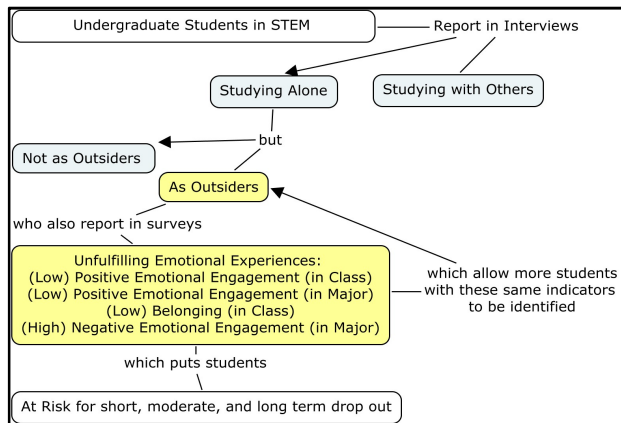


FIGURE 2. CONCEPT MAP: IDENTIFYING OUTSIDER SOLITAIRES

V. DISCUSSION AND IMPLICATIONS

The findings of this study provide insight into the differing characteristics of students who study alone by choice (preferred solitaires) and those who study alone not by choice (outsider solitaires). The findings provide further insight into how outsider solitaires differ from their rest of their academic peers, as well as how institutions might identify the at-risk outsider solitary students via easily administered quantitative methods while students are still in their academic STEM major.

We have found that engineering students who feel like outsiders and thus study alone have low feelings of positive emotional engagement, high feelings of negative emotional engagement, and an overall low sense of belonging to their major. These outsider student are not only studying alone, they also feel alone in that they are emotionally disconnected from their major peers and perceive academic resources (such as faculty) as unavailable to them.

The literature shows that engineering students, especially women, who feel isolated from their academic community are at risk of dropping out of their major or field. Our findings confirm this theory; of the eight outsider solitaires identified through our research, the majority have already seriously considered dropping out: one student dropped out of her engineering field after taking the survey; one is already planning to go into a non-engineering field upon graduation; and two are currently questioning whether or not to continue in an engineering field once they graduate.

We acknowledge that while our sample pool of outsider solitaires is small, we hypothesize that similar results would be found if using the four constructs as indicators to identify outsider solitaires from a larger pool of students. Additionally, we acknowledge the potential for response rate bias in our research as students who were interviewed actively responded to recruitment emails. Finally, we acknowledge that the majority of the outsider solitaires identified were women, many of whom were electrical engineering majors. Though we do not seek to make any specific inferences based on gender or major in this paper, we do feel this is prudent to note for further research.

VI. CONCLUSION

Our research shows that while some students are fine or even happy studying alone, others do so because they feel like ‘outsiders’ in their major. In feeling like an outsider, students report poor feelings of belonging and engagement, putting them at greater risk of dropping out from both their major and the engineering profession post-graduation. These findings are supported by literature that shows belonging and lack of community as related to student persistence [8]-[9]. Thus, we argue that identifying students with lagging engagement and belonging indicators can be an effective technique for reducing drop-out when used in conjunction with targeted interventions to help these students feel less like outsiders and more like part of the group.

In a time when universities are tightening budgets and admitting fewer undergraduate students into engineering majors, it seems in the best interest of engineering departments to ensure student retention not only in the major while these students are still in school, but also in the profession over the long term. We no longer have the luxury of turning out large numbers of engineering degrees than we need engineers in the workforce. While other studies have shown that poor academic performance often leads to drop-out, an increasing number of studies in STEM point to affective indicators as even earlier indicators of the risk of dropping out. This study adds to this growing body of literature by characterizing a specific type of student who can be identified as at-risk through surveys regarding engagement, belonging, and study habits. While this study clearly lacks the numbers of participants to make conclusions as to how prevalent the outsider solitaire is among STEM students, it provides a means for identifying this type of solitaire efficiently in future studies and interventions.

Thus, while this study is limited in that it does not allow us to identify how many students are at risk from solitary study habits, it does allow us to avoid targeting all those studying alone under the presumption that studying alone by itself creates risk for dropping out. A natural next step of this study would be to identify the number of students who fit the profile of the outsider academic solitaire by using the

survey items described herein along with an additional series of survey items targeted toward identifying solitary study habits. Our study has shown that, due to self-select bias, interviews identify a much smaller percentage of outsider solitaires in a population than are actually present. Surveys reduce this self-select bias and may be the most efficient method to identify this group of at-risk students.

The self-select bias that we see in this study also has implications to intervention with outsider solitaires. These students are likely to resist direct confrontation to change their study habits into more group-oriented modes. Thus, interventions are likely to be more successful if done more gradually, perhaps using electronic bulletin boards and other online options to transition the student into the 'insider's' circle of learning and thriving within the academic environment.

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Work in Progress: An Interactive Online Educational Support System Considering Real-World Human Relationships of Students

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Abstract—This study aims to make university lectures more enjoyable and fruitful by providing a virtual discussion space closed to outside participants. This web-based educational system has the appearance of an online game, similar to a quiz show. Fearing humiliation, some students hesitate to state their opinions or ask questions in front of unfamiliar classmates. This study tries to resolve this issue by protecting the anonymity of students, thereby providing them with an interactive and cooperative learning environment free from the influence of real-world human relationships, which can significantly influence student engagement. Students can view and compare each other's opinions, answers, response time, and confidence levels, without individual identification. Additionally, I report the results of a questionnaire administered to 107 university students regarding the integration of educational games into my classroom lectures to evaluate the effectiveness of my approach, and present a brief explanation of the educational system I am developing.

Keywords - active learning; on-line system; educational game; half-anonymity

I. INTRODUCTION

With a downward trend in birthrates, a diversification and personalization of educational services is required in universities. At the same time, students are less interested in classroom lectures because of a decline in their academic abilities. Active learning [1] is one solution to these problems. Many findings and success stories have been reported by researchers, as illustrated by [2] and [3]. As many case studies have demonstrated, instructions in the form of a game have a beneficial effect on attracting the interest of students in any generation, although [4] noted that many educational games are not based on a coherent theory of learning. I used an online educational quiz game [5] as a part of instruction in computer literacy classes between April 2008 and March 2012 and obtained some positive feedback. The students showed more positive attitudes toward the course contents than when I employed other education methods and tools, such as oral explanation, group work, online surveys, and audiovisual aids. Moreover, my preliminary survey of 17 students who had experienced each of these four methods and tools showed that 50% found game-based instruction to be the most engaging education method and that 93% supported its effectiveness. Yet, although educational games are attractive, some students remain reluctant to participate, even in the context of an online, game-like education system, involving quizzes and discussions. To resolve this issue, I propose an online educational game open to class members only, where students

are protected by a specified level of anonymity to exchange their opinions without constraint.

In this study, I clarify the following questions: (1) What makes students passive or reluctant to participate in classroom discussions? (2) Can a half-anonymized online discussion system help to deal with this issue? (3) What level of anonymity effectively encourages students' positive attitude toward class work?

I discuss these questions along with the findings from a questionnaire investigation into the effectiveness of this type of educational support system. I also give a brief explanation of the development of this half-anonymized online discussion system.

II. QUESTIONNAIRE INVESTIGATION

I administered a survey to 107 university students to investigate what discourages students from participating actively in classroom discussions, how students place educational games among many other kinds of teaching methods, and to what degree the educational game I propose meets students' needs. To examine what makes students reluctant to present their opinions in class, I asked students to rate the following statements: Q1: I actively give my opinion during class, Q2: I like to engage in discussion with a small group (if they are randomly chosen classmates), and Q3: I like to engage in discussion with a small group (if they are all my friends). The answers are shown in Fig. 1. According to the free descriptions provided, students are reluctant to state their opinions in front of less friendly classmates, since they are afraid of being humiliated.

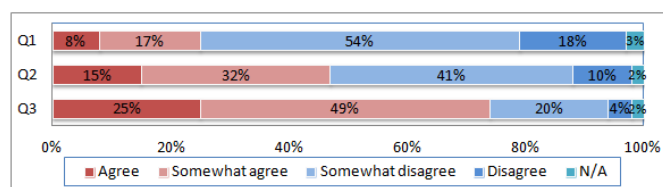


Figure 1. Students' shyness prevents them from expressing their opinions.

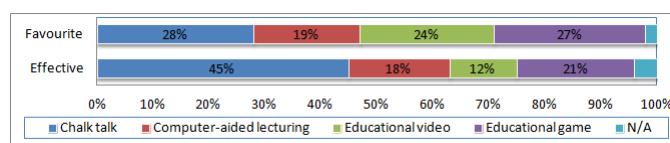


Figure 2. Student views on education methods, in terms of popularity and effectiveness.

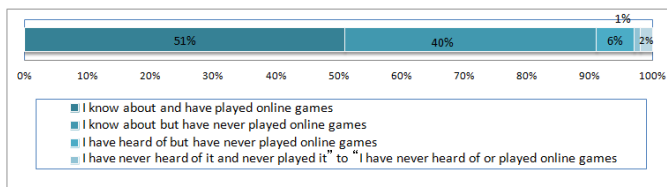


Figure 3. Popularity of online games

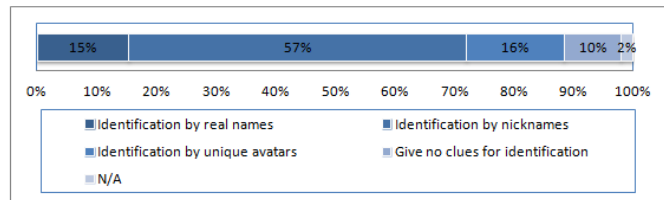


Figure 4. The desirable anonymity rating differs among students

Fig. 2 shows that educational games were ranked second in terms of popularity and effectiveness as an educational method, after “Chalk talk”. Fig. 3 shows the popularity of online games. Surprisingly, 97% of students played or knew about online games—many played such games on PCs and smart phones.

I asked students whether they would want to identify each other while conducting discussions on an online educational game open only to classmates and the instructor. The results are shown in Fig. 4. Only 15% of students wanted to use their real names, while 10% wanted to give no clues to their identification, and 73% wanted half-anonymity by displaying nicknames or using a unique avatar to identify themselves purely in their role as players of the game.

Based on the questionnaire investigation, I confirmed that educational games are supported by students, since they make classroom lectures more interesting, and because they believe that such games are effective for their learning.

III. IMPLEMENTATION

I am developing a half-anonymized, online classroom discussion system, using HTML5 and JavaScript. I use JavaScript packages [6] [7] that enable scalable, real-time chat functions. The system currently runs as a simple web system, as shown in Fig. 5, and employs a graphical user interface (GUI) with an appearance and functions similar to a quiz show to make online discussions more convenient and enjoyable. In a modified version, students log in to an online 2D quiz game and use individual avatars to answer multiple choice questions related to the course content. Students can log in to the same online quiz simultaneously and observe the behavior of one another’s avatars. The system enables participants to observe others’ decision-making process, including which options other students choose and how long it takes others to make their final decisions. While answering quizzes, students can share their opinions and publicly ask questions by sending a short message displayed as a speech balloon beside their avatar.

Fig. 5 displays our current version of the client interface for students. Students input their answer or opinion with the level of sureness using the web form shown in (A); messages submitted by students are listed in (B). Students can view and compare answers, opinions, time taken to make decisions, and

confidence ratings of other students, without being able to identify them.

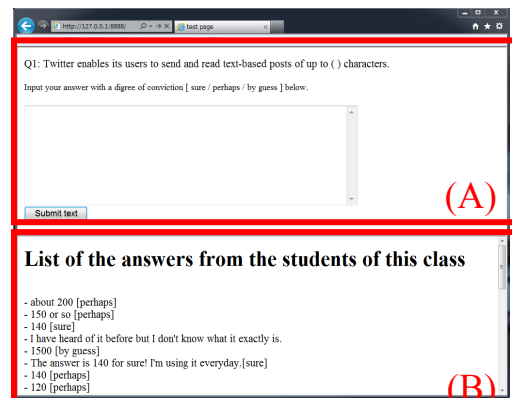


Figure 5. Current version of the client GUI (under development)

IV. FINDINGS AND FUTURE WORK

According to the results of the survey, educational games are supported by many students.

While other studies have utilized online discussion systems to enable people in different places to exchange opinions as if they are together, I focus primarily on the anonymity of the online game. A certain level of anonymity seems to help students communicate with each other without being affected by real-world relationships. Additionally, an appropriate level of anonymity might contribute to mitigating the over-competitive nature of educational games. As my immediate task, I am developing a GUI to make the system more like a quiz show and therefore more attractive and usable for students.

Additionally, a minor concern is that some educational games make lectures over-competitive so that students feel the pressure of being ranked and therefore lose confidence and interest. In future work, I will investigate how adjusting anonymity levels might lessen the impact of this issue.

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Managing International Student Collaborations

An Experience Report

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Abstract— Knowledge and experience from working in international collaborative projects prepares engineering students for their future careers in a global market. Hence this is an important element in higher education, although seldom provided in the curriculum. One reason for this lack might be uncertainty in how to manage international collaborations and to create a good learning environment for the development of skills related to international collaborations. Therefore this article describes our experiences from managing international student collaborations including theoretical underpinning for our choices when relevant. Having given the context of, and the strategies for running our two collaborations, we provide an analysis of our experiences. This includes observations of differences in the two collaborations, both when due to use of different strategies and when due to different contexts, as well as observations of similarities. With this in mind, we present recommendations for running international student collaborations.

Keywords— component; International student collaboration, open ended group project, experience report

I. INTRODUCTION

Our experiences stem from two international student collaborations in projects with real clients based on the Open-Ended Group Project (OEGP) concept [1, 2]. One collaboration is between an American site and a Turkish site (US-TUR) and the other between the same American site and a Swedish site (US-SWE). The former has run twice and the later seven times. Both collaborations include real clients and open-ended problems but the courses have different syllabuses and the collaboration between the universities is based on informal grounds. While neither international student collaborations nor the OEGP concept are new ideas, they are in the authors' opinions underused in learning environments.

Running international collaborations typically means having to deal with differences between the educational settings, e.g. learning objectives, course durations, contexts in curriculum, and grading schemes. Other general issues are cultural differences, having different holidays, few if any face-to-face meetings, and being in different time zones. In our collaborations we also have to deal with having clients local to one site, which means having language issues and students having different access to the client, and how to handle that some students are being graded by faculty from another site. Other educational issues include how to motivate students, how to provide scaffolding, how to use collaborative technology, and having a learning process focus or end-product focus for the project.

The aim of the paper is to inspire others interested in running international student collaborations by sharing our experiences from working with international student collaborative projects from a management perspective and to relate our choices in creating learning environments to relevant engineering education research.

II. CONTEXT

A. Bilkent University (BU), Ankara, Turkey

The University is the first private non-profit university in Turkey and was founded in 1984. With its approximately 12,000 students, the university is well known as a pioneer research oriented Turkish university. Starting from spring 2009, the collaborative International Term Project course has been held during the spring semester that runs from early February to the end of May, and has generally between 5 and 10 students per semester. This is a required course in a computer science education focused program in the Faculty of Education. The course aims to allow students to collaborate with peers from different cultures as part of an international team and work with a client to assess their needs and requirements to develop a technological solution. Students gain experience with interpersonal communication and conflict resolution within teams [3].

B. Uppsala University (UU), Uppsala, Sweden

The university has approximately 40,000 students and is hence one of the largest universities in the country. The IT in Society course is given in the fall semester of the IT engineering program. It runs for the whole semester, i.e. beginning of September to Christmas. It is a 15 credit course, i.e. representing half of the 30 credit study load for a semester. The course is elective and the number of students has varied between 10 and 25 during the years we have had an international collaboration, i.e. since 2005. The course has been presented elsewhere; see for example [2, 4 - 7]. The learning objectives for the course are in short to provide students with substantial knowledge and ability concerning the interplay between technology, users and organizations based on relevant areas in human-computer-interaction, psychology and system construction, as well as experiences in real systems developing projects.

C. Rose-Hulman Institute of Technology (RHIT), Terre Haute, IN, U.S.A.

A private engineering school in the United States, it was founded in 1874. The Computer Science and Software Engineering department offers undergraduate programs in

Computer Science and in Software Engineering. The Computing in a Global Society course is an elective for both majors. Learning outcomes of the course include being able to explain the importance and relevance of globalization, in particular as it relates to computer science and software engineering. Other goals are to be able to communicate effectively with teams from other countries and cultures and to demonstrate effective work with these teams to complete a project.

D. Collaboration between Swedish and US Students

The collaboration started in 2005, and has evolved using an action research framework since then. This includes a constant iteration of plan, act and evaluate which has resulted in many improvements of the course as well as some changes not contributing to improvement.

The client of the student project is the county council in charge of health care in the Uppsala region of Sweden. They have provided the student projects with different open-ended and complex problems relevant for the use of IT in the healthcare sector. Some examples of problems have been to help the county council to prevent and recognize data intrusion problems related to the use of a common patient record. The majority of students had their major in computer science or IT, but some students had other majors such as mechanical engineering. Most students had studied for three or four years at the university.

E. Collaboration between Turkish and US Students

This collaboration started in spring 2009, and is currently in its 3rd offering. For each of the collaborations, student teams complete a software project for a non-profit international organization located in Turkey. The International Children's Centre has been a client for all collaborations, and UNICEF (Turkish National Committee) for one of the collaborations.

Students from the US visit Turkey twice during the semester, once at the beginning of the project and once at the end. Students meet with the client at least once during each visit, at the beginning to analyze the problem and present their proposal, and at the end of the project to present their completed project to the client.

Although the courses are not identical to each other, the client proposal and the software design and development process form the basis of the student collaboration. During the semester, students are monitored through weekly meetings and other activities, such as progress reports.

III. INTERNATIONAL COLLABORATION CONSIDERATIONS

This section describes identified management issues regarding the collaboration including relevant theoretical underpinnings.

A. Educational Setting Differences

Running international collaborations typically means a few challenges when it comes to dealing with the differences in educational setting. The collaboration could be set in a joint course, but institutions typically want to have their courses

defined according to their own standard. Different courses mean having to overcome differences in learning objectives. This doesn't mean that it is an objective to have the courses as similar as possible, but rather that the collaborators need to be aware of the differences and have strategies for dealing with them. The challenge is to turn the differences into advantages, or at least into something that does not jeopardize the collaboration.

Other differences to manage might be different course durations, contexts in their curriculum, and grading schemes. The difference in course duration could be that one cohort continues with their course after the other has finished, which in the US-SWE collaboration is solved by the American students enrolled agree to work to finish the project after their study period has ended. A similar issue with the course duration in the US-TUR collaboration was solved by redesigning the course. That the contexts for students in the collaboration are different can either be an issue for each student to cope with, or for the faculty to try to smooth out.

B. Cultural Issues and Communication

Cultural differences affect the project in many ways including the communication and work styles of the participants. Culture impacts people's interpretation situations and how they react to them [8]. Language differences are part of this; they are experienced to different degrees within each of the collaborations. The communication language for all projects was English. While all participants in the collaborations are proficient in English to varying degrees, some students find it difficult to communicate remotely in their non-native language. Non-verbal cues may be missed, and often lead to frustration and misunderstandings. One method to address this in the US-SWE collaboration was the introduction of an external expert in intercultural collaboration and communication starting in 2007. In the US-TUR collaboration, the same expert was part of the collaboration in 2011 and other speakers with experience in both cultures have also been invited. The work with intercultural competence has been elaborated in other publications; see for example [9, 10].

In the US-TUR collaboration, although there were cultural differences, more important were the observed interdisciplinary cultural differences within the team. The Turkish students have an IT focus with a view of instructional processes and have a tendency to focus on user and learning needs. In contrast, the US students being computer science majors have a more technical focus and expectation. The Turkish students often felt that there was not enough discussion of the interface and the design components, where the US students often felt that the time would be better spent starting the implementation and working on the interface design details at a later point in the project. Although students felt the impact of these differences, they were rarely, if ever, discussed among them. The issue was addressed in part by coaching the team members, and encouraging them to recognize the different strengths and act as leaders in their specialty areas.

Issues such as different semester schedules, break weeks and holidays are important considerations in the management of the project. Time changes, holidays, and school breaks, if

they are unexpected, might lead to missed deadlines and considerable frustration within the teams. One strategy used was the preparation of a common schedule that could be accessed by the students and instructors throughout the project. The schedule included holidays, break weeks and the different dates for daylight saving switches. This allows students (and instructors) to be aware of and plan in advance for any downtime in the project.

When working in globally distributed projects, the difference in time zones makes collaborating in real time difficult and increases the response time in getting feedback from teammates [11]. As described by Holmstrom et al. [12], 'despite flexible work hours and communication technologies that enable asynchronous communication, extensive delay in responses brings with it a feeling of "being behind" and "missing out" – even losing track of the overall work process'. In most local projects, students are able to access their teammates whenever necessary to ask a question or to get immediate feedback on any issue that comes up. With global projects, students do not have this immediateness of communication and the different time zones often create difficulties for the team as they require the students to plan and prepare in advance. One strategy is to provide guidelines to the students about email/communication etiquette such as the time frame for replying to messages, the importance of replying to messages, etc. Another way the issue was addressed was to establish regular (in this case, weekly) full team meetings. This has drawbacks as well because students often wait for these meetings to get the necessary feedback instead of arranging informal sub team meetings or sending messages as needed, leading to delays.

According to Smith and Blanck [13], 'an effective team depends on open, effective communication, which in turn depends on trust among members'. They suggest that if a team can get together for face-to-face interaction, they should do it at the beginning of the project where trust can be established while planning the project. During the collaborations the US students are required to visit the partner university at least once in the project. During the visit weeks students are encouraged to spend as much time together as possible to encourage team building. Especially at the beginning of the project the face-to-face meetings are very important and they help students to establish a social interaction, and makes communication throughout the project more efficient. In cases where all students have not visited the partner institution at the outset, it has been observed that there is little social interaction, and students have a difficult time initiating communication and bonding as a team [2, 5].

C. Client Selection

After examining many current instructional models, Merrill [14] underlines that the most effective learning products or environments are those that are problem-centered. Having an external client is one way to add work related aspects [5] to the collaboration. This will, in most cases, mean that the client is local to one of the collaborating sites. One issue with such a setting could be around language, since it might be that much information is only available in a language not master by the non-local site(s). This has been the case in the past and has

been addressed by the local students providing English summaries of all relevant information.

Another issue to have strategies for is the uneven access to the client. The local students can have face-to-face meetings with the client and other personnel in the client's organization. There need to be ways to share information obtained locally, which is the same issue irrespective of the location of the client and the organization even though it is more difficult to solve. The potential for a sense of unfairness is however a unique issue to deal with that is due to the locality. There is a definite danger that the motivational reason to include the client might turn into a de-motivational factor for the non-local students. It is thus important to provide opportunities for the non-local students to feel that they can contribute with something extra that is due to them being from another place. This could, for example, be to add internationalization aspects to the project. Having the client from another city or from a third country may help to decrease the possibility for de-motivation, however this decision would increase the complexity of the settings. An ideal client may be an international organization that has units in the cities of the collaborating universities.

One issue raised by interaction with real clients is that they have other obligations and consequently it can be difficult to get reasonable access to them. This particular aspect has been mitigated in the US-SWE case by use of a single, reliable client and requiring all students to work on different aspects of a single project.

A further potential issue with a real client is that some students may feel ethically unable to help certain clients, e.g. for political, religious, or competition reasons. Because of this, we have chosen to work with the public health sector, in the US-SWE collaboration. Similar considerations in the US-TUR collaboration lead to selection of an international non-profit organization with a focus on children's rights as client.

D. Student Assessment

There are different possibilities for how to grade the students, but it is likely that faculty from a remote site will have a say in how a student is graded.

A related issue is that students might have different grading schemes. This might cause disharmony between the student cohorts. As in the US-SWE collaboration, where the Swedish students were graded on a pass/fail scale, but the American students had a much finer grading scheme. There was a rubric for how credit was earned and how it resulted in grades on the American site. The issue that almost broke the collaboration was that much of the credit was earned based on how well a group did and that the American students feared that the Swedish students would not be motivated to contribute once they had passed the pass level (as the American students saw it). This was not seen as an issue on the Swedish side, since they would not pass the course if they didn't contribute throughout the whole collaboration. A surprise exercise at the end of the project, where the students were asked to pay each team member according to how they had contributed in the project, saved the collaboration. This was because even the American students paid the Swedish students better than they paid their fellow Americans. See [15] for more details. Similar

issues were experienced in the US-TUR collaboration, which underlines the importance of making the assessment criteria clear at the outset, for all participants in the project.

E. Student Motivation

To improve motivation, Morales [16] believes that learners' free-flowing expression and sharing ideas are encouraged in learning environments and creation of these environments is facilitated with constructivist instructional design. Principles for constructivist instructional design referred to here are described by Honebein [17] as seven items: (1) provide experience with the knowledge construction process, (2) provide experience in and appreciation for multiple perspectives, (3) embed learning in realistic and relevant contexts, (4) encourage ownership and voice in the learning process, (5) embed learning in social experience, (6) encourage the use of multiple modes of representation, (7) encourage self-awareness in the knowledge construction process. These seven principles can be observed in many aspects of the course designs and activities in both collaborations. For example, embedding learning in realistic and relevant contexts principle is supported by having real clients and projects, ownership and voice is encouraged by students' own determination of the topic/scope of the project, or encouraging self-awareness is supported by reflection assignments and meetings. It is also supported indirectly through explicitly discussing the Open-Ended Group Project pedagogy [1, 2] underpinning the courses, which aids in taking ownership of the learning process.

The underlying pedagogical approach is based on the concept of the Open-Ended Group Project (OEGP) that is designed to address the type of activities where a central concern is to balance the complexity of the problem with the multiplicity of possible approaches to its solution. An important aspect of the educational setting is that the project is placed in a real environment with a real client. This provides an authentic level of complexity and also is shown to increase student motivation [18].

F. Project Scaffolding

For a satisfying learning experience in open-ended global collaborative project cases, students are expected to acquire and use various capabilities. Considering the complexity and variety of competencies required, instructional scaffolding was chosen as one of the primary strategies. Scaffolding is defined as "a variety of methods that include a sequence that gradually reduces and removes supports of various kinds (fading) and a sequence that gradually increases the acceptable standards of performance (shaping)" [19]. Simons and Klein [20] refer to scaffolding as a valuable instructional tool to enhance student performance and they emphasize its important role in problem based learning (PBL).

From a scaffolding perspective, in both collaborations, the semester was divided into phases and some milestones were enforced. Early assignments, lectures and guest speakers were also organized during the initial phases of the course. As Greening [21] points out, PBL involves a slower startup which may be due to the development of important "hidden" skills, and that at this stage of the PBL, ensuring the existence of

adequate scaffolding is critical. Throughout the semester, including the initial phases, regular reflection assignments or meetings were used to highlight students' own responsibilities and to improve the process for the following phases.

The use of scaffolding mechanisms may differ due to various settings such as students' schedules, class sizes, and resources such as the number of mentors. Such differences in scaffolding may include the pace of weekly progress meetings, the amount of resources from the previous experiences or use of structured templates. One example of scaffolding was the use of mentors. Subgroups had a faculty assigned as mentor and project leaders had an external mentor, which differ according to number of mentors and class size. Another example from the US-TUR collaboration was the use of recommended templates for the initial phases of software development. In such cases, scaffolding using templates helps a lot in order to save time for the implementation phase.

To enhance the learning, it is important to keep in mind to reduce the level of scaffolding during the process was important. For example, while making interviews with the clients, depending on readiness of the students, the mentors may prefer attending to the first or second interviews but it is also important to let students continue interviews independently later on.

G. Collaborative Technologies

Collaboration and communication tools are critical components of such global intercultural project courses [22]. Most of the communication and collaborative work is handled through technologies. General uses of technology in both collaborations (US-SWE and US-TUR) can be categorized into five groups: 1. The use of a course management system as the official platform of the course and the collaborative project (e.g. Moodle, TeamLabs), 2. Synchronous communication tools (e.g. Chat, Video conference room, Skype, Google+ Hangout) 3. Asynchronous communication tools (e.g. Moodle Forums, Facebook, e-mail) 4. Document sharing (e.g. SVN, dropbox) 5. Collaborative writing (e.g. Moodle wiki, Google docs, Trello).

As a course web page or virtual classes created on institutional course management systems (like Moodle), an official platform is provided to the students. Instructors' weekly meetings are organized and handled by using video conference rooms or tools like Skype. In addition to these, students generally decided the appropriate technology for their communication and collaboration during the first face to face meeting week. Although the official platforms and tools provide many opportunities for communication and collaboration, it is observed that students may prefer alternative tools various reasons such as: a) to have an opportunity for informal communication (since instructors are not there), b) student habits and their regular use of popular tools like Facebook, MSN Messenger, c) the tool has a user friendly interface and fun components in it, and d) the tool has specific features appropriate for the tasks (not available or not easy to use in the course management system).

From a management point of view it is critical to consider the needs and motivations behind the selection of technology.

In addition, it is also important to have a set of technologies, which can be offered at different phases of the project. For example, technology to support the generation of ideas and to build consensus may be more critical at the beginning of the project but technology to support individual work, workflow management and document sharing may come later [23].

H. End-product and Learning Process

Deciding on the type and scope of the end-product is critical. With a strong motivation to satisfy the client, there is a potential to focus more on the end-product than on the learning process. This is known as the process vs. product dilemma.

The types of outputs for the collaborations has an impact on the decision making process of the teams. In the US-SWE collaboration, the final product is a report and presentation, whereas the output of the US-TUR collaboration is a software system with user guides and a presentation. This difference can be critical because of the time and resource limitations. For example in the case of the report, students can be more free and objective when exploring and recommending solutions to the client, but in the case of developing a software they naturally limit their solutions, consider their skills-sets and knowledge in order to develop the software product before the end of the semester.

In both collaborations, while there is a strong focus on the learning process and development of competencies, the end-products are also used to grade and motivate students and to fulfill the clients' expectations. The challenge will be to maintain a balance throughout the semester.

IV. DISCUSSIONS AND RECOMMENDATIONS

From a management perspective, similarities and differences between the collaborations can provide a base to discuss various issues and may help to understand the dynamics behind the global collaborative project courses.

The two collaborations shared many similarities. In both, the client was the same for multiple semesters. This simplifies the collaboration as both the client and the faculty know their roles and expectations. With one exception, all collaborations had one project (that may or may not be divided into subprojects) and one client. For each project, the students from the US visit the partner site twice, in the beginning and towards the end of the project. In addition, they are run as separate courses, where each site maintains their own course syllabus; however the focus of the collaborations is the same. Both collaborations take a constructivist view and use the Open-Ended Group Project approach. Scaffolding is used when appropriate, and depending on the project attributes (size, product, number of students, etc.).

The effects of major differences between the two collaborations appear in the course design, during the implementation period and through the outcomes. In the US-SWE collaboration students from both sites are engineering students, however in the US-TUR collaboration, the Turkish students have computer science education focus at the faculty of education. This brings out interdisciplinary issues in addition to intercultural issues. Although the emphasis on process and

product is similar in terms of the course implementation, they are different from client's point of view. While a presentation and a report are targeted in US-SWE collaboration, a software product is targeted in US-TUR collaboration. In US-SWE collaboration the team size is typically 20 or more which results in a higher number of subgroups and their mentors, however in US-TUR collaboration, team size is 12 or less with no external mentors guiding the students.

The complexity of global collaborative project courses both for students and teachers may change a lot depending on some initial critical decisions. As an example decisions about "offering a joint course or not" or "having one project topic from one client for the whole team or having a few different projects from different clients" may affect many aspects of the course and implementation period. Another critical issue, which is directly related to many other issues like motivation, topic or client selection, is building trust and understanding among faculty, students and client. In addition to these, better planning for the visit weeks and/or the initial phases and having mechanisms to build consensus around expectations is worth seriously considering because of huge impact they may have.

There are a number of important considerations when planning for a successful collaboration. Details such as holidays, breaks, time differences, scheduled meeting times for the visit week preparation can have an impact on the success of the project. It is important that collaborators pay attention to the details, however to what degree the faculty or students are responsible for the details leads back to the discussion of whether to manage or not manage. As discussed, care must be taken to choose a project and client that is engaging for all cohorts. The client plays a key role; therefore care should be taken when selecting the client. Once selected, collaborators should have a clear idea of what is expected of the client, and the client should be informed of these expectations. Finally, while students will establish various tools for informal communication, it is important to establish a formal communication channel for faculty, students and in some cases, clients. Because the cohorts may have different preferences when it comes to collaboration tools, it may take time and effort to encourage effective communication. It may be useful to allow the student group to select the formal communication tool; however it may be difficult to achieve consensus.

Setting the level of scaffolding depends on the complexity of the educational settings and the project expected by the client. Especially when the complexity of the project is high and when there is a gap between the students' profiles and the requirements of the client, more scaffolding would be needed. To increase the learning experience satisfaction in terms of intercultural issues, project life-cycle management issues or documentary issues can be supported through working in phases or using well defined templates. If these issues and relevant competencies are considered to be the part of the course goal, deciding what to manage or support would be critical. Sharing previous years' experience and expertise of external speakers are always suggested.

Because of the challenges that communication and cultural issues bring to the collaboration, it is important that there is an

agreement on the expectations of the course between and among all participants (faculty, students and clients). This helps to establish trust and understanding from the beginning of the project.

Establishing early informal communication among the students is difficult but it is important to the success of the project and the satisfaction of the participants. When developing a collaboration, an important consideration is how to establish informal communication, and how large of a role faculty should play in this. The best way to establish this communication early is with face-to-face meetings at the beginning of the project. This meeting establishes trust and understanding among the faculty and students and helps when communication is remote and the project becomes complex.

To manage or not to manage represents a common dilemma in global collaborative project courses. For a satisfying outcome and to fulfill the expectations of the client, students are expected to perform well in various areas. The expectation of a high number of competencies, limited resources, and the challenge of a real life project forces stakeholders to manage and guide the teams efficiently. However, for a satisfying learning experience, it is meaningful to have more tolerance for failure and to encourage students' learning through experience or through interaction with other cultures. This approach enforces stakeholders to focus on learning experience and manage the production process loosely, which may easily result in decreasing quality of the end-product prepared for the client. Managers should also consider that even faculty who are teaching these courses for many years improve similar expected competencies through experience. When considering undertaking similar courses, as teachers or managers deciding whether to manage or not to manage such courses, what to manage and what not to manage, or what level of management to apply are initial questions that should be answered.

V. CONCLUSION

International collaborations are challenging for both students and faculty alike. However it is a rewarding experience that improves with each offering.

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Work in Progress: On Entrance Test Criteria for CS and IT UG Programs

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Abstract—Indian universities broadly follow an entrance process for undergraduate engineering process in which physics, chemistry and mathematics based questions are asked. Either the individual scores or some combination of these scores is used to set the admission criterion for different engineering streams. However, it has not been analyzed whether this is a good predictor of undergraduate performance or not, especially in Indian context. The broad goal of this research is to understand the relationship between entrance criterion and undergraduate Computer Science/Information Technology performance. The analysis includes data collected from the students who appeared in the entrance exams and took admission in IIIT-Delhi in between 2008 to 2010. The scores obtained in entrance exams and cumulative grade point average earned during the first year of their studies are analyzed. Preliminary analysis suggests that for computer science undergraduate studies, mathematics or numerical understanding is an important aspect. Further, logic and aptitude based tests are better correlated in context of computer science education.

I. INTRODUCTION

In India, for decades, it has been implicitly assumed that Physics, Chemistry, Maths (PCM) are the subjects that should be used for testing student's knowledge in engineering entrance tests of different universities including IITs. However, there are two fundamental questions: (1) is this assumption valid, and (2) do these tests form a good entrance test particularly for computer science? Many countries including USA admit students based on their performance in aptitude and thinking ability tests. Since the curriculum of information technology (IT) or Computer Science (CS) programs is primarily based on aptitude, logic, and computing, the insistence on PCM for entrance in Indian universities is more anomalous for these courses.

In United States, several studies are going on to understand the impact of several admission criteria such as objective and subjective in undergraduate engineering [1], [2], [3], [4]. Many of them attempt to understand the high school grade and college performance as well as finding relationship with entrance exams such as SAT. However, to the best of our knowledge, there is a lack of such analysis in Indian context. Indian context is different than United States model, primarily in terms of admission process. As mentioned previously, Indian universities conduct PCM based engineering entrance exams and successful candidates are selected for different engineering streams including computer science. However, to the best of our knowledge, there is a lack of such analysis in the Indian context; which is different than United States model primarily

in terms of the admission process. To understand it better, in this research, we have analyzed how strongly the performance in these entrance tests predicts the performance during their undergraduate studies. We also study the effect of logic and numerical based entrance exam with the undergraduate study performance.

II. RESEARCH METHODS

To perform this research, following five sets of data are collected from three different batches (year 2008 - 2010).

- 1) Performance in class XII exams, particularly in Physics, Chemistry and Maths (PCM XII),
- 2) Performance in the PCM based all-India entrance test for engineering colleges (PCM Test),
- 3) Performance in aptitude and logic based entrance tests which is specifically conducted in IIIT-Delhi (Logic Test),
- 4) Prior experience/knowledge in computer programming - it is divided into three levels, "have never written, compiled and executed a program", "have written, compiled and executed small programs, have written, compiled", and "executed larger programs in C/C++/Java".
- 5) Student's Cumulative Grade Point Average (CGPA) after second semester of their undergraduate education. The courses they have taken are Discrete Mathematics, Linear Algebra, Introduction to Programming, Basic Electronic Circuits, Data Structures and Algorithms, Digital Circuits, Theory of Computation, and System Management.

To understand if there is any relation between the performance of students in different entrance tests and their performance during undergraduate studies, four different analysis have been performed: (1) are class XII marks good predictors of student's performance, (2) are PCM based entrance tests good predictors of student's performance, (3) are aptitude and logic based entrance tests good predictors of student's performance, and (4) does prior experience in programming play any role in student's performance in Computer Science?

Statistical analysis is performed to analyze these different sets of data along with their performance in the first year of undergraduate studies in Computer Science. The results are reported in Tables I, II, III. Some key observations are as follows.

- Table III shows that the rank correlation of a major all-India test for engineering (based on PCM) with perfor-

TABLE I
ANALYZING THE SEMESTER PERFORMANCE OF STUDENTS WITH THEIR PRIOR PROGRAMMING EXPERIENCE.

| | | Have never written, compiled, and executed a program in C/C++/Java | Have written, compiled, and executed a few small programs (that fit in a screen) in C/C++/Java | Have written, compiled, and executed larger programs in C/C++/Java |
|------------|----------------|--|--|--|
| 2008 Batch | All students | 15.1% | 41.5% | 43.4% |
| | Above 8.0 CGPA | 12.5% | 20.8% | 66.7% |
| 2009 Batch | All students | 23.3% | 37.2% | 39.5 % |
| | Above 8.0 CGPA | 10.3% | 17.2% | 72.4% |

TABLE II
CORRELATION ANALYSIS OF STUDENTS ADMITTED IN IIIT-DELHI.

| Batch | GPA Condition | GPA vs Entrance Test | GPA vs PCM | PCM vs Entrance Test |
|-------|---------------|----------------------|------------|----------------------|
| 2008 | All | 0.45 | 0.51 | 0.4 |
| | Above 8 | 0.35 | 0.17 | 0.23 |
| | Below 6 | 0.005 | 0.39 | 0.33 |
| 2009 | All | 0.53 | 0.38 | 0.34 |
| | Above 8 | 0.45 | 0.07 | 0.3 |
| | Below 6 | 0.6 | 0.13 | 0.2 |
| 2010 | All | 0.46 | 0.5 | 0.4 |
| | Above 8 | 0.15 | 0.07 | -0.11 |
| | Below 6 | 0.55 | 0.41 | 0.65 |

mance in the first two semesters of undergraduate studies is extremely weak. This implies that the performance in this entrance exam had no direct predictive value for performance in the computer science undergraduate program.

- Further, it is also observed that the students who performed better in class XII also performed better in their first year of undergraduate computer science courses.
- The performance in aptitude and logic based entrance test was better correlated with students performance in the first year of undergraduate program. In another interesting observation, we found that all the top performing students (in their first year) had computing background in their class XII or before. As shown in Table I, more than 66% students had written, compiled and executed larger program in C/C++/Java.
- Detailed analysis of grades obtained in individual subjects further validated our hypothesis that the performance in Mathematics has high correlations with students performance in the undergraduate program. Therefore, it is our assertion that there is a need to understand the criterion for undergraduate admission into engineering programs, especially in the computer science program.
- For some batches, CGPA and numericals test have high R^2 values. Further, the marks obtained in XII maths and numerical section of IIIT-D entrance are correlated.

Overall, the analysis suggests that for computer science education, entrance test criteria may be based on maths, aptitude and logic, and performance in class XII.

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TABLE III
CORRELATION MATRIX FOR ALL STUDENTS WHO APPEARED FOR IIIT-DELHI ENTRANCE TEST.

| Correlation | 2008 | 2009 | 2010 |
|------------------------|------|------|------|
| AIEEE vs XII (PCM) | 0.59 | 0.2 | 0.37 |
| XII(PCM) vs IIIT Marks | 0.41 | 0.22 | 0.26 |
| IIIT Marks vs AIEEE | 0.42 | 0.24 | 0.49 |

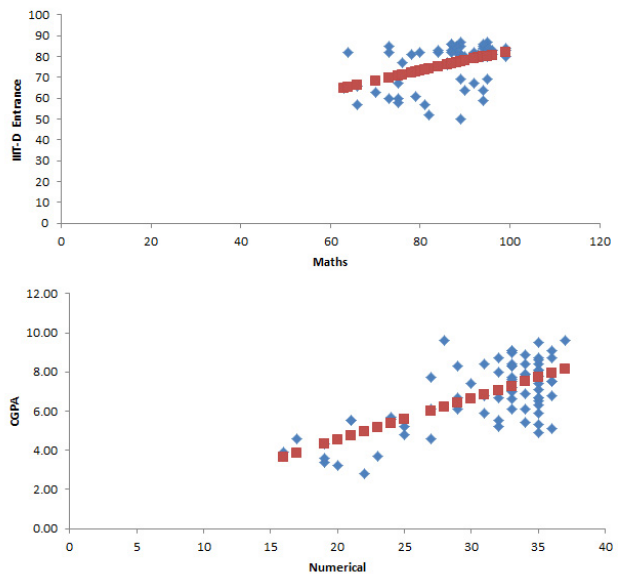


Fig. 1. Regression plots for (a) maths with IIITD entrance marks and (b) marks obtained in numerical section of the IIITD entrance with students CGPA in the semester.

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Work in Progress: International Teacher Development: Engineering into the Classroom in the Dominican Republic

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Abstract— The IEEE Teacher In Service Program (TISP) enables teachers to effectively introduce engineering into the K-12 environment. The program consists of training for engineers to hold in-service workshops for teachers who then take hands-on engineering projects into their classroom. Teachers are provided with lesson plans (available in English and Spanish), tied to educational standards in the United States, all accessible on the website tryengineering.org. Each activity is designed to be inexpensive (often less than \$10 for a classroom). This program has been successfully implemented throughout the United States for over ten years. Additionally, workshops have been implemented in other countries, including Malaysia, South Africa and Chile. The IEEE teamed with electrical engineering and engineering education faculty and students from Ohio Northern University to implement the TISP activities in a series of schools in impoverished regions in the Dominican Republic. This project allows the team to visit five schools and directly impact over 2000 students. The team will offer the initial workshops in May 2012, then visit the teachers to interview and conduct focus groups to assess the effectiveness of the workshops. A final assessment plan will be developed that will assist in assessment of other international offerings. This work-in-progress should be of interest to anyone working with international engineering education, especially within impoverished or developing countries.

Keywords; engineering education, IEEE, international, teacher workshops

I. INTRODUCTION

A. IEEE Teacher In Service Program

The IEEE Teacher In Service Program (TISP) has been in existence for over ten years. The aim of the program is to use IEEE members (mainly electrical and computer engineers) to hold training sessions for teachers during in-service times, demonstrating the use of hands-on activities to introduce or enhance engineering concepts in the K-12 classroom [1]. Most of the training opportunities have been held within the United States, but some have been held internationally. For example, recent efforts using IEEE professionals in the classroom in Hong Kong successfully allowed the introduction of engineering principles into rural schools [2]. Lesson plans are available for download and are translated into 8 languages, including Spanish.

Surveys assessing participants' satisfaction after these workshops show great promise; for example, surveys of a large implementation of TISP activities for a school district in central Indiana showed teachers agreed or strongly agreed that the activities added to their knowledge base, and nearly 90% claimed that they would implement the activities in their classrooms [3].

B. Solid Rock International in the Dominican Republic

Solid Rock International [4] is a 501c3, not-for-profit organization whom Ohio Northern University (ONU) has partnered with in a number of initiatives, including medical, education and engineering projects. They operate exclusively in the Dominican with a mission to holistically serve the poor in the Dominican Republic by focusing on all aspects of health. Solid Rock operates six schools in the Dominican, each highly sought after given the state of public education. Most of these schools are within an hour of each other in the western half of the Dominican. They include:

- Two schools in San Juan de la Maguana (San Juan) including CCED and Lucille Rupp (preschool – high school)
- Elias Piña (preschool – grade 8)
- El Cercado (grades K-4)
- El Rosario (grades K-8)
- Santo Domingo (K-12, 3-4 hours from San Juan).

The largest school, CCED in San Juan, is a complete K-12 and vocational facility with approximately 90 teachers and 2,000 students. Workshops were offered exclusively through Solid Rock schools; the implementation methodology to offer workshops in public schools is uncertain at this time.

II. INITIAL IMPLEMENTATION

A team of faculty from engineering, education and communication will accompany a team of eight engineering students, including two majoring in Engineering Education [5] to conduct a series of three workshops in the Dominican in May 2012. The team met and reviewed lesson plans available from tryengineering.org and narrowed the possible projects to be implemented to those for which materials may be obtained by local teachers. Planned lessons include:

- *Rotational equilibrium*: students calculate the balancing point of a stick with a series of distributed weights
- *Build a Robot Arm*: students use materials such as cardboard, paper clips, tape and string to design a robot arm that can transport a water bottle
- *Assembly Line*: Students design a manufacturing line to build a small project efficiently.

The team will purchase materials to implement any of the selected lessons and leave these with the schools; however, the activities must use materials that may be obtained if they are to be sustainable.

ONU and IEEE will attempt to hold a meeting of engineers who are members of IEEE from the Dominican Republic, and will attempt to engage these members in the teacher training sessions. The model where engineers are trained, then engage the teachers in training, is typical and preferred. There are fewer than 100 IEEE members in the Dominican, and most are assumed to be from Santo Domingo (3-4 hours from San Juan).

Schools will not be in session during these workshops. Workshops are planned at three locations. All teachers from each school are invited, and most are expected to participate since teachers will be offered lunch and a small stipend (500 pesos) for their participation. This is modeled after similar workshops held in the U.S. The first (CCED School in San Juan) will involve 90 teachers, seven translators and the entire team. The following two workshops (Elias Piña and El Cercado) will involve about 15 teachers with a smaller cohort of translators. The team will lead discussion on how the activities can be implemented in any classroom, and how they relate to math, science or engineering concepts. Each teacher will be surveyed and will be given a set of lesson plans for the next school year.

III. ASSESSMENT

A. Initial assessment

Initial assessment of the activities will follow a typical process: teachers and other participants will be surveyed for their appreciation of and plans to implement the activities, and how they see each activity supporting their classroom instruction. Questions on the teachers' appreciation of engineering and their perceptions of student understanding of engineering will be included.

As the workshops are underway, the team will continue to develop an assessment plan for follow up visits in November and May 2013. This round of assessment will be a mixed methods approach. We will collect quantitative data on number of students, ages and specific activities implemented at each grade level. We plan to interview teachers and a selection of students across different grade levels. Student interview data will be interpreted and "chunked" to investigate common themes, investigating instances where an appreciation of math, science or engineering concepts seems evident. Teacher interview data will be assessed to look for explanations of improvements in their perceptions of student performance. Principals and administrators familiar with the activities will be

interviewed to assess their perception of teacher "buy-in". Finally, any differences between schools/locations will be explored.

At the time of the initial assessment (expected in November 2012), additional workshops are planned for CCED (the largest school) and at least one additional site (most likely Rosario due to its proximity).

The research questions to be addressed at this assessment point include:

- Which activities were successfully implemented, in which grades and at which schools?
- Is there evidence of improvements in student performance in math, science or topics dealing with technology/engineering?
- Is there evidence of any change in teacher or student appreciation of engineering?

It is anticipated that our return visit will serve two purposes: assessment and emphasis that we intend these activities as a sustainable means to address math and science in the curriculum rather than a one-time activity. Americans serving in the Dominican over a long term have agreed that a return visit is the most applicable way to demonstrate this concept.

B. Final assessment

The assessment will be repeated toward the end of the 2012-2013 school year, with further quantitative and qualitative assessment of the effectiveness of the activities. A visit is planned in May 2013. Initial assessment results of the additional school (Rosario) will be compared to initial results from the initial implementation.

This visit will also allow the team to meet with teachers to further emphasize that these activities should be incorporated into the curriculum each year, and offer our assistance via email.

ACKNOWLEDGMENT

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Student Reflections on Collaborative Technology in a Globally Distributed Student Project

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Abstract— Collaborative Technology (CT) plays an important role in overcoming the challenges of globally distributed projects. It enables collaboration, but the specific choice of technology also imposes constraints on how projects are conducted. Over the past decade, we have engaged in an action research programme to develop an Open-Ended Group Project situated in an educational framework in which international collaboration, including interaction with a real world client, is an essential component. This paper investigates the manner in which students reflected on their patterns of CT use within the collaborative setting. In general, these reflections were found to be superficial and descriptive, exhibiting a reductive view of CT as a set of technological features, which acted as a neutral medium for communication and participation. One consequence of this was a lack of awareness of the ways in which the technology influenced the behaviour of individual students or the collaborative nature of the group. We explore some potential causes for this and reflect on some difficulties faced by the students. These have important pedagogical implications for courses in which the learning objectives include the development of suitable competencies for working in a global collaborative environment.

Keywords—*reflections; collaborative technology; open-ended group projects; global collaboration; scaffolding.*

I. INTRODUCTION

The aim of this paper is to investigate the ways in which students use collaborative technology (CT) in the context of a globally distributed group project. By CT, we mean those electronic technologies that are designed to enhance communication and cooperation over long distances. We seek to address the problem of whether the use of CT, which is essential given the geographically separated context, affects metacognitive behaviour, such as the ability of students to reflect on their own patterns of use.

Information technology now pervades most social, academic and professional environments and its availability is taken for granted across much of the world. Advances in technology facilitate communication in almost all areas of life and allow geographically separated individuals to work together across multiple time zones. From an educational perspective, this has led to a requirement for students from a wide range of disciplines, but especially those associated with science and engineering, to be proficient in CT and be able to apply this technology to enhance collaboration in teams that often work on globally distributed projects.

The experience gained by working on projects such as these can be seen as part of the relatively broad concept of digital

literacy which is now central to almost every graduate position in which university students find employment, and is crucial for effective use of CT for international collaboration. It is, therefore, an essential learning objective that students become capable of examining, criticizing and evaluating the potential benefits and consequences of CTs. Conversely, ascertaining the views and reactions of students to this technology is an important input for staff engaged in the creation of effective learning environments.

The experience gained by working on projects such as these can be seen as part of the relatively broad concept of digital literacy which is now central to almost every graduate position in which university students find employment, and is an absolute necessity for effective use of ICT for international collaboration. It is, therefore, an essential learning objective that students become capable of examining, criticizing and evaluating the potential benefits and consequences of ICTs. Conversely, ascertaining the views and reactions of students to ICT is an important input for staff engaged in the creation of effective learning environments.

One such environment, which seeks to enhance a range of professional competencies, including digital literacy and team-working skills, is a semester-long collaboration between Computer Science students at Rose-Hulman Institute of Technology in USA and IT engineering students at Uppsala University in Sweden. This learning environment is based on the Open-Ended Group Project (OEGP) concept [1, 2] in which the students gather and expand knowledge about a complex real-world issue in the healthcare domain on behalf of an external client. Close and genuine collaboration is essential for the success of this project and use of CT is a necessary component in achieving this due to the geographical distance between the two cohorts. On one level, this view is well appreciated by the students. One of them depicts the importance of CT thus:

"I don't think this project would exist without the communication tools available to us".

However, it is interesting to look more closely and ask about the perceptions students have concerning the type of group interaction that result from the adoption and use of collaborative technologies. One issue is the way in which CT, while enabling long-distance communication, still requires, for effective use, adherence to certain social protocols. For example, in order for a team to be successful, participants need to develop positive dispositions about issues such as trust, and this means finding some way of establishing mutual knowledge

in a distributed setting. These types of issues are subtler than mere appreciation of technological benefits, but are potentially more important for the successful outcome of group projects.

Methods of global communication have undoubtedly become both more sophisticated and easier to use since the collaboration first started in 2005. While there is an ongoing need to maintain and upgrade technology, this process provides new opportunities to study the way in which students interact with different tools. One of these changes occurred during the 2011 instance when Swedish students were given access to a high tech communication room. This provided data on a variety of issues concerning the adoption of specific collaborative technologies. These have been reported elsewhere [3] but one result has been a greater understanding of the multifaceted ways in which students perceive communications technology as a collaborative tool.

Data collection for this study used two assessment exercises, the first focussing on student perceptions of cultural difference and the second on their use of technology. These were submitted by the students in the course of their academic work and were supplemented by a voluntary survey regarding the use of collaborative technologies. While the first set of assignments on culture showed a significant depth of reflection, the second set about technology use showed a remarkable lack of reflective content, quite puzzling given the high level of technical proficiency displayed by the students.

The organisation of the paper is as follows. We first present the local setting to provide the reader with an understanding of the context of the study. This is followed by a general theoretical framework relevant for a discussion of the unexpectedly low level of student reflection on the value of CTs. We propose possible reasons to explain this lack of deep reflection and comment on some of the observed difficulties faced by students conducting group projects in this kind of distributed environment. Finally, we suggest possible ways in which this problem may be overcome.

II. BACKGROUND

A. The Student Collaboration

The context for this study is a collaboration between students at Uppsala University, Sweden, taking the IT in Society course and students at Rose-Hulman Institute of Technology, USA, taking the Computing in a Global Society course, where the two cohorts are almost 7000 km and six time zones apart. The educational setting, as well as different operational aspects of the project, have been described elsewhere [2, 4, 5, 6, 7, 8], but a summary is given here to provide the reader with a short review.

The main aim of the exercise is to develop those professional competencies that are essential for working in a global, collaborative environment. The underlying pedagogical approach is based on the concept of an Open-Ended Group Project (OEGP) which is designed to address the type of activities where a central concern is to balance the complexity of the problem with the multiplicity of possible approaches to its solution. An important aspect of the educational setting is that the project is placed in a real environment with a real

client. This provides an authentic level of complexity that can be shown to increase student motivation [9].

One issue raised by interaction with real clients is that they have other obligations and consequently it can be difficult to gain reasonable access to them. This particular aspect has been mitigated by use of a single, reliable client and requiring all students to work on different aspects of a single project. From an OEGP perspective, this solution has the added benefit that it adds to the complexity of the task leading to increased “open-endedness”. A further potential issue with a real client is that some students may feel ethically unable to help certain clients, e.g. for political, religious, or competition reasons. Because of this, we have chosen to work with the public health sector, i.e. the Uppsala County Council and the associated academic hospital, which was perceived very positively by participants.

Another factor, relevant to this paper, is the high level of freedom given to students to decide upon the specific communications technology that suited their task. While there were some constraints imposed by staff, e.g. some form of collaboration platform should be used and that there should be weekly synchronous meetings that should preferably include video, the choice of CT and how it was used was chosen by the students. This aspect has varied over the years and for this cohort, the team leaders also required the members to keep track of the time they spent on the project.

The students participating in the course in 2011 were all male, aged between 20 and 37. The American cohort varied between the ages of 20 and 22 years, and all but one member of the Swedish cohort was in the 21 to 24 year range. The majority of students had their major in computer science or information technology, but some students were pursuing other technical majors (e.g. mechanical engineering). This year there were ten Swedish students and eight American students. Most students had studied for three or four years at the university.

B. Critical Thinking and the Role of Reflection

An important part of the educational setting is the use of assignments where the students are asked to reflect on a relevant issue. There are both practical and pedagogical reasons for this approach. An example of the former was to alleviate an observed tendency to blame slow progress or failure on others, especially those members of the group from the other institution. We wanted to help the students see their own part in any problematic situation by analysing their role and reflecting on what they themselves actually did to contribute to progress. From a pedagogical perspective, the development of those professional competencies described in the course learning objectives is closely linked to metacognitive ability. As pointed out by Fincher, Petre, and Clark [10], “*Reflection on experience underpins the process of successful learning and is essential to the success of education.*” Using reflection as an educational tool is also supported by ideas presented by Schön [11], where he characterises effectiveness in professional work as the product of an ongoing process of reflective practice which involves self monitoring, continual improvement and action cycles (plan, act, observe, reflect).

The modern emphasis on critical thinking can be traced to Dewey’s focus on reflective thinking [12]. His characterization

of these thought processes as active, persistent and carefully considered, has formed the foundation of many later attempts to distinguish critical thinking from other modes of cognition, and laid the basis for investigation of the mechanisms by which they are promoted. Moreover, the development of a specific competence in critical thinking has come to be seen as one of the primary goals of higher education [13] and, indeed, one that has been increasingly promoted on social and economic grounds [14, 15]. Unfortunately, it is also reported, e.g. [16] that the development of these competencies by students is not a guaranteed outcome of tertiary education and this has led to the inclusion of thinking skills as a specified graduate attribute in many university programmes.

Over the past two decades, there have been significant attempts to classify the factors that lead to good critical thinking. A report by the American Philosophical Association [17] suggested that the subject could be conceptualized in two dimensions by the requisite cognitive (and metacognitive) skills, and the affective dispositions that allow the appropriate skills to be used. The precise specification of the cognitive abilities themselves, including the definition of terms, often varies depending on the details of the research study but it includes capacities for interpretation, analysis, evaluation, inference, explanation and self-regulation. These abilities are often translated into a cluster of competencies concerning the identification and analysis of pertinent issues and assumptions in an argument, recognition of important relationships, the ability to make correct inferences and deduce conclusions from information or data, and to interpret whether conclusions are warranted on the basis of data [16]. Proficiency in the use of a critical thinking skill and the disposition to exercise it are clearly interdependent and, as a result, developing an aptitude in this area depends upon affective factors. Descriptions of critical thinking dispositions mirror those found more generally when investigating positive attitudes to learning, e.g. Claxton's 'four Rs': resilience, resourcefulness, reflectiveness and reciprocity [18]. Importantly, the disposition of reflectiveness finds counterparts in a cluster of concepts around metacognition, self-regulation, self-direction, and self-efficacy [19], which are exhibited at the highest levels of critical thinking.

Barnett [14] extended this conceptual base to connect elements of cognition, metacognition and praxis in the notion of 'critical being'. *"Critical persons are more than just critical thinkers. They are able critically to engage with the world and with themselves as well as with knowledge."* The goal of the learner, therefore, becomes not only to analyse and evaluate information, but also to develop powers of critical self-reflection, which then allows the individual to take appropriate action. Here again, the process of reflection, specifically in the form of reflective practice, such as that described by Schön, acts as a fundamental link between the acquisition of critical thinking competencies and the metacognitive goal of learning self-regulation. Assessment of reflection on performance of assigned tasks then provides student and faculty with one possible mechanism for monitoring the development of competence in critical thinking, and for the self-regulation of engagement in subsequent learning activities.

Barnett also highlighted the need to consider the collaborative nature of skill development in shared activities, and in the type of learning that occurs within a community of practitioners. This analysis connects with the work of Vygotsky, his theory of the Zone of Proximal Development [20], the processes by which social interactions fundamentally shape and transform the way a learner acquires and assimilates knowledge, and so to the concept of scaffolding [21] by which a teacher or peer provides interactional support for learning. As a form of scaffolding for the development of critical thinking skills, reflective activity allows knowledge to be externalized by expressing concepts either verbally or in written form. While this kind of articulation is crucial to the organization of a student's knowledge, according to Vygotsky, the act of choosing words to represent thoughts also allows the further consideration and deliberation on the ideas being expressed. Written expression of a student's reflective comments should therefore promote critical thinking by providing students with an opportunity to articulate and refine their conceptual understanding of the learning process. As Flower [22] put it: *'writers do not simply express thought but transform it in certain complex but describable ways for the benefit of a reader'*.

Various forms of reflective activity have been used in the course over the years. While a final summative reflection followed by an individual meeting with the academic supervisor has always played a part of the assessment process, short written reflections and a varied number of individual meetings were also used. These reflections provide the staff with specific information and ideas for the development of the learning environment. In addition, they generate insights into how the educational setting functions to develop and enhance the desired professional competencies. In the 2011 instance, there were three such assignments.

III. METHOD

The data collection in this study is based on the results of two written assignments and a survey. The first assignment focused on student perceptions of cultural differences within the group, while the second sought reflections on the positive and negative aspects of different forms of collaborative technology use. This material was submitted by the students as part of their academic work. The survey concerning the use of CT was done half way through the course, shortly after the second assignment.

In both assignments, assessment was accomplished using a categorization framework based on the work of Hatton and Smith [23]. This scheme classifies writing according to the depth of reflective analysis, from an initial stage of non-reflective "descriptive writing", through basic "descriptive reflection" to the more sophisticated "dialogic reflection" and, at the deepest level, "critical reflection". This last stage is demonstrated by the elaboration of reasons for personal learning decisions that take into account a mature understanding of the psychological and pedagogical factors affecting the learning process. As such, it requires a high degree of metacognitive proficiency. The levels in this framework can be related to other classification schemes for reflective writing such as that of Moon [24], as well as those

which attempt explicitly to measure progression in critical thinking, such as that of Greenlaw and DeLoach [25].

Identification of reflective markers in student writing is often problematic and normalisation of the assessment criteria across the different supervising faculty was needed to provide a fair assessment of the assignments. This was achieved by detailed discussion, which correlated the different views on evidence identifying the different levels in the Hatton-Smith framework.

IV. RESULTS AND DISCUSSION

The first assignment, on student perceptions of issues concerning cultural differences between group members, resulted in submissions that showed a significant depth of reflection (level 3: dialogic, and level 4: critical reflection, in the Hatton-Smith framework). This differed sharply from performance on the second assignment. In this case, students were provided with a description of the Hatton-Smith framework and were explicitly asked to write reflective accounts of their CT use that specifically addressed the factors characterising higher level reflection. The results from this second exercise demonstrated a much lower level of reflective content (Hatton-Smith levels 1 and 2), with hardly any submitted work attaining the third level. This poor level of reflection in the second student assignment was somewhat unexpected given the good performance in the first assessment.

The high level of technical proficiency displayed by the students throughout the project also suggested initially that the second assignment would prove less problematic. The students were, in general, quick to grasp the possibilities and limitations of each collaborative tool they encountered, and classified them in terms of stability, user-friendliness, and their perceived potential to further the ends of the project. Critically however, it was rare for a student to show an explicit awareness of how the various tools, and the communicative contexts that they supplied, influenced the project process itself. One student observed that the *"quality of communication is mainly evident in the fact the situation does not seem personal so you do not feel connected with anyone else"*, which caused *"a lack of responsibility to the team"*. Yet, the same student also claimed that the communication tools *"allowed the group to work well together"*, and helped to *"build a better understanding of each person as a colleague and a friend"*. This seeming contradiction may mirror a gap between the general, team level, whose formal meetings sometimes suffered from a combination of poor communication and insufficient organization, and the level of work groups, whose members seem to have communicated informally and more efficiently about their more narrow areas of responsibility. A higher degree of reflection on the interrelationship between communication structures and project requirement might, if acted upon, have improved team building, to the benefit of the project.

A. Potential Causes of the Low Level of Reflection

A number of possible reasons for the observed results can be proposed. One suggestion is that information technology has become an almost invisible tool [26, 27, 28], and consequently

it is possible that the cohort was so accustomed to ubiquitous access to communication media that they saw all difficulties in long-range communication as essentially technical problems.

According to Selg [29], the Web 2.0 culture is characterized by two-way communication patterns, where users are both consumers and producers of digital content. Blogs, on-line communities, and file sharing are typical forms of activities. This contrasts with a Web 1.0 culture where CT is used for such activities as information searching, ordering products, and, predominantly, using e-mail for communication. While email is used in both cultures, instant messaging and the use of SMS as an almost synchronous communication mode are characteristic of the Web 2.0 culture where they seen as complementing each other. Furthermore, this form of technological proficiency can be seen an example of the generally high level of competence in the use of CT in that culture. This proficiency also manifests itself as an understanding of the benefits of information technology, such as the value of a large network of "weak ties" in community building, and the need for strategies for handling technology misuse. Much of what Selg reports about the behaviour that differentiates between the cultures is related to how the Web 2.0 users are able to make distinctions between personal life and professional/public life in their use of technology.

It is also possible that the low level of reflection is a consequence of how the assignment was formulated. The rubric for submission, stated that students should *"[r]eflect on the positive and negative aspects of the use of [the] different communication technologies in [the] project. What are they good for? What are their drawbacks?"*. This led predominantly to descriptive reflections, even though students were asked to address those causal and correlative factors which characterise reflection at the upper levels. It is possible that students misconstrued the assignment as being directed to efficacy of the software tools and therefore interpreted this task as a request for an appraisal of the (software) products rather than the processes involved. This may have given rise to a submission based on commentary about products, rather than reflection on communication as a process itself. The former requires comparatively lower-level cognitive skills such as categorization, querying evidence, assessing claims and stating results, whereas reflection on the process itself would need the higher-level, evaluative, cognitive skills as well as access to the metacognitive skills necessary for the higher levels of the Hatton-Smith framework.

B. Establishing Mutual Knowledge in Distributed Collaboration

Central to the effectiveness of geographically distributed collaboration is the concept of "mutual knowledge" or "common ground", as described by Cramton [30]. This type of shared understanding can be established in a number of ways. Individuals can interact directly, in which case the knowledge is grounded in their shared first-hand experience. Alternatively, individuals can interact indirectly, e.g. through a proxy or through some experience both share with a third party [31]. Finally, mutual knowledge can be based on category membership, i.e. assumptions about the knowledge someone possesses by virtue of the job they do or the role they play [32].

Establishing such mutual knowledge in a distributed collaboration in which only the last two elements are available is not an easy task. There are difficulties in conveying nuances of meaning when compared to face-to-face communication [33] and these are exacerbated by the fact that communication using information technology is slower [34]. Cramton identifies a number of problems that contribute to the difficulties in establishing mutual knowledge, such as the failure to communicate and retain contextual information, unevenly information distribution within a message, a need to understand and communicate the salience of information, differences in speed of access to information, and difficulty interpreting the meaning of silence.

The problem with mutual knowledge in distributed collaborations is compounded when collaborators are themselves unaware of the difficulties associated with this particular issue. In the study, most of the problems with establishing mutual knowledge were clearly influenced by the characteristics of the CT used, e.g. having a low capacity for providing back-channel feedback was likely to lead to misunderstandings. In this regard, the low level of reflection about CT is worrying since it may indicate a naivety concerning the impact that technology has on the ability of students to engage in establishing this mutual knowledge. There were, however, some glimpses of insight, such as this quote related to an occasion when the students were forced to use the text-only mode of Skype:

“... I realized something important after we had ended. I noticed that, despite not insignificant cultural and language differences, we still communicate using a large percentage of nonverbal cues. I did not realize just how much we can convey with spoken conversation even across a cultural barrier.”

It is interesting, however, that the student who made this remark omitted to pursue this point further by speculating about differences with regard to other forms of CT, e.g. video, or to face-to-face meetings.

C. Types of Collaborative Technology used in the Project

Clearly, technology plays a crucial role in supporting communication in globally distributed projects, and an increasing collection of collaborative tools is available. These range from ubiquitous email facilities, through wikis, blogs, text chat systems, version control systems, video-conferencing systems (from desktop applications such as Skype to dedicated rooms and services), cloud-based file sharing such as Dropbox, and virtual learning environments (which often themselves incorporate a range of these features). Personalized social networking services such as Facebook, Youtube, and Twitter also complement the more group-focused collaborative technologies. However, this abundance of choice does not necessarily contribute to effective communication in the context of a globally distributed team. There are significant challenges and, as the authors of [35] and [36] note, it is necessary to establish common ground with respect to “collaboration readiness” and “technology readiness” in order to use them successfully [3].

This may go some way to explain why students did not make extensive use social software in the collaboration. Social

networking was not used for academic purposes despite the students clearly belonged to the digitally native culture. The forums, available as part of the TeamLabs technology, remained silent, and students did not use Facebook, blogs or Twitter for the project, despite other researchers having noted an increasing use of social networking websites for academic work. It is known that active engagement in these sites can help to establish virtual relationships and provide individuals with access to a diversified set of information from multiple sources [37]. We believe that a higher level of reflection on their use of collaborative technology would have led to investigation of the capabilities of social media in order to find alternative communication mechanisms, especially since they were already very familiar with such tools.

V. CONCLUSION

The ability to evaluate the use of technology-based environments that enable communication and collaboration in globally distributed student projects is, as mentioned in the introduction, an important skill for students to learn. Reflections were chosen to help students attain this learning objective and to develop their digital literacy. However, the reflections provided by students were quite shallow, merely describing the collaborative technologies used.

This raises an important issue, namely, under what circumstances can this type of reflective exercise be used to promote the development and exemplification of critical thinking skills. As critical reflection is itself a high-level metacognitive skill associated with learning self-regulation, its exercise requires a mature engagement with a wide range of purely cognitive skills. If a student does not have the opportunity, or disposition, to exemplify enough of these, there will not be sufficient cognitive content to allow substantive metacognitive activity to take place. It would appear that reflective activities, such as those described, act as good support for critical thinking provided the person doing them has the opportunity to illustrate a significant number of the requisite cognitive skills within the reflective process itself, especially those higher level evaluative skills.

In the case of this study, despite a clear statement that the objective for the assignment was high-level reflection, most students interpreted the task in terms of superficial description of the context and operation of the software. The result was a focus on the products that mediate communication rather than processes that enable it. Given that students find the experience of this kind of reflective activity both unfamiliar and difficult, it is, perhaps, not unexpected that they would attempt to reduce the task to simpler descriptive modes of expression. However, this does not explain why they managed to do much better in the first assignment. It also highlights the need for care in articulating the learning objectives of assignments, and providing suitable scaffolding to enable engagement.

From a pedagogical perspective, activities that scaffold engagement in reflection, and so promote the development of critical thinking skills, could be based around opportunities for students to recognise cognitive conflict between contrasting or distinct sets of data (e.g. assumed conditions and reality, student and staff perspectives). Such scaffolding should

promote the dialectical aspects of critical thinking such as clarifying meaning, challenging ideas and conjecturing alternatives, and may be contrasted with activities that primarily serve to expand the number of ideas under consideration, with the consequent need for further preliminary categorisation and classification, before more advanced critique can take place.

In conclusion, results from the study indicate that these students found it more difficult to reflect on their use of CT than, for example, on intercultural communication or the personal development of other professional competencies. Most students seemed unaware of the impact such technology has on their communication and collaboration, and they appear to view CT as, for example, gender neutral, and a tool that can be used and modified according to their needs. This simplistic view has most likely influenced the collaboration in a negative way, e.g. by leading to difficulties in establishing mutual knowledge. The results of our study indicate that there may be a need for more scaffolding related to reflective writing and further work to investigate if this will impact on their use of CT is underway.

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Problem-driven learning on two continents:

Lessons in pedagogic innovation across cultural divides

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Abstract— While internationally there is an awareness that we need new, innovative approaches to engineering education, it is unclear whether a pioneering pedagogy within one cultural context will readily transfer and find acceptance in a very different cultural context. In this paper, we report on a three-site, collaborative experiment in using problem-driven learning in an introductory engineering class. Our three sites are universities in the United States, Abu Dhabi and China. In each location, first year students in biomedical engineering begin the major by joining a team of students who tackle real-world, open-ended problems. Our paper will report on 1) the development and exchange of problems across the three sites, 2) the different constraints, realizations and outcomes of the problem-driven approach at each of using problem-driven learning as a transnational pedagogy for 21st century engineering education.

Keywords- problem-based learning, global education

I. INTRODUCTION

In a recent report from the National Academy of Science, five essential 21st century skills were identified: *adaptability, complex communication/social skills, non-routine problem solving, self-management/self-development* and *systems thinking* [1]. These identified competencies are echoed in the UNESCO's 1996 Report titled "Learning: The Treasure Within" [2] and the European community's report identifying eight key competences [3] for achieving flexibility in the labor force. Students will not develop these competencies by sitting passively in lecture halls, taking notes and memorizing content. Even more interactive methods like Personal Response Systems or Student-centered Active Learning Environments for Undergraduate Programs (SCALE-UP) [4], both of which promote greater student interaction, are not specifically designed to help students develop these competencies. This is because the nature of the problems in traditional engineering classes that students are expected to master, while a first step in becoming successful engineers, are not sufficiently complex to allow students to practice essential 21st century skills. This insufficiency is not just a national concern, but also an international educational challenge. Across the globe, the urgency to transform engineering education is becoming more and more recognized.

Here we report on a collaborative transnational effort at Georgia Tech in Atlanta, Peking University in China and

Khalifa University of Science Technology and Research (KUSTAR) in Abu Dhabi to develop and deliver an introductory course in biomedical engineering. Biomedical engineering (BME), an exemplar interdisciplinary, poses significant educational challenges. Bioengineers must integrate a broad base of knowledge from several disciplines including engineering, computer technology, and cell and molecular biology. They must apply quantitative, analytical methods and representations to systems understanding. Irrefutably, adaptability, non-routine problem solving, systems thinking, and complex communication skills are essential attributes of a biomedical engineer. In the workplace, they routinely both participate in but translate across the disciplinary borders of medicine, biosciences and engineering. In this field, we cannot afford to have our students graduate without these 21st century skills.

Fostering these competencies while promoting integrative thinking and problem solving skills should be a central objective in the design of an undergraduate biomedical engineering curriculum, but arguably, just as relevant to any engineering major. Obviously new models for what happens in classrooms and what happens across a whole set of courses is desirable and necessary to achieve these ends. The questions we address in this paper are 1) whether and how new 21st century models for engineering education can be developed and 2) how readily these models can transfer across national boundaries, cultures and institutional contexts. To answer these questions, we undertook a transnational experiment in reforming engineering pedagogy at the freshman level. Here, we present the evolution of a required BME course designed at Georgia Tech to foster 21st century competencies. We then address the challenges experienced as it was exported and implemented at two offshore sites, the alterations made to accommodate cultural and institutional differences, and the shared outcomes of this educational experiment. This is not a standard research report on an educational intervention, so we do not (at this time) offer hard, quantitative data to substantiate our observations and claims about student learning and change. Rather, this work reports on a model for global collaboration in the design, development and refinement of new learning environments for engineering education that can be relevant and effective across national borders. It also illustrates how a perceived problem in engineering education is likely to be

global rather than local, so we need such collaborative efforts worldwide to produce the engineers needed to tackle the compelling global problems of food, water energy and healthcare.

II. PROBLEM-DRIVEN LEARNING

One could easily argue that problem solving is at the core of engineering education. Students in statics, dynamics, heat transfer, bio-transport and signal processing courses are all learning to solve textbook problems using an engineering approach. It is improbable, however, that such textbook problems and the associated classroom activities of lecturing or the faculty member solving a problem on the board will promote adaptability, social competencies or self-management skills, for example. This is because traditional engineering practice problems are not designed to build 21st century competencies; they are designed to build the essential fundamentals. And while these fundamentals are certainly necessary, they are no longer sufficient which poses a problem for engineering education generally. Where and how will students practice and develop the necessary fundamentals for the 21st century workplace?

In response to this need, problem-based learning or PBL has started to make inroads into engineering education [5,6,7]. First developed for medical education [8] to better prepare future doctors for clinical practice, this educational approach comprises

- An authentic, ill-structured complex problem with multiple possible routes to multiple possible solutions
- Varied but unscripted opportunities for students to identify personal knowledge gaps as starting points for individual inquiry and learning
- A team or group that works collaboratively on the problems.
- A facilitator who guides the learning on a team through asking probing questions that model expert cognitive reasoning and problem solving strategies

PBL is used in a number of ways—to engage students deeply with content [9], to apprentice them to the practices of a particular community and to practice a specific skill set such as spoken and written communication. One could easily argue that the capstone design, so prevalent in the engineering community is an excellent example of problem-based learning.

For our purposes, we adopt a slightly different term—problem-driven learning. We take this term from the work we have been doing in trying to understand reasoning, problem solving and learning in engineering research labs and then translating those findings into new models for engineering education [10]. What we see in these sites of authentic engineering activity is that learning is driven, propelled actually, by the need to solve non-routine, ill structured, and ill-constrained problems. And this problem-driven learning is what advances knowledge and drives breakthroughs in the labs. Laboratory problems are inter/multidisciplinary, which requires researchers to integrate knowledge and skills across the bioscience/ engineering divide. Researchers continually need to adapt to new and changing

conditions both in terms of personnel, problem types and the ever-present impasses encountered in frontier science. They need to manage what, when and how they learn and they need to work with others when the magnitude of the problem demands a variety of heads and hands. If engineering majors are to effectively participate as non-routine problem solvers in industry or research, they need to practice early and often the skills of tackling, defining, constraining and working through complex, interdisciplinary problems. Thus in our design of the introductory course in our biomedical engineering curriculum, we seek to *Empower students to be agents of their own learning who are fearless in the face of a complex problem.* This is a tall order and needs to start in the first year and be practiced throughout the curriculum. We contend that a single capstone experience while necessary is not sufficient.

III. PROBLEMS IN BIOMEDICAL ENGINEERING ACROSS CULTURAL CONTEXTS

Over the past ten years, we have iteratively designed and developed a set of three complex, ill-structured problems that constitute the basis for an entry-level course. In working through these problems students 1) practice the reasoning and problem-solving strategies employed by engineers with the help and scaffolding of facilitators; 2) experience the need to integrate the biosciences with engineering and 3) try on the identities of biomedical engineers. This course and the problems, first developed at Georgia Tech, have morphed and changed in response to the different cultural contexts of China and Abu Dhabi. The same learning outcomes, scoring sheets and rubrics have been passed across the continents. The best way to tell this story of international collaboration is to move from site to site, illuminating the possibilities and the challenges at each.

A. The Georgia Tech Experiment

With the inception of inaugural undergraduate and graduate degree programs in biomedical engineering in 2000, the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech (GT) committed to developing new educational models suited to educating students for integrative thinking and problem solving across engineering/biosciences. Approaching this challenge from the cognitive and learning sciences, the curriculum designers determined that working on interdisciplinary problems beginning in year one and throughout the curriculum was the way to insure this cognitive integration by year four. Separate streams of bioscience and engineering classes would not give students the needed practice of applying the quantitative engineering analysis and design to bioscience and healthcare problems. Nor would students develop the *cognitive flexibility* [11,12], or the ability to apply knowledge in diverse contexts and to engage a problem flexibly from different perspectives because building these habits of the mind takes practice. Moreover, having students work on authentic, complex interdisciplinary problems with the guidance of a faculty facilitator rather than a teacher would create the desired *cognitive apprenticeship* [13], a powerful and well-researched model for learning. In such an apprenticeship, the facilitator models her cognitive strategies by asking probing questions, by challenging the learners, by coaching the learners

and by monitoring activity and giving feedback. This pedagogical model was best suited to the learning objectives of this freshman-level required class in the biomedical engineering curriculum.

Over the years, numerous problems were developed, run and analyzed for the course until a stable set of three for each term were established that serve specific, desired learning goals. The learning outcomes for the course address four skill areas: *inquiry skills*, *problem-solving skills*, *knowledge building skills* and *team skills*. Assessment rubrics for the course as well as a number of problems can be found at <http://pbl.bme.gatech.edu/assessment.php>. Each of the three problems has a central core over which different “skins” or story lines can be affixed. For example, the first problem focuses on screening in the context of disease. The problem brings together issues of sensitivity/specificity/positive predictive value (probability) in health screening, issues of scale in the context of disease, and the development of quantitative methods of analysis for evaluation/decision-making in the face of conflicting and changing information. A significant intended learning outcome for the whole course generally but this problem very specifically, is the development of efficient/effective inquiry skills. Each term, a new disease can be explored. Generally cancer of one kind or another has been used but more recently endometriosis and sickle cell disease have been topics. The second problem has experimental design at its core and the third has mathematical modeling and computer simulation. These core problems offer enough flexibility that each semester is very different for both students and faculty. For example, one semester students might determine through modeling and simulation whether an outbreak of an infectious disease could occur on campus and whether particular measures would be effective in halting the spread while the next semester they might look at the potential for experimental viral traps to halt the spread of HIV. (See two versions of this problem at the end of this paper.) This potential to redo the core problem each term with a different story line keeps the course fresh and current for both faculty and students. Since faculty are not expected to teach the material but to facilitate the problem solving process, they find the kinds of interactions with their students to be very similar to those they have with their graduate students during lab meetings. Significantly, as all faculty in the department teach this course and see the capabilities of the undergraduate students first hand as facilitators, they are eager to have undergraduates in their research lab accounting for the fact that significant numbers find work in research labs before graduating.

At Georgia Tech, unparalleled resources support the course. First, special rooms were designed for the team problem solving that measure approximately 25 feet by 25 feet. Importantly, the rooms have writable walls to the ceiling designed to support a *distributed cognitive system* [14] among team members as they work in defining the problem, gathering the necessary resources, applying those sources, developing a problem solving strategy, determining a solution, designing a presentation for other teams and then writing a technical report. In addition, it was determined early on that the team size would be eight students and that enough faculty, graduate students and post-docs would be assigned to the course so that every team

had their own facilitator. At the time of this writing, this class has 165 students divided into twenty-one teams with fourteen faculty and post-docs assigned to the course. Finally, over the years, scoring rubrics for each type of problem presentation and report were developed and tested as well as guidelines for developing the technical reports. Further, self and peer assessment sheets used at the end of the problems and at the end of term were also developed. Taken together, these course resources provide a significant scaffolding system that allows first year students to take on and tackle authentic complex, interdisciplinary problems in biomedical engineering.

Augmenting the three hours of class time devoted to the team working on the problem is a weekly one-hour lecture carefully timed to infuse important skills or knowledge into the problem space. For example, two weeks into a cancer detection problem, a faculty member whose research area is cancer will give a talk on the cellular mechanisms involved in the disease. Interestingly, students always applaud after these lectures indicating that somehow this faculty presentation is more like a research presentation than a traditional lecture class.

Measuring the efficacy of this learning experience has been a challenge as its intent is to build skills not mastery of a certain content area. One measure, we believe, of the course’s success is the significant number of students who go on to seek research experiences as undergraduates. By the fourth year, we find that 65% of our 1200 undergraduates have worked in labs. We propose this as an appropriate measure of course success as it has been designed to simulate a research lab experience. Another measure is an alumna survey in which 60% of respondents spontaneously credited this problem-driven learning experience as making them better prepared in the workplace. Finally in an end-of-course student survey, the majority of the students indicate that they have learned “more” or “much more” in this course than a traditional lecture class. While these measure techniques are not rigorous, they do attest to the value of this course.

B. The Abu Dhabi experiment

Similar to Georgia Tech, Khalifa University of Science, Technology and Research (KUSTAR) developed a new degree program in biomedical engineering beginning in 2009. Wanting to infuse problem-driven learning in the curriculum, they decided to follow the established GT model and use the previously designed problems, scoring rubrics and assessment strategies. At the time, no university in Abu Dhabi was experimenting with problem-driven approaches and the cultural educational norms experienced by students prior to coming to the KUSTAR were very different from those of the United States. To assist KUSTAR in developing this approach, a strong collaboration was established that involved 1) an on-site workshop in Abu Dhabi by the lead author to introduce faculty to this approach, 2) access to copies of all assessment and support resources developed at GT; 3) access to the GT course management system so the KUSTAR faculty could see the GT students’ work for calibration purposes 4) Skype meetings to assist KUSTAR faculty in developing culturally relevant problems. Even with all this support, it was unclear how difficult the transition to this novel educational approach would

be. Given the limited space of this conference paper, we discuss two issues: the design of problems for a different context and the local resource and cultural challenges.

The Abu Dhabi team was able to work with the core concepts of the three problems from GT and affix “skins” relevant to the Abu Dhabi context. Specifically, diabetes mellitus type II, obesity and trauma from road fatalities—all important issues to this UAE—became the contexts for developing inquiry skills, problem-solving skills, knowledge building skills and team skills. Using the problem prompts from GT as templates, a faculty member was able to design culturally relevant and timely problems for their first year students to address. The chance to work as engineers on problems facing their nation was very motivating to the KUSTAR students. However, unlike GT, KUSTAR faculty lacked certain essential resources. They used small conference rooms not PBL rooms and while these worked, lacking the expansive writing space constrained group interactions to some extent. The students did not have access to the Pub Med and Medline databases needed to do effective inquiry. For the first time in their education, men and women students were sitting in the same room working together. English for these students is not their native language and yet the course and the materials were all in English. And finally, prior educational experiences had only prepared them for listening passively in lecture with no idea how to be agents of their own learning. Naturally it was necessary to develop additional scaffolding for this student population and institutional/cultural context. Firstly, the faculty had to special order bibliographic resources for the students or provide a set of possible resources for them to sift through and use as required. Facilitation had to support the interaction across genders as students transitioned to a co-ed environment of learning and working. Facilitation was also needed in encouraging and transitioning students to become independent self-directed learners.

Now in its second year, the problem driven learning experiment has become a central feature of the biomedical engineering curriculum at KUSTAR. The second author of this paper describes below outcomes of this educational experiment from her experience designing problems, facilitating student teams and observing them in follow-on classes.

- Empowerment and ownership of learning were invaluable to some students in terms of raising their confidence level with respect to the ability to solve the problems and the ability to present the solution to an audience. This is of particular importance for females in our culture, as cultural constraints may hinder the development of their confidence level and soft skills in parallel with their male counterparts.
- The diverse composition of teams taught the students how to work effectively with others. Furthermore, peer mentorship was also observed in teams throughout the problem cycle, where students were helping each other develop or improve certain skills.
- Exposure to real-world hands-on engineering /clinical problems with cultural and societal impact not only motivated the students to learn, but also exposed them to the iterative engineering design and design thinking

approach critical for solving open-ended, ill-posed, complex problems.

- The PBL class encouraged students to do research, design and development. The direct outcomes included one ASME conference publication (Creating a Mathematical Model to decrease Obesity in the UAE. ASME Meeting, Seoul, South Korea, June 2011), the modification of the design of commercial pedometer to increase precision and accuracy, and the design and development of an intelligent system to control traffic accidents.

C. The China Experiment

Like KUSTAR, in 2009 Peking University (PKU) in Beijing was developing an undergraduate program in biomedical engineering. At that time, GT and PKU were also building a joint PhD program that would foster research collaboration and exchange through PhD students transiting between the two institutions. After visiting the GT problem-driven learning classrooms, the PKU faculty also decided to follow the GT model thinking that since PKU students are in the elite class of highly talented Chinese students, they would bring impressive capabilities to this learning environment. Similar to KUSTAR, PKU received significant mentoring and support from Georgia Tech in the form of an on-site workshop, assistance in developing locally relevant problems, access to the course management system and course materials and just-in-time Skype consultations. Interestingly, PKU was able to use the GT problems with small changes. For example, breast cancer is a significant health problem in China like the US, so when this GT problem was given to PKU students rewritten to foreground the Chinese context, students were highly motivated to help their nation. One student wrote to his facilitator:

After class, I talked to my classmate. We both thought that we are doing something really meaningful: we are thinking deeply and thoroughly about solving China's breast cancer. We thought that maybe except for our class, no one else in China would actually try to systematically and deeply research on the current conditions of China's breast cancer, as well as how to make the conditions better. We were discussing, getting more and more excited, feeling as though we were really burdened with some huge responsibility!

However, as would be expected, there were significant local challenges associated with this educational experiment. PKU students take a very heavy load of eight or more courses each term, which means that class time is approximately one and a half hours a week while the GT classes meet a total of 4. This course load also means that PKU students have to study for a number of courses simultaneously, leaving less time for a problem-driven course which often requires a lot of time outside of class to find the appropriate sources, to digest them and to determine how the resources can be used in the problem. In Chinese high schools, teamwork and discussion are for all purposes nonexistent, so working on a team for a whole term on problems that require constant discussion and negotiation is a very foreign concept and experience for these students.

Finally, a traditional lecture style classroom was the available space for this class with no white boards for distributing the cognitive task and load.

Over three terms, the PKU faculty was able to make important adjustments to better approximate the GT conditions. First, they added a recitation period and office hours, which they used to augment the time that the facilitators meet with the students. These meetings were often in their offices so they could use the white boards there. For one problem that requires GT teams to buy a biomedical device for testing and experimental design, the PKU faculty bought the devices and distributed them to the teams.

The third author on this paper shares the following unexpected outcomes of the problem-driven learning experiment at PKU:

- Unlike USA students who are assigned tasks to investigate very broad topics even in elementary school, the students in China seldom have such an opportunity. For the tradition of education, the students are even regarded as threatening or not respectful to the teacher if he/she asks a question without the teacher's invitation. Therefore, the students are very excited to solve such broad questions. We find how we organize the just in-time lecture component of the course is very important. For example, when we invited the breast cancer-imaging physician to give the lecture, the students asked her questions for about 2 hours after 2 hours' class!
- The practice of giving a speech improves the students' communication skills and prepares them for future career needs. Especially, we have requested them to give several final presentations in English. We found that it helps the students to break the language barrier when communicating with foreigners.
- Chinese students are not very comfortable with discussion—they feel embarrassed to challenge or be challenged about their thinking until they establish friendship that makes them feel safe. This also delays the initial group working efficiency.
- For cultural reasons, the Chinese students have no experience to evaluate other students/collaborators. If they have to do so, they tend to speak only the positive side. Therefore, we have to encourage them to do so, and emphasizing that this will help their friends to growth. Once they started to self/peer reflection, they can sense the feedback really helps them to work more efficiently.

IV. DISCUSSION

In this paper, we presented a story of educational and cultural exchange and collaboration towards building new global models for engineering learning. What we have collectively discovered is that problem-driven approaches applied to engineering classrooms can positively motivate students across the globe to take on challenges, adopt new behaviors and become engaged in major problems facing their cultures. Another lesson learned is that a local faculty

champion is necessary to best address the local differences and challenges. While the off-site GT mentor could help with problem development generally, it was the country-based team that could identify local problem topics that would quickly resonate with the students. A third lesson is the need to share exemplars of desired student work. For both faculty members at KUSTAR and PKU being able to see what the GT students were producing in terms of presentations and reports helped them in adjusting their expectations and scaffolding strategies. This access also gave them a benchmark against which they could evaluate the fidelity of their learning environment to the GT conditions. Importantly, we found that with careful design, problems from one classroom can be rewritten for a different cultural context with the same learning benefits.

At this stage in our transnational experiment, we have reached a kind of steady state that will allow us to take the next steps. These are to collect solid comparative data that measure the outcomes of engaging in open-ended complex problem solving in the first year of an engineering major. A challenge for our group is to translate the five 21st century competencies that frame this paper into measures that can be turned into authentic performance assessment strategies. While it is easy to test isolated engineering concepts like a free body diagram, developing measures and instruments for 21st century skills is critical to preparing the next generation of engineers. In fact, this is perhaps the most significant challenge facing all of engineering education globally. How do we show through careful design and measurement that we are doing our best to build 21st century competencies?

PROBLEM III

Version 1: In 2011, Ron Fouchier, a Dutch scientist, created a mutant H5N1 virus, which has the capability to be transmitted from person-to-person. Fouchier wants to publish his findings in *Science*, but many warn that this work could be replicated and used for bioterrorism. Your team has been hired by the National Science Advisory Board for Biosecurity to launch a quantitative engineering analysis to determine what effect publishing Fouchier work. Develop a mathematical/computational model and test various scenarios to determine whether he should publish or not.

Version 2: Zombies infected with something called "Rage" (developed at the U of I campus) are moving towards and threatening your campus. This virus is readily transmitted via blood-to-blood contact from zombies to humans. Once infected, humans rapidly (in about 1 minute!) become zombies. The zombies seem incapable of holding down food, so eventually they starve to death. Develop a strategy to protect the campus using mathematical and computational modeling.

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Work in Progress: Can Bourdieu's Habitus provide a theoretical framework for Engineering Education Research?

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Abstract— This paper explores the use of Bourdieu's Theory of Habitus as a theoretical framework for a PhD study on the dispositions enabling non-traditional students to succeed in their first year of engineering studies. It provides a review of Bourdieu's sociological Theory of Habitus and the application of this framework to higher education settings and in particular to engineering education.

Bourdieu's theory of Habitus provides a framework for exploring and analyzing the behavior of individuals within a particular environment. It can provide insight into the behavior, and subsequent academic performance, of an increasingly diverse student cohort in the Australian higher education system. Bourdieu's theory offers researchers the opportunity to understand the complexity of human interactions within the education system. Moreover it is currently an underutilized tool for developing research methodologies as well as providing a framework for subsequent analysis [1].

Keywords- Bourdieu, habitus, disposition, student diversity

I. INTRODUCTION

Pierre Bourdieu was a renowned French intellectual of the late 20th century. He had a passion for social justice and much of his work involved the study of social inequality and the ways in which it is perpetuated, mostly without conscious recognition [2-4]. Bourdieu drew on the fields of philosophy, social anthropology and sociology [2] to develop his own sociological theories dealing with the stratification of contemporary society and its implications for individuals. His writings were voluminous and not terribly accessible to the those who are new to his work [4], which may explain why his concepts have been widely used in sociological explorations of higher education but not yet been widely adopted within the field of engineering education research.

II. BOURDIEU'S THEORY OF HABITUS

Bourdieu is notorious for not succinctly defining the concepts on which his theory is based and for using them in a fluid manner throughout his writing. However a working description of habitus, which is appropriate for the intended application, is that it is a collection of mostly subconscious dispositions which an individual initially acquires in early childhood via familial interactions and which are then

constantly modified by subsequent life experiences [4]. An individual's dispositions will be expressed as their thoughts, preferences, beliefs and aspirations, concerning themselves and the structure of the social world around them [5]. These dispositions then influence how a person will behave in a particular situation. Habitus is both shaped by the social structures within which it is formed and regulates the actions of an individual within those social structures [6]. Thus, individuals from a particular socio-economic group will usually have many dispositions in common. A person's dispositions will include beliefs about their chances of success in a given endeavor. Bourdieu postulates that one's aspirations, and subsequent actions, are then adjusted to the perceived chances of success. He refers to this idea as the "causality of the probable" [4].

Bourdieu uses his concept of 'Field' as a metaphor for all the organizations and individuals involved in a particular social or cultural arena and the interactions between them [4]. He sees every field as a situation of struggle, competition or conflict, the objective for each individual being to optimize their accumulation or retention of 'capital'. Bourdieu's concept of capital extends beyond mere economic capital to also encompass symbolic, cultural, social and linguistic capital. Each of these types of capital has a social value and can be 'inherited', through the circumstances of one's early upbringing, or accumulated, exchanged and leveraged much like economic capital [4].

Bourdieu's work is acclaimed by Rogers Brubaker [6] as one of the most significant attempts to adapt sociological theory to the empirical study of contemporary society. He articulated a 'reflexive, post-structuralist' position whereby individuals influence the fields within which they operate while concurrently being influenced by their own habitus; a construct of societal structures (including various fields) both past and present within which they have interacted [4, 6, 7].

III. BOURDIEU AND EDUCATIONAL SYSTEMS

Bourdieu sees the sociology of education as the foundation of sociology; a key setting through which cultural stratification is perpetuated. Bourdieu sees education as a form of cultural capital, which can be acquired through time, effort and money and which can be exchanged for a prestigious and profitable career [5]. Cultural capital can be acquired through education,

but more easily so by students already possessing large amounts of cultural capital through inherited wealth and/or position [4, 8]. Educational settings are also responsible for reinforcing the social class system or hierarchy through the classification systems adopted (admission & assessment) [5].

Bourdieu proposes that the educational decisions made by students (where and what to study) are the result of their dispositions, which in turn have been developed as a result of their personal habitus [5]. Student achievement or success is also addressed by Bourdieu. He proposes that whether students stay in school or drop out is largely determined by their perceptions of the probability of success for students of their background [4]. This is reflected in current expectancy value theory studies showing the importance of student expectations on academic achievement (e.g. [9]). Bourdieu further argues that a child's expectations of education and career are largely determined by their parents and early educational influences during the formation of their habitus.

Having been used by Bourdieu in the context of the French educational system the validity of Bourdieu's theories for applications in other cultures has been raised [7]. However Bourdieu was very interested in the applicability of the particular to explain the universal in society and his latter writings address the adoption of his concepts by English readers [7]. Reay [1] and Robbins [7] both point to extensive use in British educational sociology research. Berger [10] discusses the increasing popularity in the USA of Bourdieu's framework for exploring inequities in educational achievement, higher education organizational studies, student persistence and retention.

It has been argued [1, 7] that Bourdieu's theories have been widely misused, particularly by English speaking sociologists, who tend to examine their data using Bourdieu's theories rather than underpinning their research methodology with the theoretical framework that they can provide. Reay [1] argues that Bourdieu's theory of habitus is meant as a research methodology: a means of informing the investigations undertaken rather than simply as a lens through which to view the data collected in a study. Bourdieu's own data collection methods combine statistical techniques with observations and interrogation of relevant interactions, discourses and documentation [11]. He advocates the use of the methodological procedure that is most appropriate to the question at hand, close attention to the underlying theory of the research design and implementation and continual methodological review and refinement [11].

IV. THE PROPOSED APPLICATION OF BOURDIEU'S THEORIES

The recent Bradley Review [12] of higher education in Australia, makes recommendations for increasing participation in higher education. This coupled with the high demand for engineers has created a diversity of students enrolling in engineering programs. This trend requires extensive research as faculties attempt to develop appropriate systems, curricula and pedagogies to support non-traditional students. i.e. those who may not share the habitus and dispositions of existing engineering faculty and the academy at large. This proposed study targets those students who perform better academically that Bourdieu's theory of capital and habitus might predict.

Moore [13] discusses the exceptions which arise when using cultural capital alone to explain the excellent academic performance of these students. He explores Bourdieu's statements regarding such exceptional students in terms of the recognition of different groups within a given social class and the existence of 'particularities' or 'exceptional qualities' that enable these students' academic performance. This study will focus on the identification and explanation of these qualities, on which Bourdieu does not elaborate [13], using an ethnographic style methodology, based on Bourdieu's framework.

V. CONCLUSION

This paper presents only a preliminary introduction to Bourdieu's complex work and is intended to generate discussion about the possibilities it presents for engineering education research. As yet, Bourdieu's concepts have not been used as a framework within Engineering education research in Australia, where the field of engineering Education Research is dominated by academics with a technical engineering background and an interest in education. The disciplines and theories associated with sociology and education research tend to be secondary to their core training, so the adoption of these theories presents a challenge to such researchers. Bourdieu's call to English readers regarding the adoption of his theories (in his 1998 work *Homo Academicus*, as cited by Robbins, 2004) can be extended to engineering educators as a call to adopt or adapt this theoretical framework for underpinning new research methodologies and analyses of engineering education phenomena.

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Work in Progress: Towards a Framework for Adaptive Learning Systems

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Abstract—The development of systems which adapt to the needs of student learning is a complex task. Learning involves several factors, including effective communication in a specific context. In this paper, we propose a conceptual framework to allow the integration of adaptive hypermedia in learning management systems from a cognitive-semantic perspective.

Keywords - *adaptive learning systems, Relevance Theory, ontology*

I. INTRODUCTION

The use of computers in education aims to promote student learning and help him develop important skills to achieve an active participation in society. One of the problems, reported by [1], is that students are treated as having always the same profile, goals and knowledge. Conventional applications, in general, do not take student's current context into account. One of the problems, reported by [1], is that students are treated as having always the same profile, goals and knowledge. In this research, we are dealing with cognitive contexts. Considering this, we propose a conceptual framework to allow the integration of adaptive hypermedia in learning management systems from a cognitive-semantic perspective based on some Relevance Theory principles. The semantic perspective considered the use of a domain ontology as the knowledge structure. The chosen domain is the area of preparation for JLPT (Japanese Language Proficiency Test) certification.

II. RELATED WORK

Some candidates to JLPT pointed out that they had difficulties in finding specific support to study in the Web. There are many software with material on the Japanese language, especially about *kanji*, which may make the study and preparation handicapped by the lack of appropriate material and guidance. Although, there is some software available in the Internet which supports JLPT preparation. Table I presents some features considered important in this type of software.

TABLE I. COMPARISON OF JLPT SOFTWARE

| System | Features | | | |
|--------------------|----------------------------|---|----------------------------|---------------------------|
| | <i>Kanji-only oriented</i> | <i>Satisfactory amount of questions</i> | <i>Cognitive construct</i> | <i>Adaptive resources</i> |
| JLPT Oficial Page | | | | |
| JLPT Study Page | | | | |
| Study Japanese | X | X | X | |
| Renshuu | | X | X | X |
| JLPT Kanji Project | X | X | | |
| e-JLPT System | | X | X | X |

The use of a cognitive construct or the existence of tutoring shows interest in customize the learning process, exercise and test preparation. There are three systems that use these resources: Study Japanese, Renshuu and e-JLPT system. The first two use the spaced repetition learning technique [2]. The e-JLPT system uses Relevance Theory as cognitive support and only Renshuu and e-JLPT system have adaptive resources. The e-JLPT system adapts navigation through the method of suggesting relevant topics of study. By the comparison table, e-JLPT seems to be an interesting option to be considered and explored by candidates to JLPT.

III. ADAPTIVE FRAMEWORK

Frameworks are techniques used in the design of object-oriented software. The great advantage of its use is the potential for reuse of parts of software already developed and the development of new software components.

The development of software for a specific implementation consists in instantiate the referred framework, through the specialization of its components.

A. The Conceptual Framework and its instantiation

The proposal to develop a conceptual framework came from the need to organize e-JLPT system, integrating the various components developed.

The proposed computational model uses domain ontologies as knowledge structure. This usage is largely related to portability, capacity to add new concepts and features as well as clarity, reuse, among others. The idea of using ontologies in the field of education is well-founded, as can be seen in [3][4] [5]. The proposed framework can be seen in Fig. 1. Its main components are:

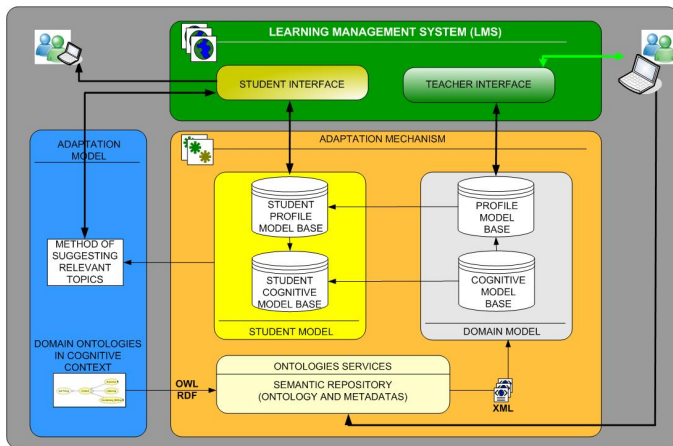


Figure 1. Conceptual framework

Learning management system – is a subsystem containing the hypermedia base and the students and teachers classes. It is the system interface layer with the actors involved which allows the definition of profiles rules to adapt to student's needs and the visualization of hypermedia adapted semantic-cognitively.

Adaptation Model – is the model that establishes policies for the environment adaptation, specifying the necessary components to the base of the adaptation mechanism. It consists of two components: the method of suggesting relevant topics and the domain ontology from the perspective of Relevance Theory.

Adaptation Mechanism – is formed by the user and domain bases obtained from the ontologies services, which are responsible for storing ontologies (semantic repository). Associated with these bases are the specific bases, with the rules for students' adaptation, consisting of Student Profile base and Student Cognitive base.

The instantiation of this framework took place in the area of preparation for certification of proficiency in Japanese language. It was implemented using a partial functional validation of use cases for adaptation scenarios identified in the environment. The validation was made using a study case.

The e-JLPT system is not a complete learning management system but it has the main functionalities to simulate a JLPT. It is based on JLPT domain ontology under Relevance Theory perspective. The profile and domain bases were modeled with features associated to JLPT. The proposal is to model the domain taking into consideration the several possibilities to navigate in the context.

Next subsection describes the development process of e-JLPT system and the tools used in the process.

B. Development Process and Tools

To implement the framework, there were five development stages. Each stage had its testing phase, with the help of the "Test::Unit" tool. These stages are described next:

a) Programming Language Migration

The proposed framework was originally built in ASP. The system went through a migration process to Ruby on Rails. This greatly improved the structural organization of the system, and has given a design pattern basis to work at, the MVC (Model-View-Controller).

b) First version – New Layout and Functionality Enhancements.

After migration, a version was created with a new usability perspective. This first version has benefited from new versions of web technologies like HTML 5, which allowed us to work without *plugins*. Functionalities such as registration procedure and first access to the system have been simplified.

c) Second version – Non-adapted Module and Function to Ontology Import

With the stable version already in operation, it was implemented the import function of JLPT domain ontology in RDF format, beginning the transformation of the system in a LMS with the proposed Adaptation Model. RDF.rb was the library used for RDF parsing.

With the domain ontology integrated to the system, in the form of JLPT topics of study, the Non-Adapted module was developed, with the creation of JLPT tests from a questions database, free choice of the student.

d) Third version – Adapted module.

In the development of the Adapted Module, two new functionalities were created: the permission of Japanese experts to define the relevance of each of topics of study presented in the ontology and the adaptation of the generation of tests, based on Relevance Theory.

e) Deployment and Maintenance.

For this work, Git was used to manage e-JLPT versions. Its branching model and flexibility assisted us on our goals, making each version well encapsulated from the other.

At the end of the development process, e-JLPT was available on the web and released for use. Bug fixing and improvements, result of suggestions and observations, were implemented, without any interference in the main goals of the framework, for a better interaction between user and environment.

IV. FINAL CONSIDERATIONS

This paper presented the evolution of a system which included a proposal for an adaptive conceptual framework. Its first instantiation was done in the Japanese Language Proficiency Test case study. The main components of this instantiated framework are: an educational system called e-JLPT, an adaptation model based on JLPT domain ontology and an adaptation mechanism based on the proposed method of relevance suggestion. This case study allowed a partial functional validation of the proposed framework.

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Work in Progress: A Constructivist Didactic Methodology for a Humanoid Robotics Workshop

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Abstract— This paper presents a constructivist methodology oriented to training Robotics in its wide sense, and its implementation in higher education. A humanoid robotics workshop is included as a part of the curriculum of ‘Industrial Robotics’ in the Industrial Engineering. This workshop covers one third of the laboratory practices of this subject. A constructivist view for learning is adopted, whereby robotic technologies are not seen as mere tools, but rather as potential vehicles of new ways of thinking about teaching, learning and education at large. Students, in a constructivist learning environment, are invited to work on experiments and authentic problem-solving; with selective use of available resources according to their own interests, research and learning strategies. The authors, as trainers of this workshop, chose ROBONOVA humanoid robots, among other devices, which attempt to partner technology with ideas of constructivism. The materials used in the workshop offer building parts, sensors thus connecting a robot with the external environment and programming software with a simple graphical interface intended for the creation of robot behavioral movements. The idea is “learning by design”, which is central in the constructivist pedagogy introduced firstly by Resnick. In this workshop we corroborate this idea through the project-based learning approach in robotics. Learning tasks of the workshop are organized as projects (small and large) that encourage students to develop their own designs. Projects are either instructor led or completely arisen from students.

Keywords- *Constructivism, Robotics, Humanoid robots*

I. INTRODUCTION

Robotics is a synonym of progress and technological development. Countries and companies with a strong presence of robots not only achieve high productivity, but also convey an image of modernization. It is for this reason that in developed countries investment resources in robotics have grown significantly in recent years. The application fields for robotics are becoming broader. Among these fields, one of the most investigated is humanoid robotics. These robots are characterized by their human appearance or by performing human functions. Although it may take the form of an entire human, many humanoid robotics projects are based on the study and behavior of a specific body part body such as hands, arms, legs or head (including eyes, mouth, ears or even artificial intelligence). The main application field of humanoid robots is human interaction, with an increase in its human like appearance, people are more willing to work with this type of

robot. Other areas where humanoid robots are being used include research. The need to understand the movements, behavior, cognition or the response of humans to some stimuli in order to incorporate them into a robot; also leads to a better understanding of the human body and brain. Humanoid robotics has provided new perspectives for the study of cognitive science. Last but not least, humanoid robots are being used in teaching. In the last few years, robotics is being introduced in school education from kindergarten to high school either as interdisciplinary, project-based learning activity or focused on school subjects; such as science, mathematics, informatics and technology [1]. The University has been working within this field for a number of years; research into educational robotics is an ever increasing area due to the social necessity of knowledge in this discipline. Engineering students should understand and be able to develop and solve real problems of human-machine engineering, in a cognitive way that will translate to professional life. A team of lecturers and instructors of Robotics in different degrees at the Technical University of Catalonia have analyzed the present situation of the students that enter at the University. They have detected, among other things, a lack of previous and basic knowledge related with robotics (mathematics, mechanics, electronics, automation) that any student at high school with a technological profile should have acquired prior to enrollment in an engineering degree.

In this work our main objective is the successful introduction of robotics to classrooms in an entertaining way. The role of the instructor is crucial for achieving this success in the teaching-learning process. A constructivist pedagogical methodology is used, [2] with the aim that the students achieve cognitive skills and abilities as well as the generic competences (sustainability, English) of the curriculum, in a solid way by learning resources of real-life, occupational situations and promoting the creativity and ideas of the student encouraging the cooperative learning [5][7]. This paper mainly presents a novel humanoid robotics workshop for high school pupils. A constructivist methodology is used. We will explain in detail some interactive experimental sessions designed to introduce students in the humanoid robotics world. In Section II, the context and objectives of the whole project are presented. Section III states the laboratory equipment needed to carry out the experimental sessions which description is on Section IV. It ends with the assessment of the workshop and the most relevant conclusions.

II. ROBOTICS WORKSHOP

A. Context: Robotics and Constructivism in Education

In this workshop a constructivist view for learning is adopted, whereby robotics technologies are not seen as mere tools, but rather as potential vehicles of new ways of thinking about teaching, learning and education at large [2]. This didactical methodology promotes the idea of “learning design”, which is central in the constructivist pedagogy introduced firstly by Resnick [1]. In this workshop we corroborate this idea through the project-based learning approach in robotics [8]. Learning tasks of the workshop are organized as projects (small and large) that encourage pupils to design and develop their own ideas are either instructor led or completely arisen from students. In our workshop we support this idea through the project-based learning approach. Pupils, in a constructivist learning environment, are invited to work on experiments and authentic problem-solving with selective use of available resources according to their own interests, research and learning strategies. Seeking solutions to real world problems based on a technological framework means to engage students’ curiosity and initiate motivation [6]. Learning tasks of the workshop are organized as small or large scale projects that encourage trainees to design and develop their own ideas. The active involvement of the trainees in all the parts of the workshop is another objective of the workshop [4].

To offer a good education it is necessary to ensure that the faculty remains at the cutting edge of relevant technologies, such as humanoid robotics, because technology changes rapidly over time. For this reason it is crucial that universities include this field in their engineering education. As it is said in [1] and [3], pedagogic robotics contributes in education:

- As knowledge and applied skills from several areas are needed, students expand their studies and interests.
- The use of the scientific method for solving problems and proposed exercises promote creativity, planning and organization of thinking strategies.
- Students, as a part of an active learning in which decisions are reached continuously and where errors are a key factor, are encouraged to supply new ideas and alternative solutions.
- Because robotics experimental sessions are often faced in small groups, students create a collective and cooperative consciousness, learn to appreciate their colleagues work and establish constructive dialogues in order to take decisions.
- Since this kind of learning is interactive and fun, students show more availability which makes teaching easier.

B. Motivation and Objectives

This project was born from the desire to expand the content of the experimental sessions of the Industrial Robotics course carried out in the Engineering degree in the Industrial Engineering School of Barcelona (ETSEIB) with some introductory sessions to humanoid robotics. Previously these

sessions consisted in working with some robotic arms and a brief introduction to computer vision and image processing. Nevertheless, the increasing integration of humanoid robotics in our society gave the chance to add this field to our education by means of some experimental sessions in an understandable and entertaining way. As a consequence, students will have another Robotic area to experiment with.

Moreover, with these practices, students carry out controlled activities in which they apply their previous knowledge to new situations and acquire basic skills and procedures of how to confront some problems related to the subject under study.

The main goal of this project is the design, development and implementation of some experimental sessions that provides to students a first contact with humanoid robots. These sessions consist of several creative and interactive activities that facilitate memory, transfer and generalization of learning. Besides, it will offer to students a practical way to apply their theoretical and cognitive concepts from courses already taken or that will be taken in a future, for example Automatic Control, Computer Science, Electronics or Mechanics.

Each experimental session remains open in order that the students increase and consolidate the corresponding skills; however every session has its own objectives that are expressed to the students at the beginning of the script. Following this scheme, the script is divided in two parts. The first one presents some essential concepts needed for the practice. Some of them will be only as a reminder while other ones have not been seen in prior courses and must be understood for the proper running of the session. It also includes commands and orders that students may not know, in order to use the working material and are deemed necessary as a helping hand. The second part of the script includes a series of exercises related to the previously explained theory, students will have to face up, implement a solution and finally test on the robot in order to check if the program designed works as required.

III. LABORATORY EQUIPMENT

The practice sessions with humanoid robotics are held at the Robotics Laboratory that the Automatic Control Department has available in the Industrial Engineering School. The laboratory has seven Robonova humanoid robots equipped with an ultrasound sensor, an infrared sensor, a sound sensor and an accelerometer.

A. Hardware

Robonova-I from HITEC is a humanoid robot designed specifically to get started in this area of robotics. However, it is also a robot for more experienced people. Its control board permits upgrading both the software and the hardware leading to new possibilities of utilization. The robot is 45 cm tall and it weighs 2 kg.

Robonova has 16 operative HSR-8498HB servomotors located as shown in Fig. 1 (6 in arms and 10 in legs). Nevertheless, the control board allows up to 24 servomotors.

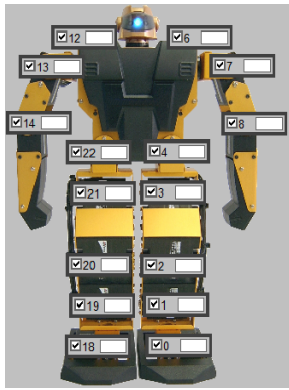


Figure 1. Servomotors Location at Robonova-I HITEC.

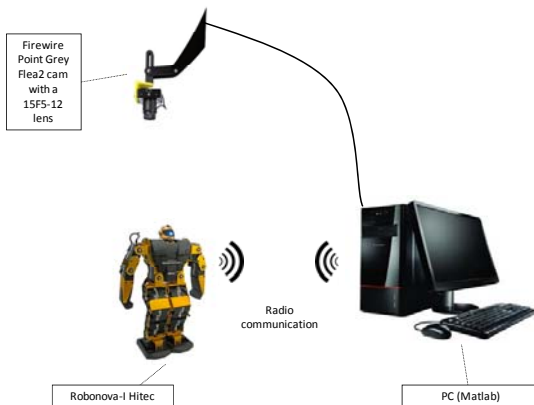


Figure 2. Stage of the visual-servoing experimental session.

Over the basic robot, various sensors have been incorporated. First, an infrared sensor (SHARP GPD12) with distance measurement range from 10 to 80 cm. Second, an ultrasound sensor (Maxsonar EZ1) with distance measurement range from 0 to 6.45 m. Third, a two-axis accelerometer (ADLX322) with g-force measurement range from -2 to +2 g. Lastly, a sound sensor can measure sound from 80 dB.

B. Software and Programming Language

RoboBasic is the language used for programming Robonova. This code is a variation of the BASIC language designed specifically for humanoid robots. The commands needed to control a robot have been added to the general BASIC programming language, although most of the language still resembles to BASIC. In addition, the default software has some applications in order to create and download programs in the control board so that they could be executed autonomously. The first one is also called RoboBasic. It is the most used programming environment and this application is utilized in the script of the experimental sessions.

C. Visual Servoing Session

For the realization of the visual-servoing practice, it is necessary to incorporate some extra devices to the robot and prepare a special stage. Fig. 2 shows this stage set to perform this experimental session. So that the robot can walk

independently it is necessary to use some wireless communication with the computer. In our project, we have used radio communication. For this reason, the communication is realized by means of two YS-C10U receiver/transmitter devices that transform the ETX/EX serial signal into radio and vice versa. In addition, in order to capture the robot motion we have fixed a Firewire Point Grey Flea2 camera with a 15F5-12 lens in the ceiling.

IV. ASSESSMENT OF THE WORKSHOP AND DISCUSSIONS

The workshop has been organized for three weeks in the summer (45 hours), when the regular course in high schools is finished. Over 20 students have participated in the workshop, selected from high schools that have demonstrated their interest in this new didactical experience. All the students have finished the workshop with excellent grades showing high interest in the new robotics approach. After a set of questions, it is concluded that they found the experience very fruitful and their interest in enrolling in an engineering degree is higher than ever. The authors are already preparing a second edition of the workshop because the experience has been also very enriching for all the instructors involved.

V. CONCLUSIONS

In this article the novel workshop, "Humanoid Robotics" for high school pupils has been presented. This workshop has been carried out based on a constructivist pedagogical methodology and four experimental sessions have been prepared. From the assessment of the workshop it appears that the training methodology ensured the students active participation and this encourages the authors to repeat the event. These practices were also carried out successfully as a part of the Industrial Robotics course at the Industrial School of Engineering at the UPC.

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Work in Progress: Identification of Misconceptions governed by Emergent Phenomena in Photovoltaics Content using the Delphi Method

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Abstract— With the emphasis and growth of solar energy, there is a rising need to educate students to perform in PV engineering. However, the curriculum for PV Engineering has not been well-articulated - needing both a focus on what that content is, and also what learning challenges students face when they learn it. Misconceptions, primarily those resulting from a limited understanding of emergent phenomena, can act as significant barriers to learning, and as such should be considered in curriculum development. The purpose of this work-in-progress is to use the Delphi Method to identify emergent phenomena in PV that is critical to the understanding of PV, while highlighting the resulting misconceptions that can result when students learn this content.

Keywords—*photovoltaics; semiconductors; emergent processes; complexity; misconceptions; delphi*

I. INTRODUCTION

At the top of the list of Grand Challenges released by the National Academy of Engineering (NAE) is the development of solar energy. The NAE states that, if left unanswered, these challenges could have a significant deleterious effect on our way of life (NAE). Photovoltaics (PV), solar cell devices that convert the sun's energy into electricity, is the technology poised to meet this challenge. At the current growth rate of 40% per year, solar cells could be fulfilling all of the U.S.'s additional energy needs within 5 to 10 years [1]. The most significant limiting factor at this time, however, is not technology, but human capital. The advances made in the PV industry have outpaced the rate at which universities prepare students to fill the many positions that PV creates, from research and development to installation and maintenance. Few degree programs are offered within the field of PV. Further, because PV content is often taught building on semiconductor fundamentals, it does not thoroughly address the knowledge needed for an accurate understanding of PV. If we are to meet the need for human capital in PV, steps must be taken to develop a PV curriculum that effectively engages students and promotes learning [2].

The photovoltaic curriculum is in its earliest stages of development, which presents a challenge, but also an opportunity—to build an entire curriculum for the field from scratch, incorporating cutting-edge educational research from cognitive science, educational psychology and engineering education. Although there are many facets to curriculum development, a reasonable first step is to identify the critical

concepts, processes, and procedures that provide fundamental understanding of PV. In addition, we need to identify the conceptual challenges that students face when they encounter this content. These challenges can act as potential learning barriers for students, both cognitively and motivationally.

Some of the most tenacious problems in understanding scientific concepts are the presence or development of misconceptions. Unlike procedural errors or lapses of memory, which are relatively easy to detect and remedy, misconceptions often go unnoticed by students and instructors, and can be extremely difficult to unlearn [3]. Thus, we are particularly interested in identifying misconceptions as we go forward in determining the key PV content.

Understanding PV (and semiconductors more generally) relies heavily on understanding emergent, as opposed to direct, processes. Emergent phenomena are those processes that result from the interaction of numerous lower level interactions, not resulting from a singular direct causal factor [4]. Research in other areas of scientific content has shown that emergent phenomena frequently lead to the development of more robust misconceptions than do direct phenomena [5]. Although we do not yet have a set of critical concepts for PV education, we suspect that emergent phenomena will be central to the challenges of mastering PV, and we will be paying particular attention to misconceptions relating to emergence while developing a comprehensive map of the critical concepts and challenges PV creates.

The aim of this work-in-progress, therefore, is to describe our use of the Delphi method for the purpose of identifying the most significant and challenging phenomena for the ongoing development of the PV curriculum, with an emphasis on emergent phenomena. As we will elaborate below, we believe that the Delphi method is the best way to achieve expert consensus.

II. METHODS

A. The Delphi Method

The Delphi method is a well-established process for finding solutions to complex problems that do not lend themselves to quantitative or algorithmic solutions. Instead they require qualitative approaches [6]. The Delphi method has been used in numerous fields; in engineering education, it has been successfully employed in the development of concept inventories [7]. The method requires a group of subject matter experts (SMEs) to come to consensus through a rigorous,

iterative process in which each wave of inquiry influences the scope and direction of further investigation - revising and refining the problem space until consensus is reached. The Delphi method can be implemented in a number of ways [6]. We will be using a face-to-face approach because the curricular problems are not well known.

This study will be conducted in three phases. The purpose of Phase I is to develop preliminary materials to provide a starting point for expert discussion, and, in doing so, identify the SMEs needed for a broad examination of PV content. The preliminary materials, drawn from existing texts and syllabi will provide a succinct yet detailed account of the current state of PV education, and introduce the SMEs to the cognitive and motivational landscape underpinning students learning of PV.

Phase II, which will take place during an intensive 2-day workshop, will alternate the SMEs between meetings as a complete group and in focus groups of approximately 8 participants. The larger assemblies will be used to provide background information and to report out and discuss the results of the focus groups. The goal will be to collect the data needed to develop a preliminary account of the critical concepts in, and challenges to learning PV.

In Phase III, the data will be analyzed and further elaborated and refined through small online meetings about specific topics. Ultimately, the goal will be to organize and rank the critical concepts and challenges, especially those challenges regarding misconceptions related to emergence.

B. Subject Matter Experts

Essential to the Delphi method is the recruitment of experts from all areas relevant to the question at hand. Experts must be willing and capable of articulating not only explicit knowledge, but also the tacit knowledge and practices that contribute to a problem and its solution. The group must be large enough to ensure breadth, and small enough to facilitate in-depth conversation and debate [6]. We anticipate recruiting a group of approximately 25-30 experts in the areas of PV and semiconductors, to address the specific content, and experts in cognitive and motivation psychology to address the learning issues associated with mastering that content. Because of the transdisciplinary nature of the project, these experts must be willing to engage in the hard work of cross-disciplinary talk, and learning at least the basics of the disciplines involved. In Phase I, this work will begin with providing all participants with a basic grounding in the relevant disciplines. In Phases II and III, balanced groups will be created that ensure all areas of expertise are represented in all conversations.

C. Data Analysis

The information gathered in Phases I and II will be qualitatively analyzed from artifacts, audio-visual data, and field notes. The researchers will be responsible for extracting both the explicit and tacit content from these data sources for expert evaluation and feedback in Phase III. Initially, Phase III will also rely on qualitative coding methods, leading up to the development of a survey that will be quantitatively analyzed to measure the degree of consensus and to identify areas of greatest and least consensus.

III. OUTCOMES, LIMITATIONS, AND FUTURE RESEARCH

The results of this study will represent only the first step in identifying how to best design an effective PV curriculum. Without a clear picture of the content and challenges involved in PV education, incorporating such issues would be premature; nevertheless, the researchers will be looking for areas of potential opportunity and impasse related to these areas.

A second limitation is that, although the project is intended to culminate in a closed-ended survey, it may prove that this step is not yet indicated. We cannot know how complex the results will be, nor how much or little consensus will be achieved. Still, we believe we will be closer to that goal at the end of the project than we are now.

Regarding future research, our goals are as follows: (a) use the knowledge gleaned here to build the PV curriculum and test its effectiveness in limiting learning barriers, (b) develop interventions to help students overcome misconceptions from incorrect conceptualizations of emergent phenomena, and (c) determine how to overcome misconceptions through promoting intentional conceptual change[8].

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Work in Progress: A Developmental Approach to Better Problem Solving: A Model for Bridging the Alverno Gap

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Abstract— The department has adopted a holistic student-centered approach to support attributes of the Engineer of 2020. Among these include a culture that embraces intellectual diversity, better team skills, improved problem solving skills, and better complex thinking skills. Strategies incorporating classroom inversion, active learning, and team projects have demonstrated remarkable gains in retention, intellectual diversity, and general problem solving skills. While well above the national average, continued intellectual growth has stagnated over the past three years and remains below that desired both by industry and by the department. In an effort to improve complex thinking skills the department is adopting a developmental approach modeled by Alverno College which has demonstrated substantial growth in many of the attributes of the Engineer of 2020. As a first step towards reducing this "Alverno Gap", the department has adopted a developmental approach which is focused on improved problem solving skills within a team environment. In this paper, we describe the Alverno model, discuss an explicit developmental approach to team skills and processes, and provide some initial insight into using embedded assessment as an integral component of transformative curriculum.

Keywords—component; developmental; problem solving skills

I. THE NEED FOR TRANSFORMATION

As a result of a global economy and the move to lean enterprises, industry has taken a stronger stance in asking for a different type of engineering graduate that has the leadership and complex thinking skills needed by today's industry. To maintain the nation's economic competitiveness and improve the quality of life for people around the world, engineering educators and curriculum developers must anticipate dramatic changes in engineering practice and adapt their programs accordingly [1]. This report and a companion phase II report [2] identifies some of the ideal attributes of the engineer of 2020 as well as recommendations for curricular innovations that begin to address these attributes. Further, this is not an isolated study. The Accreditation Board for Engineering and Technology (ABET) implemented a revolutionary approach to accreditation by focusing on what is learned rather than

what is taught, thereby fostering innovation [3]. Industry increasingly demands development of team skills, leadership skills, a better understanding of business processes, an ability to innovate and think outside of the box, and an ability to communicate effectively in a diverse environment (see, for example, [4]). In short, industry needs engineering graduates that can help solve and implement solutions to the complex problems industry is faced with today. Figure 1 below provides a conceptual framework for skill development for the engineer of 2020.

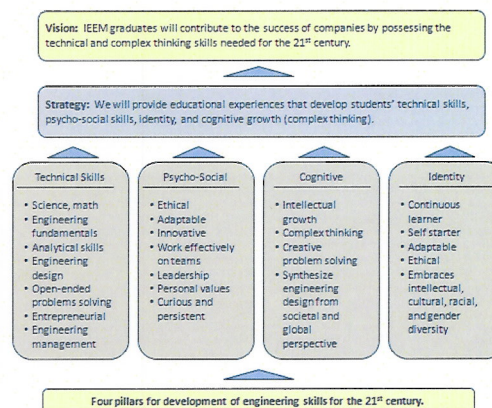


Figure 1. Four Pillars of Development of the Engineer of 2020

While Figure 1 displays the skills and attributes for the engineer of 2020, it provides only a limited framework for development of these skills. In this regard, the department has incorporated a research based approach to engineering education, assessment, and best practices. For nearly a decade the department has adopted a best practice approach for pedagogies of engagement [5], intellectual diversity [6], and intellectual development [7-10]. Department courses routinely integrate cases, role plays, simulations, active/collaborative learning, multi-disciplinary team projects, and service learning components.

As a result of these initiatives, the department has seen remarkable results in terms of intellectual diversity and improved problem solving. For example, of the last 144

students completing a typological index in the first semester, the program has lost only 5 students, which roughly translates to a 95% four year retention rate. More importantly, by explicitly stating an expectation for intellectual diversity the department has seen a corresponding increase in intellectual growth using the Reflections on Current Issues instrument. Nevertheless, complex thinking skills remain below level 5 which is a stated goal of the department. By incorporating an explicit developmental framework to student learning, Alverno College graduates consistently achieve higher levels of intellectual development. We refer to this gap as the Alverno gap and we have launched a stronger developmental approach for improved problem solving by incorporating a similar approach.

II. THE ALVERNO MODEL

The Alverno model consists of a conceptual shift from a course-based distribution of what is taught to a curriculum-based, metacognitive approach to what is learned by students as developing learners, thinkers, and performers within the engineering profession. By placing the learner at the center of the curricular enterprise and how she/he experiences the curriculum and demonstrates learning outcomes shifts the focus from teaching content alone to integrating content and knowledge in a more constructive manner.

A key component of the Alverno model is reframing assessment as an opportunity for student learning. Consider, for example, a traditional view of curriculum development: we note a problem for improvement, devise an intervention strategy, and assess the result. In this approach, assessment is viewed as a necessary burden for demonstrated efficacy of the intervention. Alternatively, by explicitly stating required performance outcomes, one provides a learning environment where student self-assessment coupled with faculty and peer feedback provides a construct for learning that lasts [11].

In order to shift from a knowledge transmission curricular system to a system where students integrate and transfer learning outcomes across courses and discipline content areas, one must consider learning outcomes along developmental lines. For example, a goal of every university is that students can demonstrate a capacity to transfer understanding of different problem solving techniques into a variety of contexts and it is in that manner that we typically teach. However, the ability to transfer and adapt across different contexts is a high level thinking skill and is not likely to be achievable if lower skills are not developed and reinforced along the way. If a student cannot articulate the problem solving process, it is not possible to transfer the problem solving framework from one context to another. Consequently, we must explicitly state these outcomes for students and require demonstrated performance along developmental lines as the student progresses through the curriculum. A rubric defining a developmental approach for general problem solving is shown in Table 1 below.

TABLE 1. DEVELOPMENTAL RUBRIC FOR PROBLEM SOLVING

| Attribute | Demonstrated Abilities | Level |
|----------------------|--|---------|
| Problem definition | Can articulate the problem solving process by making explicit steps to approach a problem | Level 1 |
| Problem articulation | Can identify and detail appropriate alternatives and constraints | Level 1 |
| Define elements | Practices elements of a disciplinary process to approach problems | Level 2 |
| Problem analysis | Can independently analyze, evaluate, and select various approaches to develop solutions | Level 3 |
| Problem evaluation | Performs all phases within a disciplinary problem solving process including evaluation and real or simulated implementation | Level 4 |
| Problem transference | Demonstrates a capacity to transfer understanding of different problem solving techniques into a variety of contexts | Level 5 |
| Applies frameworks | Applies methods and frameworks from a variety of disciplinary perspectives and adapts them to a specific context; demonstrates independence and creativity in problem solving activities | Level 6 |

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Special Session: The CS2013 Computer Science Curriculum Guidelines Project

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Abstract—Work began in late 2010 on a project to revise the ACM/IEEE-Computer Society Computer Science volume of Computing Curricula 2001 and the interim review CS 2008. The new guidelines for computer science are scheduled for release in 2013. This interactive session will give the computing education community an opportunity to review current working documents created by the CS2013 Steering Committee and thus influence the CS2013 volume scheduled for release in 2013. The Strawman draft of CS2013 was released in early 2012, containing new knowledge areas as well as significant updates to previous knowledge areas. The Steering Committee will present the Strawman draft and discuss changes to that draft that are being considered as a result of the first round of public comments. The majority of the session will be devoted to engaging attendees in guided discussions of sections for which additional community input is particularly relevant.

Keywords—computer science education, computing, curricula, CS2013.

I. INTRODUCTION

Since the publication of Curriculum 68 [1] over 40 years ago, the ACM/IEEE-CS Computing Curricula volumes have helped to set international curricular guidelines for undergraduate programs in computing. The most recent complete Computer Science curricular volume was released in 2001 (CC2001) [2] and was followed by a review effort that concluded in 2008 (CS2008) [3]. The next curricular volume in the series is targeted for publication in 2013. This panel seeks to update and engage the computing community on the Computer Science 2013 (CS2013) effort.

The rapid changes and expanding diversity in the computing fields makes the development of guidelines challenging. Moreover, the growing diversity of topics in Computer Science and the integration of computing with other disciplines create additional challenges and opportunities in defining computing curricula. Balancing this topical growth with the need to keep recommendations realistic and implementable in the context of undergraduate education is particularly challenging. It is vital to the success of the project that the new volume be based on broad participation by the community of CS educators.

By considering both the current state of the field and promising future directions, and by rethinking the knowledge and skills essential for a CS curriculum, CS2013 strives to

provide advice and guidance to the computing education community throughout the current decade.

The high-level themes on which the CS2013 effort is based include:

- *The “Big Tent” view of CS* – As CS expands to include more multi-disciplinary work and new programs of the form “Computational X” are developed, it is important to embrace an outward looking view in computing that sees CS as a discipline actively seeking to work with, draw from, and integrate into other disciplines.
- *Managing the size of the curriculum* – Although the knowledge base of CS has expanded dramatically in the past decade, it is not feasible to proportionately expand the size of the curriculum. CS2013 must re-evaluate “essential topics” without requiring more total instructional hours than the previous guidelines. The circumscription of curriculum size is necessary to promote more flexible models for curricula without losing the essence of a rigorous CS education.
- *Actual course exemplars as opposed to stylized course guidance* – CS2001 took on the significant challenge of providing descriptions of stylized courses incorporating the knowledge units defined in that report. While this was a valiant effort, it was felt in retrospect that such course guidance did not have much impact on actual course design. As a result, CS2013 takes a different approach: identifying existing successful courses and curricula as fielded exemplars of how relevant knowledge units can be addressed in actual programs. This bears similarity to the report by CRA-E [4], although that report focused on preparing students for research careers.
- *Institutional needs* – Curricula exist in the context of specific institutional needs, goals, and resource constraints. As a result, CS2013 allows for explicit flexibility in curricular structure through a tiered set of core topics, where a small set of Tier 1 topics are considered essential for all CS programs, but individual programs have flexibility with regard to their coverage of Tier 2 topics.

II. CS2013 BODY OF KNOWLEDGE

The Strawman draft of CS2013, available in spring of 2012, focuses primarily on updating the Body of Knowledge in computer science, organized around 18 Knowledge Areas, outlined below:

- Algorithms and Complexity (AL)
- Architecture and Organization (AR)
- Computational Science (CN)
- Discrete Structures (DS)
- Graphics and Visual Computing (GV)
- Human-Computer Interaction (HC)
- Information Assurance and Security (IAS)
- Information Management (IM)
- Intelligent Systems (IS)
- Networking and Communications (NC)
- Operating Systems (OS)
- Platform-Based Development (PBD)
- Parallel and Distributed Computing (PD)
- Programming Languages (PL)
- Software Development Fundamentals (SDF)
- Software Engineering (SE)
- System Fundamentals (SF)
- Social and Professional Issues (SP)

Two substantial reorganizations in the Body of Knowledge include introductory programming and systems. In the area now called Software Development Fundamentals (previously called Programming Fundamentals), we have extracted fundamental software development concepts, including topics in algorithms, design, programming, and software development processes. In systems, we have identified common themes among operating systems, networking, and computer architecture that are captured in a new area called Systems Fundamentals. Additionally, specific developments in the field in the past decade (such as the pervasiveness of parallel computing and the need for better understanding computer security) have given rise to the development of knowledge areas in Parallel and Distributed Computing, Information Assurance and Security, and Platform-Based Development.

III. DESCRIPTION OF THE SPECIAL SESSION

The goal of this panel is not simply to provide an update on the state of CS 2013, but to actively engage the community in

work that will eventually manifest in the final published volume. Holding this panel at FIE is an important step in further engendering that engagement in a broad forum. Indeed, the CS2013 effort has already reached out to a number of communities, holding presentations at SIGCSE-12, SIGCSE-11, CSEET-11, FIE-11, FCRC-11, EAAI-11, as well as being involved in curricular discussions at SIGCOMM-11 and SPLASH-11.

The desired outcomes of the session include

- Increased awareness and participation in the CS 2013 Project among the computer science community;
- Review of several sections of the Body of Knowledge, including revision of outcomes;
- Review of comments and responses generated from the open comment period for Strawman; and
- Discussion of and guidance on the identification and documentation of course and curricula exemplars.

The session will start with a brief overview of CS2013 and the Strawman draft. Participants will then break out into small groups based on their areas of interest to review sections of the draft. Members of the Steering Committee will facilitate these discussions. In this way, session participants will have the opportunity to influence the next draft of CS2013 and the ongoing work of the Steering Committee.

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Harnessing Theory in the Service of Engineering Education Research

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Abstract—Research questions in STEM disciplines are frequently strongly contextualised in the teaching and learning practice of the researcher. In this paper we chart a number of possible paths a researcher can follow from a single research proposition, or fundamental research question, to results which can vary significantly in nature. In order to do this, we establish a theoretical framework for research activity and examine the meaning of "theory" as a cognitive and research tool that helps engineering education practitioners and researchers. The paper reflects on the nature and role of different types of theory at four distinct stages of engineering education research: disciplinary, methodological, analytical, and interpretive. We illustrate how theory applies to the framing and integration of study results, and assists in the process of relating theories of learner development and learning to results of empirical data analysis.

INTRODUCTION

In this paper, we respond to criticism of engineering education research (EER) as methodologically unsound and contribute to a nuanced understanding of the nature of engineering education research by discussing how it draws upon different types of theory. The goal is to understand how theory is used in our research field and to provide opportunity for self-reflection about the philosophical and epistemological commitments that underly engineering education research.

The structure of a teaching and learning study, and the nature of the evidence it produces is important for the relevance to the target audience of a piece of research. We argued in Daniels and Pears [1] and Thota et al. [2] that the relationship between the research question and the nature of expected research outcomes are central to the process of resolving alternative epistemological positions and in choosing research method, and data collection and analysis approach.

In our previous work, we propose meta-level frameworks, which can be used to reason about the implications of epistemological and methodological choices on the nature of the results that can be obtained. The tree metaphor proposed

by Kinnunen illustrates the epistemological implications of data collection methods, linking types of data collection to theoretical positions and the methodological root which a study implicitly acquires as a result of research design choices.

This paper combines these results and illustrates their complementary applications. The remainder of this paper is organized as follows. In section 2, the implications of theories and hypotheses of tertiary learning processes, and the role and meaning of the term "theory" in that process are examined. Section 3 illustrates different ways to research the same question, and how this results in different choices and outcomes. In section 4 we discuss how the practitioner-researcher gap can be bridged through the use of theory. We commence with a discussion of theory related to learning of the discipline itself. Following this, is a discussion of theory as it applies to methodological choices and to data collection and analysis of data, and theory as a tool to reason about the meaning of results. Finally we summarise our contribution to the discourse on relationship between research questions and results.

EPISTEMOLOGICAL ROOTS AND THEIR IMPLICATIONS

The implications of theories and hypotheses of tertiary learning processes in the disciplines, and the role and meaning of the term "theory" in that process, is not a new topic in educational research. We commence our discussion with examples of classifications proffered by two prominent scholars as a background to a discussion of the role and significance of different types of theory to the pursuit of EER.

One view of the discourse on the role of theory is that of Cohen et al., adapted from Barr Greenfield (1975) [3]. They discuss two major types of theory.

- Theory as objective: A rational edifice built by scientists to explain human behaviour.
- Theory as subjective: Sets of meanings which people use to make sense of their world and behaviour within it.

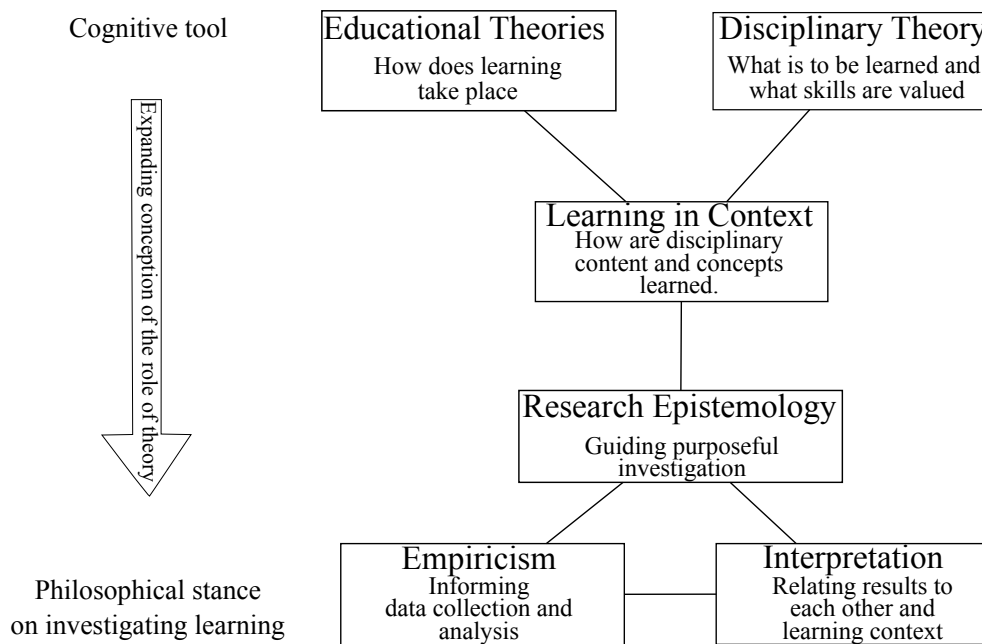


FIGURE 1. Roles of theory and relationship to researcher conceptions of theory

In his critical evaluation of sociological theory, Mouzelis [4] also identifies and discusses what he distinguishes as two distinct kinds of theory:

- Theory as tools for thinking.
- Theory as a set of statements telling us something new about the social world and which can be proved or disproved by empirical investigation.

The common feature of these classifications is that they focus on the manner in which theory is used. So, what do we mean by using the term “theory” in EER? To answer this question we commence with an attempt to define the term and how it is applied in the EER context. Looking at how the EER community literature reports on its research, we suggest that one can define theory as, “a way to reason about the nature and structure of observable learning phenomena, and their operation and inter-relationships”.

We also propose that the contribution of theory be viewed in two ways. The first of these is explanatory power, which is related to the richness of the theory as a tool for explaining and reasoning about the properties and interrelationships of the phenomena being observed. The other is the utility of the theory as a means to structure activity and guide structured investigation. In both cases a key property is the relationship between theory and empirical study.

Theories are adopted and discarded by research communities based on their perceived explanatory power and utility in relation to empirical investigation. Part of the process of harnessing theory in the service of EER is to discuss these two aspects of theory in relation to research in our discipline. To do this however, it is necessary to provide a structured approach to theory, and how theory is used in our research.

We suggest that the focus of the research activity has an

influence on the importance attached to the explanatory power and structural utility of different types of theory, and that theory means slightly different things depending on the type and level of abstraction of the research activity. To explore this series of claims we provide a classification of modes of use of theory in EER. In figure 1, we integrate the views of theory advanced by Cohen and Mouzelis and combine these with our own views of the development of EER. The top section of our diagram integrates objective theories, which are often related to the discipline and describing learning.

As theories are combined and used by researchers earlier theoretical stances give rise to domain specific theories which are used to reason about learning of a specific discipline area. These theories can relate to learning specific concepts and skills, for instance in Physics, Maths or Computer Science. There are a number of examples of such studies across disciplines of which we are aware, some examples include the following papers [5]–[7].

The lower half of figure 1 relates theory to investigative purpose in a research study. Epistemological and ontological works often guide our research providing structure and coherence. They also establish the grounds for collecting and arguing from evidence, providing a value system within which to consider what constitutes evidence, how claims are made and supported, and upon what constitutes “proof”. However, these types of theories do not operate in a vacuum. They form a research ecology in relation to theories and methods for data collection and analysis that generally derive from an epistemological stance or research tradition.

Finally, higher level theories allow us to reason about the broader implications of the results of individual studies, often allowing us to combine results which were obtained

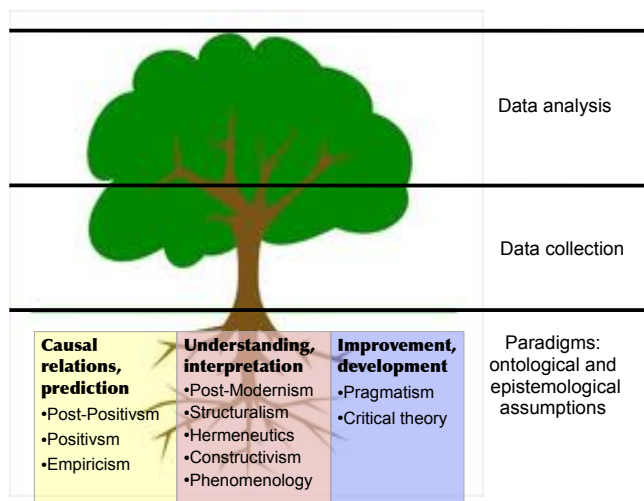


FIGURE 2. Implications of epistemological basis for method and outcome

by methods drawing on different epistemological roots. An example of such a theory might be Wenger's social theory of learning [8] which might be used to integrate results related to identity derived from interview data using phenomenography [9], with other results on social position in a community of practice [10] obtained from classroom observation and ethnographic analysis.

THREE PERSPECTIVES

In this section, we discuss three perspectives on research that provide different views of the overall model presented in figure 1. As we have already argued, the impact of the tacit epistemological basis upon which much pragmatic educational research in engineering is conducted has profound influences on the results. This impact can be discussed from three different viewpoints, namely data collection, research question, and research ecology. After the discussion of the three frameworks, the current paper adds to the discussion by focusing on how the practitioner-researcher gap is bridged through use of theory.

Noting that many research studies commence with a choice of data collection and analysis method, Kinnunen proposes a tree analogy, which provides a vivid representation of the manner in which choice of data collection method is strongly connected to an underlying epistemology. This observation has far reaching theoretical implications for the entire research enterprise (See figure 2).

The tree can be viewed as a metaphor for the research process. In its simplest interpretation it allows us to visualise how methodological choices are connected to the ontological and epistemological beliefs of the researcher (whether they are conscious of them or not). For example, if a researcher chooses to collect data through interviews (semi-structured/open) that reflects what the researcher believes to be valid information.

At a more advanced level, the tree can be used to analyse research examples by overlaying them on the three levels of abstraction that the tree is a metaphor for. This makes it possible to discuss the implications of choices made at all

three levels of abstraction in a structured manner. For example, a study that has its roots in phenomenology and hermeneutics, can be expected to have a trunk in phenomenography, the leaves include interviews as a data collection method and thematising and categorizing (and building up the outcome space) as data analysis "strategy". This constructs a coherent line from roots to the leaves¹.

The next viewpoint (figure 3), takes its point of departure in the research question, and the nature of the enlightenment the research is designed to gain. The type of answer a study provides depends on the path that is chosen through the levels depicted by the figure. Each path in this figure is analogous to following one of Kinnunen's research trees, and uses the research question to identify and reason about choice of a suitable root.

What does following one of these paths actually involve? Since each path represents the study of an aspect of our question, the design in each case will be strongly influenced by the research approach. The point of using methods from other disciplines in EER, is to be able to address different aspects of the research question at hand. Each possible path results in distinct answers, but they will have different properties depending on the approach taken.

In general, the nature of a research approach lifts some facets of the question into sharp focus while others remain blurred and in the background [11]. Richer answers to any question can be expected if more of the relevant facets are explored. Informed choice of research approaches in a multi-method study provides the researcher with a richer set of data. Such data, in turn, helps to build a stronger case by providing several types of the support for claims in regard to improving learning outcomes.

Astute readers will perhaps wonder why the research question is not completely enclosed in figure 3. The lightly sketched segments are a reminder that EER is not the only research field interested in such questions. Other candidate areas might be education or social sciences, where studies based on the same question, can be expected to generate results which might have little relevance for the learning and teaching of engineering, but contribute to a broader understanding of how learning takes place.

The final viewpoint in figure 4, depicts a mixed-methods research framework as an interaction of research elements rather than as a linear process. In any research study, the research purpose, philosophical assumptions, and research design choices made by the researcher influence the research outcomes. The researcher's theoretical, personal and/or professional goals determine the problem and aid in formulating research questions which are then refined through the process of literature review. The philosophical assumptions that a researcher adopts include world views that shape methodological choices. The research validity and credibility criteria used in a study also stem from the researcher's conceptual orientations.

¹As examples cumulated we noted how many different roots there are (and how there are certain root families).

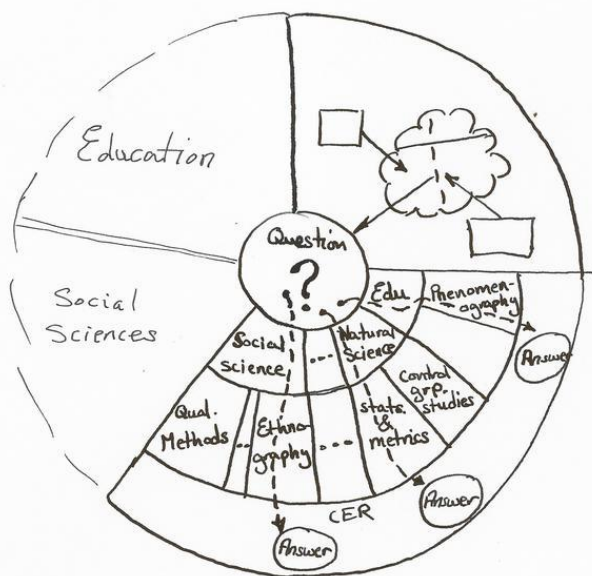


FIGURE 3. An holistic model of pragmatic EER

Figure 4 shows that the research purposes and the underlying philosophical assumptions in turn, influence the nature of the design typology, the selection of the data collection instruments, and the analytical methods that are followed. Research studies, that include the collection of qualitative and quantitative data collection, undergo an iterative process as the findings get integrated at various stages. The conclusions and inferences from such studies are a synthesis of the research study elements as the researcher revisits the research questions/issues and justifies the methodology for each of the data collection method and the analysed results.

BRIDGING THE PRACTITIONER-RESEARCHER GAP

Why is the choice of underlying theoretical approach important for a practitioner turned researcher? In pragmatic EER, the point of departure for a majority of research studies is a desire to investigate a teaching and learning situation and to obtain illumination regarding aspects of a problem that faces the practitioner/researcher. In common with other families of embedded research, of which action research is an excellent example, the researcher is actively engaged in both research and the activity on which the research is being conducted. The implication of this standpoint is that the choice of research approach derives from the nature of the research question facing the researcher, and the type of insight the researcher deems will be most useful in helping to resolve the issue (with the subsequent impact on improvement of the overall learning environment in which the research question is situated).

Extending these ideas we discuss how theory is used in practice when we conduct investigations, and reason about

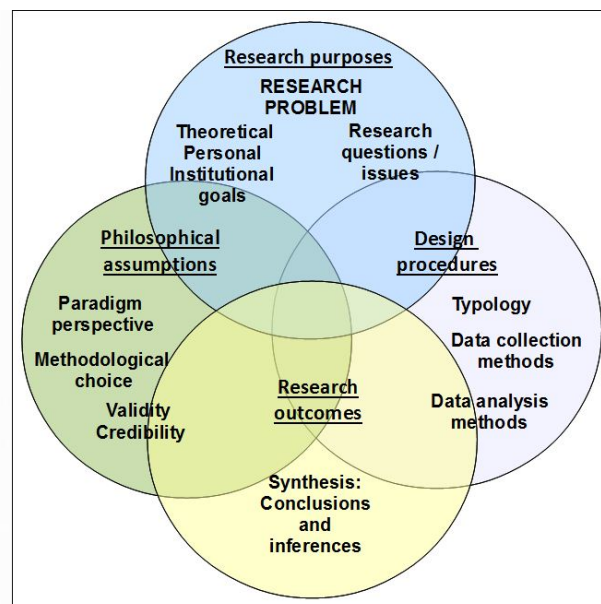


FIGURE 4. Illustration of the interaction of research elements [2]

the implications of study results for teaching and learning in engineering. We position the role of theory in computing/engineering education research in terms of the following:

- 1) Cognitive tools that help to map areas in learning and teaching computing/engineering.
- 2) Methodological guideline to define research approach, and methods for data collection and analysis.

Theories, as cognitive tools, help computing/engineering education practitioners by providing:

- Teaching theories related to computing and engineering i.e. Theory of the discipline (Body of Knowledge). They include the what and how of learning in that area, and the theories of the discipline itself.
- Guidelines to develop pedagogic frameworks for courses and lessons (laying the groundwork for scholarly curriculum and instructional design).

Theory related to understanding learning in engineering appears to have a more complex nature in its manifestations in the research literature. We have been able to identify several categories of theory use based on a broad sample of research literature which we have collectively reviewed over the last ten or so years.

On the level of more general EER, theories can be seen as methodological guidelines which help computing/engineering education researchers in their work. Our categorisation of theory in the lower section of figure 1 assists the researcher-turned-practitioner by distinguishing between:

- meta-theory, dealing with paradigm and methodological choices e.g. pragmatism, critical theory.
- support for structured data collection and analysis, e.g. interview techniques, population sampling.
- helping to integrate and interpret the results of investigations e.g. phenomenography, content analysis.

- For interpreting outcomes of investigations and relating them to a broader educational context e.g. activity theory, grounded theory.

CONCLUSIONS

In this paper we explore several aspects of how theory is used to support research activity, both with different purposes and at different levels of abstraction. A general research model is proposed, and its implications explored in relation to research activity of different types using three different analogies, or metaphors.

We conclude that there are several ways in which theory can be experienced as having value in the engineering education research endeavour. Practitioners have immediate use of engineering education research theories as cognitive tools, which guide innovative curriculum and instructional design. In this paper, by suggesting categories of theories as methodological guidelines for research. Our work contributes to a discourse which bridges the practitioner-researcher gap, and contextualises the use of theory in pragmatic engineering education research activity.. Understanding the philosophical stance of EER, and the expression of this philosophy in the manner in which theory is defined and used, contributes to the systematic and structured development of our research paradigm. In particular the models we propose provide a focus for structured reflection, and discussion about the nature and future development of EER. Finally, the models provide multiple views of research, and research validity and quality. Discussion of these values informs an ongoing discussion about what constitutes rigorous engineering education research.

ACKNOWLEDGMENTS

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Work in Progress: Theoretical Approach to Characterizing Changes in Students' and Engineers' Conceptual Understanding and Personal Epistemologies

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Abstract—Successfully preparing students to become practicing engineers requires the development of their conceptual and epistemological approaches to the world around them. This paper describes a robust, flexible and empirically testable framework developed to characterize engineering students' conceptual understanding and personal epistemologies as they develop from their sophomore year to their second year of engineering practice. The strength of the framework lies in the balances struck between firm commitments that can be confirmed or falsified, and open-endedness where existing theories are too contradictory to warrant such a commitment. The frameworks were developed through literature review drawing from the fields of cognitive science, educational psychology, science education, philosophy and learning theory.

Keywords- *epistemology; conceptual change; qualitative research; personal epistemology*

I. THEORETICAL FRAMEWORKS

Successfully preparing students to become practicing engineers requires the development of their conceptual and epistemological approaches to the world around them. Conceptual understanding of various topics could be considered akin to the tools students have to interpret, explain and predict phenomena in the world around them. In this analogy the students' personal epistemologies would be the ways they think about those tools in terms of their organization, purpose and limitations. Taken together, an individuals' conceptual understanding (CU) and personal epistemology (PE) determine how they will try to solve problems, and as engineers are expected in large part to be problem-solvers both conceptual understanding and personal epistemology need to be developed during undergraduate engineering education.

The purpose of this paper is to describe theoretical frameworks developed in the context of a longitudinal study of CU and PE from the sophomore year through the second year of engineering practice. The frameworks can both be defined in terms of three key assumptions. These stances are based on existing theoretical and empirical works [1-21].

CU and PE are assumed to be unstable across time and contexts [19, 22-26], despite a small set of tantalizingly powerful common patterns [1, 6, 14, 27-34]. These theoretical frameworks define conceptual understanding and personal epistemology as responses to particular circumstances, as perceived by the participant. Conceptual understanding is defined as the resources available to an individual for the interpretation, explanation and prediction of phenomena, while personal epistemology is defined as the collection of stances an individual takes on issues of knowledge and knowing. Conceptual understanding and personal epistemology are assumed to consist of the smallest components proposed by theorists, but again the data collection is organized and designed with potential larger groupings in mind. Similarly, personal epistemology is defined in terms of stances on issues. Inspired by work tracing the philosophical roots of personal epistemology [35], this approach does not assume any connections between individuals' stances across issues, although consistency would be easily recognizable. Both conceptual understanding and personal epistemology are assumed to be communicative behaviors in order to avoid the problematic assumption that researchers can infer unobservable cognitive phenomena [27, 36-40].

II. METHODOLOGICAL IMPLICATIONS

The open-endedness of this theoretical approach to conceptual understanding and personal epistemology needs to be balanced by more diligence in data collection. If CU and PE are assumed to vary across domain and interview context, but identifiable patterns are expected, then participants CU's and PE's must be explored in a variety of domains and contexts (which need to be carefully documented), and be characterized longitudinally over a meaningful amount of time. The importance of exploring different contexts, and the difficulty of expressing epistemological stances requires that data collection be somewhat opportunistic. Carefully designed interview protocols must be balanced with the freedom to occasionally derail those protocols in pursuit of a new way of approaching the data.

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Work-in-Progress: Exploring the essential nature of engineering education through philosophical inquiry.

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Abstract—In regard to the ongoing efforts to reform engineering education, this working paper proposes the methods of philosophical reasoning and argumentation for constructing and analyzing educational beliefs about the ontology and epistemology of engineering and engineering education.

Modern views of philosophy tend toward an instrumental perspective—one that believes that philosophy provides a rigorous method for describing and evaluating our understandings of knowledge and truth. Philosophical reasoning can help reconcile diverse beliefs resulting in more coherent and comprehensive statements about the nature of engineering and education.

Employing philosophical reasoning in the articulation of one's philosophy of engineering education can lead to a more coherent and consistent statement about what it is that engineering educators aim to achieve. This paper briefly describes the methods of philosophical reasoning and argumentation introduced in workshops on the philosophy of engineering education conducted at previous FIE conferences. A follow-up workshop focused on these methods is planned for this year's FIE conference. The outcomes of the upcoming workshop will be included in a final version of this paper on the topic of developing a philosophy of engineering education.

Keywords- *argumentation; rhetorical criticism; philosophy of engineering education; ontology; epistemology*

I. INTRODUCTION

There has been an ongoing discussion about revising engineering education for nearly a century. Some of the recommendations advocate for a greater emphasis on practical matters, others for a more liberal education for engineering students. And then there is the prevailing view that science and math form the core knowledge base of engineering. Different positions in this discussion generally stand on two questions: (a) What is engineering and (b) what is the best way to learn to become an engineer? The first question is a type of ontological question about the reality or nature of engineering. The second question is a type of epistemological question about what counts as knowledge and how do we come to know it. Ontology and epistemology are major branches of

philosophy with an immense history of development and debate. This paper describes methods useful for constructing and analyzing reasoned arguments about the ontology and epistemology of engineering and engineering education.

II. CONTRIBUTION

As mentioned above, there are two important questions that affect the teaching of engineering students: (a) What is engineering and (b) what is the best way to learn to become an engineer? While educators can usually provide immediate answers to these questions—when probed more deeply there appear additional questions and assumptions about which there is little agreement. This is especially so regarding how to educate students aspiring to be engineers.

These deeper questions cannot be answered fully with empirical evidence, the scientific method, or by appeals to history, authority, or prior beliefs [1]. At the deepest levels, they are philosophical questions and require the use of rigorous methods developed for philosophical reasoning and argumentation [1, 2, 3]. Philosophical reasoning and argumentation are analogues of the scientific method useful for sorting out and making sense of difficult ideas and concepts, which are not open to empirical verification and generalization [1]. Critically working out the conflicts and inconsistencies among the concepts and ideas that make up one's belief systems is a way to achieve a better understanding for better practice [2].

In the practice of education, educators continually make decisions based on their beliefs about how students learn. These decisions can proceed from an uncritical acceptance of an educational technique or from a critical understanding of the complexities undergirding the educational process [4, 5]. The contribution of philosophical reasoning to the educational process has enormous potential to enhance the development and quality of the educational enterprise for engineering faculty and students alike.

III. DESCRIPTION

The stream of this research on the contribution of philosophy to engineering education goes back several years including FIE papers and special sessions [5]. Several colleagues have presented various arguments at FIE

supporting the need for the philosophical development of engineering education.

A. Context

Three years ago, a special session at FIE, co-facilitated by the author, focused on the notion of philosophical inquiry as a means to strengthen and enhance the critical examination of engineering education. It was our belief that educators could develop their critical reasoning skills in the pursuit of a more rigorous and efficacious practice of engineering education, which in turn would contribute to the development of the field. This purpose was the core of a two-day workshop prior to last year's FIE conference. That workshop, organized by the author and colleagues, included keynote presentations by four eminent philosophers focused on engineering and engineering education: Steven Goldman (Lehigh University); William Pitt (Virginia Tech); Larry Bucciarelli (MIT), and Billy Van Koen (University of Texas, Austin). Along with lively discussions, there appeared little consensus—except to continue to pursue this line of research. One point of agreement that came from this workshop was the need to develop the participants' skills in philosophical inquiry. Thus, the author proposed a pre-conference workshop at this year's FIE (2012) and developed this working paper describing the methods for this workshop.

B. Methods

McCarthy [6] described philosophy as the critical quest for genuine knowledge about our world. Philosophical reasoning can help reconcile diverse views resulting in more coherent and comprehensive statements regarding our beliefs in what is engineering and how best to educate students in engineering.

Working out the differences and inconsistencies between conceptual frameworks is a goal of philosophy facilitated by methods of philosophical reasoning and argumentation [2]. Employing philosophical reasoning in the articulation of one's philosophy of engineering education can lead to a more coherent and consistent statement about what it is that engineering education aims to achieve. The philosopher is an artisan working with concepts assessing which ones are viable, which are arbitrary and inconsistent, and which survive the test of time [7]. In addition to philosophy, one can employ other fields such as communication studies, linguistics, psychology, computer science [8], as well as education, management, and organization studies.

Aristotle identified three forms of argument: apodictic—the demonstration of reliable knowledge based verifiable evidence; rhetorical—typically a one-sided effort focused on persuading an audience to accept the speaker's claims; and dialectical—a dialogue among participants for the purpose of settling on a consensus or compromised position [9]. Forming rigorous arguments is a primary means to working out the conflicts and incoherencies in competing belief systems. In the service of engineering education, the rigorous assessment and critique of one's belief systems regarding engineering and education is essential to the advancement of the profession of engineering and the field of engineering education.

C. Research Questions

The questions driving this project stem from the earlier work to clearly articulate a philosophy of engineering education. Specific to this paper, the primary question is: *How can the methods of philosophical reasoning and argumentation be used to articulate a clear and coherent philosophy of engineering education?*

D. The Contribution of Philosophy to Engineering Education

There is a growing tension between engineering and science [10]. For example, engineering scholarship is increasingly recognizing the contingent, contextual, values-driven, and pluralistic characteristics of engineering practice. This contrasts with the universal, context-free, values-neutral goals of science [6, 10]. And while many do not dispute the multifaceted nature of engineering—composed of science, math, practical, and social dimensions—integrating these different concepts is a difficult task.

Philosophical reasoning and argumentation are essential to the development of science and knowledge. It is a form of thinking and sense-making that helps foster conceptual change allowing for greater understanding and accommodation of alternative perspectives. Advancing one's facility with argumentation skills enhances one's ability to solve difficult, ill-structured problems [9]. Certainly the debate around alternative perspectives on engineering and engineering education are ill-structured problems having multiple solutions and multiple criteria for resolution. Developing these skills can benefit the articulation of a more coherent view of engineering and engineering education.

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Work in Progress: Do students need to learn to speak “Engineering-ese?” Conceptual change as language acquisition in engineering

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Abstract—Conceptual change is often approached with a concrete epistemology in which students must replace their misconceptions with correct conceptions. Drawing upon the literature and our research, we propose that we need a new, discursive epistemology that describes conceptual change as language acquisition.

Keywords—philosophy; epistemology; discourse; language; conceptual change; engineering education

I. INTRODUCTION

“The real problems of the differences between scientific concepts and those characteristic of everyday life have less to do with conceptual difficulties or misconceptions... and more to do with the problem that people do not have access to contexts in which science talk is functional and necessary.” [1]

When conceptual knowledge is discussed among educators, it is often described as a concrete object that resides within students’ minds. This concrete epistemology is often conveyed through the verbal imagery of terms such as *mental models* or *replacing* students’ misconceptions with correct conceptions.

In this work-in-progress, we propose that this concrete epistemology by itself is inadequate to describe and explain the learning process, and in particular, conceptual change. Drawing on multiple theoretical traditions that describe the role of language in cognition, we describe two key implications of changing to a more discourse-focused epistemology: (1) expert’s perception of students’ conceptual difficulties is as much a function of language as it is a function of science and engineering and (2) engineering students’ conceptual difficulties are rooted in their difficulties in distinguishing the engineering dialect of English - “Engineering-ese” - from colloquial dialects of English.

Many words from colloquial English (for example “stress” or “if and only if”) mean subtly different things in Engineering-ese, and students who are unaware of this difference struggle to develop accurate, consistent concepts and communicate these concepts. We provide evidence from the literature and our previous research to demonstrate that students struggle to switch between colloquial English and Engineering-ese and that this ability to switch between dialects may be critical to conceptual change and learning.

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II. FOUNDATIONAL THEORIES: LEARNING

A. Constructivist theory

Constructivist theory argues that students need to build their knowledge upon their own prior knowledge. Hence, the emphasis of constructivism is the knowledge which a student possesses. Constructivists argue then that learning happens when students are “forced” to access their prior knowledge, wrestle with it, and purposefully construct new knowledge. Constructivist theory is built on a concrete knowledge epistemology, so conceptual change is the process of students replacing their misconceptions through reasoning [2].

B. Sociocultural theory

The sociocultural perspective argues that new knowledge is only truly meaningful within the context of a group of people. Consequently, conceptual change and development is not so much the creation of new knowledge within a student, but the ability to learn the values and distinctions that are important to a certain group. All knowledge, it is argued, is immutably situated in contexts of learning and application, and efforts to abstract or generalize outside of recognizable social contexts will interfere with learning [3].

C. Language in Conceptual Change

Saljo argues that conceptual change research should move to an emphasis on discourse rather than concepts or other intangible constructs [1]. This stance has not inspired a great deal of language-centric research efforts, although some conceptual change researchers are now concerned with the role that writing and speaking play in conceptual change [4].

III. FOUNDATIONAL THEORIES: LANGUAGE

The philosophy of language is vital and central to this inquiry, but is currently a source of questions rather than answers [5]. We are continuing to investigate philosophical works on the nature of language in order to understand the broader context and develop conscious, informed stances in the development of this research

However, studies demonstrate the interconnectedness between language and concepts. For example, native German and Spanish speakers conceive of objects differently based on the gender that their languages attribute to the object. Germans describe bridges (feminine in German) as “beautiful” and “slender,” but Spanish speakers describe bridges (masculine in Spanish) as “sturdy” and “towering [6].”

IV. TWO IMPLICATIONS OF ENGINEERING-ESE

A. Expert's Interpretations of Novice Language

Researchers interested in students' ways of thinking almost universally access that thinking through language. Thus, research efforts are colored by an as-of-yet invisible process of interpretation and translation from the students' language (which may be entirely engineering-ese, entirely colloquial, or a mixture of both) to the researchers' engineering-ese.

Research methodologies and instruction must consider how experts' use of terms and distinctions differs from students' use. When exploring conceptual change interviews, we have found that pairing a content novice with a content expert during analysis has revealed that experts struggle to understand the difficulty that students have in acquiring new vocabulary in a discipline [7]. For example, when analyzing students' understanding of mechanics of materials, the novice researcher could better understand what the students were saying about stress and strain and would perceive that the students possessed a higher quality of conceptual understanding than the expert.

B. Students' Learning Through Engineering-ese

Based on how the gender of nouns moderates conceptions, we propose that language moderates conceptual change by directing the formation of concepts and how we access or use them. Furthermore, these distinctions must be seen as relevant and important to communication. For example, we might assert that the concept of an *emergent* process, processes such as diffusion and equilibrium [8], will form concurrently with the acquisition of the term *emergent* into a students' discourse.

Similar to how the gender of a noun influences a speaker's perception of an object or concept, the linguistic context in which certain terms were learned can affect our perception and understanding of the concept as well as what features we consider to be important about that concept.

The concept of shear stresses and strains in Mechanics of Materials and the concept of exclusive-OR in Boolean logic provide two examples of the importance of the creation of linguistic distinctions [7].

When students develop their initial conceptions of shear stresses and strains, they initially connect the term shear with arrows in the vertical direction. For example, students have said, “the stress is vertical, so it would be shear stress.” This failure to distinguish “shear” from “vertical” may be caused by a lack of situations in which a distinction between vertical and shear were linguistically useful. Shear appears to be a difficult concept to acquire because it lacks linguistic purpose

– students are not placed in situations where messages of importance rely on the distinction between the words *shear* and the idea of vertical forces [7].

In contrast, students are taught the difference between inclusive-OR (I can own a cat or a dog OR BOTH) and exclusive-OR (I can turn left or right, BUT NOT BOTH) by making the distinction that exclusive-OR *excludes* the case when both conditions are true. Students quickly learn this distinction as it proves relevant in conversation [9].

The emotional and linguistic implications of language also impact what students perceive about terms and concepts. For example in Boolean logic, the concepts of “A *if and only if* B” and “A *if* B” are distinct. However, they are the same concept in English, except the “*and only if*” is emphatic. When translating technical specifications into logic expressions, students rarely perceive the presence of the phrase “and only if” and automatically retranslate the specification into A *if* B. Because the “*and only if*” is an emotional tool rather than an informative tool in English, students fail to see its informative importance in Engineering-ese. Students who can parse “*if and only if*” as a unique Engineering-ese term, could also conceptually distinguish “A *if and only if* B” from “A *if* B”.

V. FUTURE CONSIDERATIONS

If conceptual change in engineering is fundamentally the acquisition of a new dialect, then should instruction emphasize communication as more than “just a soft skill?” Can we provide evidence that the best-practices for language acquisition and communication may actually be the best-practices for learning engineering?

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Work in Progress: Abstraction as a Vector

Distinguishing Engineering and Science

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Abstract—A goal of the philosophy of engineering and engineering education is to more clearly distinguish engineering and engineering education from science and science education. This paper advances the suggestion that one distinction between the activities of science and engineering is the role of abstract thinking. Engineering and science both engage in abstract thinking, but the direction of the abstraction process points in different directions for the two disciplines. The view advanced in this paper may help to clarify the difference between engineering and science in a way that is less prone to value judgments based on supposed differences between pure and applied activity. Science proceeds towards abstract theory; engineering proceeds from the abstract idea of function.

Index Terms—philosophy of engineering education, philosophy of engineering.

I. INTRODUCTION

Current efforts to develop the philosophy of engineering and engineering education intend to help clarify the nature of engineering activity and to demonstrate how engineering differs from applied science. In addition, a well-developed philosophy of engineering is expected to aid in resolving the perceived imbalance between the status attributed to scientific inquiry and that associated with the engineering design process [1,2]. It is anticipated that an articulation of the philosophy of engineering and engineering education will also inform the practice of engineering education [3,4].

II. SCIENTIFIC METHOD AND ENGINEERING DESIGN

Frequently engineering and science are distinguished by reference to differences in the output products of engineering and scientific work. A common explanation is that science creates theories about the natural world while engineering creates artifacts to provide for human needs and wants [5-8]. Although this distinction is a useful place to start an inquiry, it leaves a number of questions unanswered. There is little reason offered by this distinction to think that the two fields share much in common; in addition, the processes of science and engineering are left undefined, and thus any difference in the education required for the respective disciplines is unclear. Although there may be reasons to question this common explanation of the distinction between science and engineering, the purpose of this paper is instead merely to help fill in some of its gaps, paying particular attention to the role of abstract thought in each discipline.

A primary objective of scientific activity is the development of theories which are about a set of natural phenomena, but which are abstracted from those phenomena. “The scientific method” is the term generally applied to the processes by which such theories are developed. The roles of abstraction in these processes are complex. The collection of any particular observational data depends in part upon at least tentative prior acceptance of abstract theory; but acceptance or rejection of theory is justified in part by successful application to particular experiment. A scientist must be able to understand an abstract theory distinct from its particular instantiations in order to recognize new experimental results, but must also be able to perceive and imagine particular instantiations of theory in order to design an experiment. Theories are sometimes created to fit prior technological successes, such as the development of optics to fit the success of the telescope; but technological successes often rely upon prior acceptance of approximately accurate theory. Nevertheless, the theory-oriented nature of science suggests that scientific activity places a premium on articulation of abstract theory. That does not mean that the work of individual scientists is more theoretical than applied; it only indicates that an individual scientist’s work is understood to be scientific largely by the extent to which it promotes successful development and articulation of theory. As such, the scientific process can be seen as aimed towards abstraction even if not all individual scientists create abstract theory.

In engineering activity, the goal of the design process is to create a solution to a human problem or need. Thus, the engineer must first grasp the abstract or generalized description of the problem or need prior to designing the particular physical object or technological system that would solve it. This requisite abstraction of the problem to be solved – a problem with perhaps multiple possible solutions – from the particular circumstances presented to the engineer indicates that the process of engineering depends upon the ability to engage in abstract thought prior to engaging in the design of a solution taken as characteristic of the discipline. In other words, abstract function is grasped prior to creating a functional object.

The process of devising a solution involves creating an object that produces needed outputs from the required, desired, or available inputs. In order to create such an object, an engineer must have a prior conception of how function is related to the physical or technological structure of objects. In addition, insofar as overall function is a compilation of

subfunctions, and insofar as the overall structure of the object is a compilation of its components, an engineer must be able to grasp these relations, so that the inputs and outputs of each component or subfunction match at each component interface. The conceptual design phase may even explore alternative configurations of subfunctions as well as alternative choices for the types of components to achieve those subfunctions. Thus, the design process requires an understanding of the relationship of function and structure, and of the relationship of whole and parts, abstracted from the particular case. Abstract thought is therefore required not only for understanding of the problem to be solved but also as part of the design of a solution.

III. UNITY IN ABSTRACT THINKING

Consideration of the role of abstraction or abstract thinking in both science and engineering leads to a more symmetric valuation of the thought processes required by these two different disciplines. Abstract thinking is central to both science and engineering but its role in each differs. If abstraction is considered as a vector quantity, scientific and engineering abstract thinking are of the same magnitude but differ in direction.

Abstraction is an output of scientific activity, and prominent among science's goals are the development and articulation of theory. Thus, one of the primary outputs of science is abstract theory, and the success of scientific activity is measured largely in terms of what is valued in theories. The processes of science are devised to a significant degree for such theoretical successes. Individual scientists must therefore be guided in part by consideration of the contributions they make towards such theoretical successes. In this way, they proceed towards abstraction.

In contrast, engineering begins in abstraction, but abstraction is not one of its primary outputs. Engineering design starts from abstract concepts of function and creates the specific physical objects that are the products of engineering. The success of engineering activity is measured largely in terms of what is valued about those products, and the processes of engineering are not devised for theoretical success. In this way, engineers are guided by abstraction but do not proceed towards it.

These different roles of abstraction helps to illustrate that science assumes that universal principles exist and these can be discerned if only in approximate fashion and are subject to refinement. Science assumes there are universals to be abstracted from particulars; engineering assumes that abstract concepts of function are universal and can be projected back into the particular. Examples of such functions include supporting load, conducting current, or amplifying signal.

While this work-in-progress has outlined a potential starting point of inquiry, a more detailed review of this issue might consider whether types of abstraction differ across disciplines, whether learning style is a factor in developing abstraction

skills in students, and whether abstraction ability transfers across disciplines.

IV. CONCLUSIONS

A clarification of the role of abstraction in engineering can help inform the philosophy of engineering education by demonstrating how the practice of engineering requires abstraction abilities different in kind but not degree from science. In addition clarification of the abstract function as the starting point for the engineering design process can help to avoid a common problem among student engineers. Novice engineers have a tendency to leap to one specific hardware implementation of a perceived solution, often forgoing the potentially richer spectrum of design concepts which can emerge from a more reflective analysis of functional requirements achieved through abstraction.

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Enhancing the Engineering Curriculum: Defining Discovery Learning at Marquette University

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Abstract— This paper summarizes the results of our investigation into the feasibility of increasing the level of discovery learning in the College of Engineering (COE) at Marquette University. We review the education literature, document examples of discovery learning currently practiced in the COE and other schools, and propose a Marquette COE-specific definition of discovery learning. Based on our assessment of the benefits, costs, and tradeoffs associated with increasing the level of discovery learning, we present several recommendations and identify resources required for implementation. These recommendations may be helpful in enhancing engineering education at other schools.

Keywords: *Discovery learning, student-centered learning, active learning.*

I. INTRODUCTION

The College of Engineering at Marquette University is on a mission to increase the level of discovery learning in our curriculum. Until recently, there was no clear definition of “discovery learning,” prompting a survey to determine how faculty defined the term. The results indicated that the pure form of discovery learning (unguided by the instructor, as described in the education literature) was not being practiced. Faculty members were employing a wide range of student-centered and active learning methods, all under the umbrella of discovery learning.

An investigation into the use of the term “discovery learning” in U.S. engineering programs showed that the term is used inconsistently. Some schools have their own, institution-specific definition of the term that includes a variety of learning approaches, such as undergraduate research projects, co-ops and internships, and other forms of experiential learning. Other schools include student-centered learning methods, such as active, problem-based, application-based, and collaborative learning, in their definition. Based on our investigation we concluded that a Marquette-specific definition of discovery learning was warranted.

II. WHAT IS DISCOVERY LEARNING?

A. Definitions from the Education Literature

The education literature reveals different definitions of discovery learning. Presented here are generally accepted

definitions of active, collaborative, cooperative, and problem-based learning, terms often associated with discovery learning. (The definitions are drawn from several sources, primarily Prince [1].) Figure 1 summarizes three student-centered learning methods, including inductive learning, which encompasses discovery learning. Although there are no universally accepted definitions of discovery learning in the literature, the accepted view is that discovery learning is a form of student-centered learning in which the focus shifts from the teacher to the learners.

Active learning is an instructional method that engages students in the learning process. In active learning students conduct meaningful learning activities and think about and are connected to what they are doing [2]. While this definition could include traditional activities such as homework, in the education literature active learning most commonly refers to activities that are introduced in the classroom. The core elements of active learning are activities that engage students. Active learning is often contrasted with the traditional lecture format where students passively receive information from an instructor.

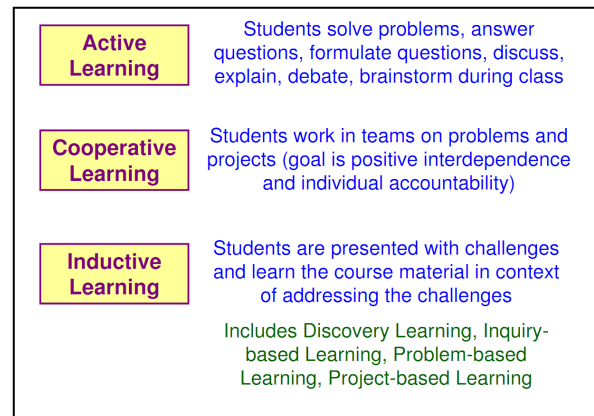


Figure 1. Summary of three student-centered learning methods. Note that discovery learning is classified as a form of inductive learning.

The more active students are in the classroom, the more engaged they are in the learning process and the more they remember. Edgar Dale’s “cone of learning” [3] suggests that student retention, as measured two weeks later, depends on the level of active learning. Classroom activities in which students

simulate a real experience or “do the real thing” involve them the most in the learning process and result in them remembering more of what instructors do and say [4].

Collaborative learning refers to an instructional method in which students work together in small groups toward a common goal [5]. As such, collaborative learning encompasses all group-based instructional methods, including cooperative learning [6-10]. In collaborative learning the emphasis is on student interactions rather than on learning as a solitary activity.

Cooperative learning is a structured form of group work where students pursue common goals while being assessed individually [6,11]. The most common model of cooperative learning includes five specific tenets: individual accountability, mutual interdependence, face-to-face interaction, appropriate practice of interpersonal skills, and regular self-assessment of team functioning [12,13]. The common core element among models is a focus on cooperative incentives rather than competition to promote learning.

Problem-based learning is an instructional method where relevant problems are introduced at the beginning of the instruction cycle and used to provide the context and motivation for the learning that follows. It is always active and usually collaborative or cooperative per the above definitions. Problem-based learning typically involves significant amounts of self-directed learning on the part of the students [1].

B. Discovery Learning in Higher Education [14-16]

In discovery learning, students are confronted with a challenge and left to work out the solution on their own [17, 18]. Students are presented with a question to answer, a problem to solve, or a set of observations to explain, and then work in a largely self-directed manner to complete their assigned tasks and draw appropriate inferences from the outcomes, “discovering” the desired factual and conceptual knowledge in the process [17]. The instructor may provide feedback in response to student efforts but offers little or no direction before or during those efforts. The lack of structure and guidance provided by the instructor and the trial-and-error approach consequently required of students are the defining features of discovery learning relative to other inductive methods.

In the purest form of discovery learning, teachers set the problems and provide feedback on the students’ efforts but do not direct or guide those efforts. This form of inductive teaching was developed for pre-college education and has not been embraced in undergraduate classes. The method is rarely used in higher education, among other reasons because instructors who hear about it fear – probably with good cause – that they would only be able to cover a small fraction of their prescribed content if students were required to discover everything for themselves. The only way to counter this fear would be to present solid evidence that discovery learning improves learning outcomes without requiring a major sacrifice of content.

There is little empirical evidence for the effectiveness of discovery learning in higher education. What instructors are more likely to adopt is a variant of discovery learning – sometimes called “guided discovery” – in which the instructor pro-

vides some guidance throughout the learning process [19]. In this case, the distinctions between discovery and guided inquiry or problem-based learning tend to disappear [14].

Student-centered methods have been shown to be superior to the traditional teacher-centered approach to instruction, a conclusion that applies whether the assessed outcome is short-term mastery, long-term retention, depth of understanding of course material, acquisition of critical thinking or creative problem-solving skills, formation of positive attitudes toward the subject being taught, or level of confidence in knowledge or skills [16]. Although many studies suggest that discovery learning can enhance students’ retention of material, others reach the opposite conclusion. For example, Leonard [20] studied the use of guided inquiry and discovery learning in science laboratory courses, and found no statistically significant differences in student scores on tests and lab reports.

The studies that show a positive effect also suggest that retention is improved only when the learning task is based on previously understood principles. Singer and Pease [21] compared the effectiveness of guided inquiry and discovery learning on the acquisition, transfer and retention of motor skills. They concluded that for learning new tasks, guided inquiry was more efficient, and for transferring learned skills to tasks of similar or greater difficulty there was no difference.

Prince and Felder [14] state:

“We do not recommend using the pure form of discovery learning – in which students work with little or no guidance from instructors — in undergraduate engineering curricula.

While the quality of research data supporting the different inductive methods is variable, the collective evidence favoring the inductive approach over traditional deductive pedagogy is conclusive. Induction is supported by widely accepted educational theories such as cognitive and social constructivism, by brain research, and by empirical studies of teaching and learning. Inductive methods promote students’ adoption of a deep (meaning-oriented) approach to learning, as opposed to a surface (memorization-intensive) approach. They also promote intellectual development, challenging the dualistic type of thinking that characterizes many entering college students (which holds that all knowledge is certain, professors have it, and the task of students is to absorb and repeat it) and helping the students acquire the critical thinking and self-directed learning skills that characterize expert scientists and engineers.”

There is significant evidence for the benefits of involving undergraduate students in independent research [14]. Undergraduate research does not usually qualify as discovery learning because the advisor typically provides significant structure and guidance [22]. The literature supports the use of student-centered learning and teaching methods. However, there is little empirical evidence for the effectiveness of the pure form of discovery learning at the undergraduate level and it is not recommended for use in that setting [15].

C. Definitions from the COE Faculty

In 2010, the Dean of the COE solicited comments from the COE faculty regarding their definitions and impressions of

discovery learning. Specifically, the Dean posed the following question: "What is Discovery Learning and what is your opinion of it at Marquette University?" The responses revealed different definitions of discovery learning among the faculty, underscoring the need for a compelling, unifying definition. Responses included many common themes and attributes, as indicated by the following faculty-suggested definitions of discovery learning:

- Giving students opportunities to solve open-ended problems/challenges that require them to put theory into practice with real-world constraints, and providing them with the tools needed to solve these problems.
- A method of inquiry-based learning in which students utilize their existing knowledge and past experiences to identify new relationships and facts through a process of investigation and self-discovery of the world guided by the instructor. In this framework, students learn to "teach themselves," promoting a philosophy of life-long learning.
- Student-centered learning, more applied and more hands-on. There is less reliance on the traditional lecture as the primary means of communicating. Students are actively engaged in authentic, real-life projects.
- Allowing students to learn through experimentation that reinforces lectures and text-based learning.
- The education practice in which students play an active role in learning. Students are expected to (i) apply what they know (from previous courses, from experience, from books and the Internet, etc.), (ii) ask questions and formulate their own tentative answers, and (iii) deduce general principles from practical examples and laboratory experiences.

Based on these responses and other comments from the COE faculty, we concluded that the pure form of discovery learning was not actually being practiced in the COE. Instead, a guided form of discovery learning, active learning, cooperative learning, and other forms of guided inquiry-based learning were being employed.

III. EXAMPLES OF DISCOVERY LEARNING

A. *Examples of Discovery Learning in the COE*

There are many examples of student-centered learning methods, including guided discovery learning, being practiced in the COE. These range from student projects to in-class activities in courses in each department. A few examples are presented here.

Extracurricular Student Projects

Faculty-mentored teams of students are currently involved in a wide range of extracurricular projects that give students the opportunity to apply what they have learned in their undergraduate experience (be it from the classroom, laboratory, co-op position, internship, etc.) to the solution of a problem. Many of these projects are part of national and international student design competitions such as the Formula I Race Car, Concrete Canoe, Solar Powered Boat, and Human Powered

Vehicle, sponsored by professional organizations and societies, such as:

- American Society of Civil Engineers (ASCE)
- American Society of Mechanical Engineers (ASME)
- Association of Computing Machinery
- Biomedical Engineering Society
- Engineering World Health
- Engineers Without Borders (EWB)
- Institute of Electrical and Electronics Engineers (IEEE)
- Institute of Transportation Engineers
- National Collegiate Inventors and Innovators Alliance (NCIIA)
- Society of Automotive Engineers (SAE)
- Society of Manufacturing Engineers (SME)
- Solar Energy Society

In the past few years students participated in the SAE Aero Competition, NASA Lunabotics Challenge, Rocket Competition (Wisconsin Space Grant Consortium), MATE International Remote Underwater Vehicle competition, BMEstart design competition, and others.

Courses and Programs

In the COE many courses in the curriculum include attributes of discovery learning methods. The following represent only a small sample of such courses.

- BIEN 1100 and 1110: Introduction to Biomedical Engineering Methods I and II. These courses include open-ended design challenges, lectures, readings, and exams. Students are presented with problems and customer needs and are encouraged to find the information needed to solve the problem. Design challenges reflect the multidisciplinary nature of the biomedical engineering curriculum and require students to solve problems involving physiological monitoring, data acquisition, medical imaging, biomaterials, and rehabilitation engineering. Students are encouraged to apply the tools and information provided to them through class lectures, readings, and laboratory experiences. The course includes a module on business and entrepreneurship and uses an application-based approach to teach students about the design process. The resources needed to successfully teach this required freshman course include TAs, administrative support, and many guest speakers.
- BIEN/ELEN/COEN/EECE/MEEN 4920/4998: Principles of Design/Senior Design. This capstone design course is the culmination of the undergraduate biomedical, electrical, computer, and mechanical engineering curricula and requires students to apply what they have learned from previous coursework and co-op, internship, and research experiences. Students work on multidisciplinary project teams for two semesters to solve real-world problems. Projects are advised by COE faculty members who provide technical guidance and assistance to student teams. Required course deliverables mimic those that are used in industry and required by ISO 9001. This team-based project design experience allows students to learn about the design process, apply knowledge acquired in previous

courses, and develop communication, teamwork, and project management skills.

- Construction Engineering Management Program. This program provides students with a hands-on, applications-based learning experience through the use of guest lecturers, field trips to construction projects on campus and throughout Milwaukee and Chicago, Associated General Contractors (AGC) student chapter meetings and trips, American Society of Civil Engineers (ASCE) student design competitions, and many open-ended team project assignments. Significant financial resources required to run the program are provided by an endowment.
- ELEN/COEN/EECE Courses. Many courses taught in the electrical and computer engineering program contain elements of student-centered and applications based learning. These courses include projects that require students to design, simulate, and build prototypes, create useful databases, write programs in various languages to perform various functions, and test a CPU. These courses require students to synthesize and apply what they have learned.
- MEEN 2210: Electromechanical Engineering Systems. This required sophomore course is heavily studio based with open-ended design challenges. Students work in teams of two to investigate and solve real-world exercises involving electrical circuits (electronics for sensors, actuators, and controls), electromechanical actuators (solenoid, vibration exciter, DC motor), and control systems. Industrial examples emphasize integration. Students are encouraged to apply analysis, simulation, and hardware tools that they learn through class lectures, outside readings, independent investigations, and laboratory experiences.

B. Examples of Discovery Learning at Other Schools

The following is a small sample of how discovery learning is defined and incorporated in engineering programs at other schools.

- University of Delaware. At the University of Delaware (<http://www.ugs.udel.edu/DLE/>) all students are required to participate in a Discovery Learning Experience, defined as experiential learning that involves instructional experiences (out-of-class and beyond typical curriculum courses). These enrichment experiences exist for students under the supervision of a faculty member. Discovery Learning Experiences include internship, service learning, independent study, undergraduate research, and study abroad.
- University of Colorado. The Discovery Learning Program (<http://engineering.colorado.edu/dlc/about.html>) at the University of Colorado enables students to develop critical thinking, problem solving, and research skills while sharing fresh perspectives as members of integrated research teams. The discovery learning model established by the College of Engineering and Applied Science creates collaborative teams involving undergraduate and graduate students, faculty, and industrial partners. This

advances student learning through an inquiry-based approach that complements the academic curriculum.

- Rose-Hulman Institute of Technology. At Rose-Hulman, discovery and student-centered learning appear in extracurricular student projects and in-class, hands-on experiences. Student teams work on competitive project teams for the Eco-Car, Formula SAE, Human Powered Vehicle, and the design/build/fly AIAA national student design competitions. Students do not receive credit for these activities. Faculty mentors and team advisors volunteer their time to work with the students on these projects and do not receive additional salary for their involvement. The school provides a budget of at least \$10,000 per project, space to work, and access to test facilities (wind tunnel, composite testing, and other facilities). In addition to extracurricular projects, students are engaged in in-class activities such as fluids laboratory demonstrations and projectile motion modeling, measurement, and validation experiments ending with an in-class competition. A lead equipment technician is employed to design and maintain technical equipment used in classes, laboratories, and student projects.

Of the three schools mentioned above, there is no consensus on the definition of discovery learning or what activities qualify as discovery learning. The University of Delaware considers experiential learning (study abroad, internships, co-op experiences, etc.) to be a form of discovery learning. The University of Colorado regards undergraduate research activities to constitute discovery learning. Rose-Hulman views extracurricular student projects and in-class, hands-on activities to be forms of discovery learning. The disparate use of the term underscores the need for agreement on what constitutes discovery learning within the Marquette COE.

IV. CONCERNS AND TRADEOFFS

Student-centered learning requires a culture in which students take responsibility for their education and shift from passive to active learners. It also requires faculty commitment ("buy-in") to change from traditional "tell-and-test" pedagogies to more active teaching methods. Whether students and faculty embrace these cultural changes is a concern.

Discovery learning will not necessarily replace all lectures, as not everything students must learn is amenable to classroom discovery. Even when students have the capacity to discover complex knowledge, there may not be sufficient time or appropriate resources to complete the task. Formal lecture presentations provide a fairly efficient way of conveying complex knowledge to a large group of diverse learners [23]. A question to be resolved is the appropriate mix of lecture and student-centered methods.

Discovery and other student-centered learning methods involve increased faculty time and resources. A common concern among faculty regarding discovery learning is that they would only be able to cover a small fraction of their prescribed content if students were required to discover everything for themselves. According to Cornell and Clark [24], "Less teacher talk requires more teacher time." Even though motivation and

student learning are enhanced through discovery and student-centered learning methods, it requires more work for teachers when designing projects and preparing for class. From interviews we conducted, faculty indicated a need for additional support personnel to successfully implement student-centered learning methods as well as resources such as additional teaching assistants, technical support staff (e.g., technicians to develop and maintain equipment), and space.

V. IMPLEMENTATION ACTIVITIES

A. Defining Discovery Learning within the COE

The term “discovery learning” (based on its strict definition) does not appropriately capture the current practice in the COE. A more accurate term to reflect what is currently being practiced would be “student-centered learning,” which includes active, problem-based, application-based, and collaborative learning.

Our investigation found that other schools use the term “discovery learning” to describe activities and teaching methods that do not fit the traditional definition of discovery learning. These schools have their own, institution-specific definitions of the term. What they are describing would be more correctly described as “student-centered learning.”

We proposed that a COE-specific definition of the term “discovery learning” be developed. This definition needed to incorporate the following activities and teaching methods that include student-centered learning components:

- Class activities such as hands-on demonstrations, case studies, student projects and presentations, design competitions, laboratory experiments, field trips, and other activities that require students to apply what they have learned in the class.
- Extracurricular activities such as student design projects for national student design competitions, co-op and internship experiences, and other activities that provide opportunities for students to “learn by doing” and apply what they have learned throughout the engineering curriculum.

We adopted the following COE-specific definition of discovery learning, which reflects our strong focus on student-centered learning:

Discovery learning within the Marquette University College of Engineering consists of student-centered learning methods that employ in-class and extracurricular activities that allow students to learn by doing and to apply what they have learned.

We retained the term “discovery learning” for multiple reasons, including its broad meaning and consistency with prior mission statements.

B. Implementing a Plan

The goal of increasing student-centered learning in our curriculum is similar to that of many European Union (EU) countries as part of the Bologna Process intended to improve higher

education in the EU [25]. We are accomplishing this goal by meeting four main objectives:

- Increase the use of student-centered learning in the classroom. We are providing faculty with resources for course redesign including educational support in the form of seminars to make faculty aware of the best practices in student-centered learning, and a course development consultant to work with faculty.
- Increase the number and variety of mentored extracurricular projects. Additional opportunities for students to work on project teams outside of class are being provided. To optimize the learning experience, these projects include some level of guided instruction provided by project mentors (faculty members, alumni, or industry sponsors). Various types of extracurricular student projects are encouraged and supported by the COE such as:
 - Projects that allow students to explore areas of interest to them
 - Projects in which students compete in national design competitions
 - Projects sponsored by and of benefit to local industry
 - Assistive technology projects to benefit a single client with a specific disability
 - Service learning projects to solve problems of the developing world or local community
 - Projects based on ideas generated by students with entrepreneurial interests
- Support the current cooperative education and undergraduate research programs. The COE has a successful cooperative education program and provides opportunities for internships and undergraduate research. The COE is continuing to support these activities that provide valuable student-centered learning experiences.
- Overcome institutional barriers to implementation. It is essential to obtain institutional, faculty, and student “buy-in,” develop incentives, and reform promotion-and-tenure criteria to reflect the value and importance of a higher level of discovery learning in the COE. To help promote dialogue, solicit ideas for implementation, and foster a change in culture we are initiating a seminar series, conducting focus groups, and considering other activities.

C. Adding Resources

To reach our goal of increasing the level of discovery learning in the COE, we identified the following needed resources:

Educational Support for Faculty

- Course development consultant(s) to assist faculty with course redesign.
- Technicians responsible for design, construction, storage, and maintenance of demonstration equipment, laboratory experiment hardware, course “props,” etc., used for in-class demonstrations, laboratory exercises, etc.
- COE seminar series on discovery learning to include guest speakers from within and outside of MU to present best practices in student centered learning.
- Graduate and undergraduate student TA(s), if needed.

Space and Equipment for Student Projects

- Space for student team collaboration and design work, including videoconferencing capabilities.
- Space for storage of prototypes, hardware, etc.
- Facilities for prototyping and testing (machine shop, rapid prototyping equipment, wind tunnel, materials testing, hand tools, etc.).

VI. SUMMARY

The term “discovery learning” as used in the education literature refers to unguided discovery learning and is not what is currently practiced in the COE. Instead, a guided form of discovery learning, active learning, cooperative learning, and other forms of guided inquiry-based learning are being employed. A more appropriate term would be “student-centered learning,” which includes methods of active, problem-based, application-based, and collaborative learning.

Our investigation found that other schools use the term “discovery learning” to describe activities and teaching methods that also do not fit with the formal definition of discovery learning. Schools have created their own, institution-specific definitions of the term. What they are describing would more aptly be described as “student-centered learning.” We adopted a COE-specific definition for “discovery learning.”

The goal of increasing the level of discovery and student-centered learning in the COE is being accomplished by (1) increasing the use of student-centered learning in the classroom, (2) increasing the number and variety of mentored extracurricular projects, (3) supporting our cooperative education and undergraduate research programs, and (4) overcoming institutional barriers to the proposed plan. Implementing this plan requires (1) educational support and resources for COE faculty, (2) faculty as well as student “buy-in” to a culture which shifts responsibility to students for their education, and (3) space and equipment for use by student project teams. The process presented here may be helpful in enhancing engineering education at other schools and is recommended for faculty working to increase the level of active and student-centered learning in their engineering curriculum.

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Qualitative Inquiry of Best Practices and Challenges Faced by Faculty Engaged in Learning Through Service Efforts

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Abstract— Learning Through Service (LTS) is a pedagogical method that encompasses curricular and extracurricular service learning in engineering. Though the numerous benefits of LTS are apparent to those who engage in it, the barriers are also plentiful, as evident by the reluctance of many instructors to engage in LTS. As a joint effort to create a community of LTS scholars, a summit held in Fall 2011 brought together faculty members actively engaged in LTS activities in a wide variety of capacities and from a wide variety of disciplines. In addition to the many workshops conducted as part of the summit, three semi-structured focus groups were held during which open dialogue ensued regarding the best practices and challenges in the execution of LTS. The current study presents thematic findings that emerged from these focus groups.

Keywords—*Learning Through Service; Faculty Perspective; Focus Group; Qualitative Methods; Service-Learning*

I. INTRODUCTION

Learning Through Service (LTS), an innovative pedagogical method that incorporates service as a means of meeting academic learning outcomes, provides an avenue for a much needed paradigm shift in engineering education. Organizations such as the NAE [1], ASCE [2], AAEE [3] and ASME [4] are all calling for the more comprehensive training of a holistic engineer to include various technical and non-technical skills, as well as a community-oriented professional vision. LTS is one tool that can be used to help meet these learning objectives [5] [6] [7] [8]. Service learning “spawns development on multiple levels, ultimately leading to maturation, heightened self-awareness, and greater complexity in cognitive thinking,” and results in highly motivated students with a professional passion [9]. Such attributes are important for future engineers who face a rapid pace of technological

progress as well as future challenges in globalization, sustainability, and increased complexity of engineering projects.

LTS is becoming an increasingly popular pedagogical method in engineering education [10]. The widespread use of LTS is exemplified by such organizations as Engineers for a Sustainable World Engineering World Health, and Engineers Without Borders, among others. Despite the growing prevalence and interest in LTS among both faculty and students, a thorough understanding of faculty’s experience with LTS is lacking [10] [11]. Nonetheless, we do know that faculty tend to be split on whether or not LTS should be tied to accreditation, and frequently cite time, money, promotion, and tenure as obstacles to implementing LTS in the curriculum [11]. In addition, previous research strongly indicates that faculty also recognize numerous benefits of LTS, such as increased student learning outcomes, deeper engagement with the material, and stronger affiliation with the engineering profession [8] [9] [12]. According to a recent survey, factors such as departmental support and improved learning outcomes function as catalysts for implementing LTS [13]. Next, we describe a collaborative effort launched to improve the understanding of a multi-faceted nature of LTS.

A multidisciplinary LTS Experts Summit was organized by the NSF funded Engineering Faculty Engagement LTS (EFELTS) project to explore issues that faculty face in regards to benefits and barriers to LTS engagement [14]. At this summit, three focus groups were conducted to further probe these issues; the resulting discourse forms the data for this study. The ultimate goal is to enable more faculty across disciplines to share their experience with one another, engage in more productive and informed LTS efforts, thus making a positive impact on student learning through authentic and

meaningful service. Acknowledging disciplinary differences and the diversity of existing LTS efforts, the focus group protocol was semi-structured to allow for a broad range of input regarding the best practices and challenges associated with the LTS efforts. The preliminary findings from these focus groups offer a rich understanding of the benefits and barriers faced by faculty who have engaged in LTS activities. We anticipate that continued review of the focus group transcripts will lead to development of a framework upon which LTS-interested faculty can be empowered to strengthen or initiate their own LTS efforts.

II. PURPOSE

The purpose of the current study is to obtain a deeper understanding of faculty's experience with LTS, including benefits, barriers, and strategies associated with the successful execution of LTS. Through a better understanding of the experiences of faculty who are already engaged in LTS, we can formulate strategies to enable and better support future faculty who wish to also conduct LTS activities in their classroom. This effort also provides insight into the sources of barriers for faculty- personal, professional and institutional- that potentially dissuade faculty from implementing LTS methods. In order to gather this information, we held three focus groups, which are an effective and efficient method for gathering qualitative data [15]. In particular, we were interested in the personal stories, anecdotes, and observations based on the faculty members' experiences with LTS.

III. METHODS

In order to encourage natural dialogue and an open exchange of ideas between participants, three semi-structured focus groups were held during the EFELTS summit in the Fall of 2011. To facilitate the discussion, the following prompts were used: What stands out to you the most out of your experience with LTS; How did you become involved with LTS; What are the most challenging aspects of LTS? The focus group facilitator monitored the discussion while keeping her interventions at a minimum. With the participants' consent, focus groups were recorded and later transcribed. The resulting qualitative data are in a form of a free-flowing narrative, touching upon a variety of topics. Thematic analysis of the resulting narrative allowed for a deeper investigation of faculty members' experiences with LTS.

A. Participants

Faculty members who did not participate in the individual interviews conducted concurrently were invited to participate in the focus groups. Purposive sampling was not employed for recruiting participants for interviews or focus groups; therefore, focus group participants can be considered randomly selected and representative of all EFELTS attendees. All faculty members invited agreed to participate in the focus groups and gave their consent for audio-recording. The first focus group consisted of three males and three females representing engineering, English/Media Studies, K-12 education, and Higher Education Administration. The second focus group had two female participants; both directors of LTS related programs. The final focus group consisted of three participants,

two male and one female, who all represented different engineering disciplines.

B. Analysis

Three researchers worked independently on the analysis of the focus group data: one transcribed the audio-recordings, and two served as primary coders. An emergent coding approach was employed in this study, meaning that themes were not defined a priori, but rather emerged freely from the data [16]. The emergent coding, rooted in the methods of grounded theory [17], was deemed most appropriate given the exploratory purpose of the study.

IV. RESULTS

The main themes that emerged from the thematic network analysis of the three focus group transcripts are presented below.

A. Theme I: Defining LTS

"LTS is work that has both academic value and community-based value." (Focus Group Participant)

The focus group participants grappled with issues of defining LTS. Faculty overwhelmingly agreed that LTS is a form of "adventure learning" that is "alternative," "experiential," and "expeditionary" that results in both "civic and academic outcomes." As ardent advocates for LTS, faculty spoke liberally about the value of LTS as a pedagogical method. For instance, one participant referred to LTS as "a power platform for liberal learning regardless of the major, which expands the personal transformation, moral, spiritual, as well as intellectual and it also provides a way for students to think about their place in society." Another participant simply noted that LTS is "the best thing pedagogically since sliced bread." Yet another commented that LTS not only promotes "a sense of civic responsibility" in students, but also brings them a step closer towards conducting "authentic intellectual work."

Although participants unanimously agreed on the value of LTS, the issue as to what exactly constitutes LTS remained unresolved. Everyone agreed with the expressed notion that LTS is "curriculum-based service learning" that involves "direct contact with the community" but also that LTS could encompass "a whole spectrum of possibilities." LTS was compared and contrasted to similar alternative pedagogical methods such as problem-based or project-based learning, and inquiry-based learning. Direct contact with communities and academic credit surfaced as critical aspects for defining LTS and as possible differentiating elements from the aforementioned pedagogical methods. Exemplifying the difficulty of defining LTS, many commented on having struggled with definitional boundaries and, when considering a community-based project, often pondered – "is that a service learning program or not?" At the heart of the discussion around defining LTS was the attempt to define the bounds of the term "service". One participant posited a common misconception that LTS has to involve "work with underrepresented minority communities otherwise it is not considered service". Another agreed, stating a misconception that with "service learning... you only work with poor people". These misconceptions, and

others, may be why some LTS opponents refer to it as “forced volunteerism”. However, the question remains – does it have to be *pro bono* to be Learning Through Service? Does the community organization served have to be strictly non-profit? Consider the following excerpt from one of the participants’ accounts:

Well this is one that I learned something about in terms of the definition. So I had been working in this small city in upstate New York and we had been working with the neighborhood housing agency and we had looked at housing needs and conditions in a number of neighborhoods, many of them lower income. A certain percentage of the grade was assigned by the community partners and they would jury the projects as students presented the projects. Anyway we had done several semesters of working and one of the recommendations that came out of those previous projects was a viable downtown or the older neighborhoods were really going to be in trouble. The next semester we decided to work with the downtown businesses and the merchants association. We were looking at parking issues and asking people about their perceptions on how long they would want to park. Anyway one day after having toured the downtown businesses after we had spoken to the chamber of commerce and laid out some of the research questions one of my students said in class, “Can I ask a question?” And she said, “Well it says here in the syllabus that this is a service learning course, so why are we working with these businesses and the capitalism and all of that?” Well, it was a great question and it involved bringing in some of the neighborhood people and taking a look at who these sort of greedy capitalist pigs were. They were candle makers in a little hardware store and they were candy stores and a little drugstore, all local businesses. But it made me think about being careful about terminology, checking assumptions, and having an open discussion with students on how this feels to them because one of the ideas of service learning is you only work with poor people and you only do direct work. I consulted with the University and it had to be underrepresented minority communities otherwise it wasn’t considered service. That ethos was always there so this student asked this wonderful question that lead to a couple of weeks of wonderful teaching.

The lack of clarity regarding the boundaries of “service” is not limited to faculty, but also seems to challenge students themselves. As an umbrella term, “learning through service” encompasses various community clients, regardless of whether they draw profit or not. However, it appears to be the case that conceptualizations of LTS vary from campus to campus, and the common, agreed-upon, definition has not yet been clearly delineated.

B. Theme II: Increased Contextual Learning

“In order to really learn, you have to problematize the situation” (Focus Group Participant)

This recurring theme pertains to the benefits of LTS for students’ learning of skills, rather than content. Both civic and academic outcomes came up frequently as student benefits resulting from LTS. Furthermore, faculty noted that students who graduate with LTS experience have a heightened “sense of

social responsibility.” Alluding to John Dewey [18], one participant noted that “in order to really learn you have to problematize the situation.” Another participant said the following regarding problem-based learning: “In going out and solving a problem you have to be able to understand the problem and it has to be in a contemporary context so you know that is something that we really need to think about in terms of affecting some change that really promotes community based learning.” Moreover, others emphasized the role of LTS in promoting critical thinking skills, “the ability to do problem-solving and analysis.” Consider the opinion of this participant:

We need to focus more on learning skills and providing students with the opportunity to learn about lifelong learning skills and to get that mentality, that attitude that their learning does not stop when they graduate. I think that some of that can come from service learning and the ability to look at community based problems and think about how the world evolves and changes.

The emphasis on life-long learning and long-term effect of LTS was also evident when participants discussed the career paths that their students chose. LTS was said “to challenge students’ maturity level” and prompt them to seriously consider future occupations. According to the faculty participants, LTS itself has become a career path for some students, and “it expanded the personal, moral, spiritual, as well as intellectual transformation, and provided a way for all students to think about their place in society”.

C. Theme III: Increased Motivation for Learning

“If you could in fact have a carrot why would you insist on only using a stick?” (Focus Group Participant)

Faculty participants spoke at length about the motivational power of LTS. Although often demanding for students both in terms of cognitive challenge and emotional strain, LTS projects appeared to inspire a hunger for learning. According to one participant, “the authentic need inherent in the project” drove students to “actually want to learn.” Another participant commented that his students enjoyed working on an LTS project building a wheelchair because “it was real, not a fictitious sort of thing.” For another illustrative example, consider the following account from a professor whose students conducted a project at the homeless shelter while learning the concept of distributive justice:

The room was abuzz with conversation. People were leaning over and talking to each other. I couldn’t get any of the conversation to die down and all of it to do with what they had experienced during their week at the shelter. Some of them were really shaken to their core. They were shaken by the moral assumptions that they had brought in and that were challenged while they were there. They were shaken by the physical resemblance between these people and people in their families. Some of them fell back into a hard defensive posture, “I didn’t cause that problem” but they were engaged wherever they came out on that. This was not simply a text that they were reading it was something that they had to process and it

had completely transformed the conversation on distributive justice.

Evidently, this experience touched students in ways that the faculty members had not seen in traditional course methods. Another participant commented on how contextualized learning naturally sparked students' curiosity:

All of a sudden they were inquiring out of their own curiosity, questions that we were studying at a particular level and what I discovered out of that was that I really wanted to create learning environments where I created a context where students were seeking learning or were trying to do a task that required their learning. I became a coach to have them do something they thought was important to do. Then they learn it because they wanted information as opposed to traditional instruction where I had to do singing or dancing or something to keep their attention, manipulating them or trying to coerce them into wanting to learn.

LTS appeared to provide a natural context for learning and engaging students, thereby making the instructors' job easier and the whole experience more beneficial for everyone. As one of the participants eloquently put, "If you could in fact have a carrot why would you insist on only using a stick?"

A participant who was an expert on LTS in the K-12 context commented both on the value of this pedagogical method and the challenges educators in K-12 face with LTS. She said: "We are really finding the actual achievement levels of our elementary schools as well as our high schools have actually been increasing when they use service learning." Sadly, she also mentioned that LTS is harder to maintain in K-12, that it "dissipates when a teacher leaves" and that happens quite frequently due to a quick turnover in public schools. Nonetheless, the teachers who attempted to engage public school students in LTS reported that for the first time they observed students "who did something because they wanted to do something."

D. Theme IV: Lack of Professionalism

"The job of an engineer involves writing and communicating with people who don't understand engineering." (Focus Group Participant)

In one of the focus groups, the issue of guiding students who did not know how to appropriately interact with community partners was discussed as a significant barrier to faculty members who use LTS. *Lack of Professionalism* emerged as a theme out of this discussion. For example, one participant noted that students struggle with differentiating "what is considered professional and unprofessional" and "telling the difference between a community partner and a friend". In the similar vein, faculty participants commented that students tend to lack "overall maturity and cultural sensitivity". Consider the following quote: "I think the bigger issue for us is that these are 18 year olds who are not always very culturally sensitive and who are not really familiar with the causes of some of the global issues, such as poverty". Another participant added that their faculty have "sensitivity filters in place for students". Several others agreed that

"maturity issues" among students are a significant issue for faculty to be aware of. Also, appropriate dress came up as an issue. Understandably, students did not pick up such unspoken rules of professional conduct in the classroom. It may be that offering cultural sensitivity training or professional behavioral standards of sorts to younger students starting with LTS is a worthwhile endeavor.

Related to the lack of professionalism mentioned above are the students' poor communication skills, which are another hurdle that faculty have to be aware of in conducting LTS effectively. More specifically, written communication skills are weak among the students, according to focus group participants. When discussing the challenges of writing, they mentioned that "putting together a credible argument that is well supported by evidence is very difficult" for students. Others said that this difficulty may be due to the lack of formality in writing. For instance, one participant said that "the challenge is that they are so used to texting that they don't find it offensive to start the email with 'hey' and just using short abbreviations". Language barriers also came up as an issue, especially when student teams are nationally diverse and one person's "first language is English and everyone else's first language is something else, usually Mandarin". Faculty also mentioned strategies they use to overcome these communication challenges. The most frequently mentioned strategy was using rehearsals for any student presentation that is to be given to an external audience. For example, one participant said that students first present to their peers, get feedback, rehearse again, and only present to the client after that. Another one said that instructors take an extra step and require students to "draft and submit the phone script to them before phoning a client". Consider the following account:

They have to write up a script for all of the questions they are going ask, how they are going to enter the room, how they are going to introduce themselves to the client. They write a script for that first meeting with the client, but not the second and third one. They have three meetings with the client but the first meeting with the client we get the script, before they are allowed to have their meeting with the client.

It is clear that written and oral communications skills are of ultimate importance to engineers-in-training, and that engaging in LTS forces faculty to confront the common shortcomings of students' communication skills. Another participant summarized the role of communication in the following way: "The job of an engineer involves writing and communicating with people who don't understand engineering". Overall, faculty participants agreed that technical competency in students is necessary but not sufficient for successful LTS projects; professional communication skills in students are also essential for successful collaboration with community members.

E. Theme V: Team Dynamics

Stemming from the conversation on professional communication, the next theme identified was *Team Dynamics*. Given that most LTS projects discussed by faculty are team-based, it is not surprising that successful functioning in a team emerged as another prominent hurdle that faculty must address in their students. Faculty spoke about the benefits and pitfalls of putting friends on the same team. Further, they discussed different social roles that students working on a team take on, such as “social loafers, hitchhikers, leaders, isolationists”. One participant commented on the importance of thinking long-term and considering the risk of team disintegration when they said:

If the team implodes then there is a decent chance the team will disintegrate. You don’t want them to lose the only social network that they’ve got at the university. You know, when you’re a first year, you might only have a very limited number of friends.

Everyone agreed that team work is a major component of any LTS project and is oftentimes one of the most difficult aspects. According to another participant, “teamwork and communication” are in the list of top ten skills most required by employers. Similar to communication skills and professionalism, LTS can be an effective tool to address teamwork skills in students, who seem to be falling short of industry expectations according to the focus group participants. The necessity for these professional skills in conducting effective LTS can be seen as both an opportunity and as a source of difficulty for faculty.

F. Theme VI: Community Partnerships

The final significant theme that emerged in the focus groups pertained to the nature of the partnerships with the community clients. The importance of articulating the expectations at the onset of the project was emphasized. For example, one participant said that sometimes clients have “unreasonable expectations”, mostly because they are not engineers themselves and are not used to dealing with students. According to one account, “community partners were town planners who didn’t necessarily understand what they could expect and it took some energy to discuss these expectations with them”. On the other hand, a different focus group participant noted that community partners from non-profit organizations are often pleasantly surprised with the level of professionalism and engagement that early career engineering students bring because they are “used to dealing with high school volunteers”. Yet another participant shared a story of the LTS project in which students completed the project that seemingly met clients’ needs, but the client was dissatisfied with the results, nonetheless. Although learning objectives tied to the project were met and students’ grades were not affected by the negative feedback, they were “really devastated from an emotional point of view”. Other participants agreed that, occasionally, such outcomes are inevitable and are a part of working on “real-world” projects. However, delineating the

conditions of the LTS project with the community clients is essential to minimizing such outcomes. These conditions may include strictly designating the time devoted by students to the LTS project, clearly articulating the client’s needs and requirements, deciding on who conducts the assessment of students’ progress, and agreeing on terms for future engagement on a volunteer basis. Taking these steps prior to commencing a partnership with the community client is a recommended LTS practice.

V. CONCLUSION

The thematic network analysis of transcripts from focus groups of faculty members actively engaged in LTS methods has been revelatory in terms of benefits, barriers, and strategies of LTS. A natural, free-flowing dialogue among participants allowed the following main themes to emerge: how to define LTS, benefits to students including increased contextual learning and increased motivation, difficulties including lack of professionalism, communication skills and team dynamics, and best strategies for maintaining community partnerships. All in all, these themes point to the fact that LTS efforts enable students to engage and learn from real-world and authentic experiences with real clients and stakeholders. Integrating LTS experiences in curricula is an ideal means to preparing students for engineering practice. The themes that emerged highlight how invaluable LTS experiences are to students’ cognitive and affective learning gains, but also to faculty. Whereas some of the findings (e.g., increased students’ enthusiasm) aligned with prior findings [10] [20], others (e.g., students’ lack of professionalism) are novel. Thus, the current study corroborates previous findings, as well as contributes to the growing body of knowledge of LTS and its multiple facets. Ultimately, it has been known that LTS experiences are invaluable, but what has been a challenge is understanding the practices that will lead to effective engagement of faculty, students, and the community in these partnerships. The work herein provides this in-depth insight through the stories told by LTS experts. Both LTS experts and LTS novices are likely to benefit from familiarizing themselves with the challenges and benefits encountered by seasoned LTS pedagogues. In tandem, prior and current findings will aid in the development of a framework to help other faculty members successfully implement LTS methods into their pedagogical practice. Such framework can be used in the upcoming training workshops organized by the EFELTS faculty participants. Ultimately, the end goal of such an empirically-based framework and rigorous workshops is to broaden and strengthen the community of faculty engaged in LTS activities.

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Awareness of and Receptiveness to Active Learning Strategies among STEM Faculty

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Abstract – Despite strong evidence of the positive impact of active learning strategies, STEM faculty demonstrate a spectrum of receptiveness to incorporating active learning into their classrooms, and for a variety of reasons, engineering classes continue to be dominated by a passive lecture style. This paper draws on data from a four-year study that investigated the use of five social instruction strategies, including active learning. Twenty-four STEM faculty at 4 institutions were interviewed regarding their understanding of and attitudes toward these strategies. This paper focuses on the results of the active learning component of these interviews. Faculty most often interpreted active learning as what students *do* and viewed self-motivation as a key component of what students *think* while active learning. These results, while drawn from a small sample population, can nevertheless make an important contribution to understanding why passive learning remains predominant in the STEM classroom. This paper examines how the findings from this study can inform efforts to promote changes in STEM education that would bring more active learning to the classroom.

Index Terms –Active learning, classroom practice, faculty.

I. INTRODUCTION

The positive impact of active learning strategies on student learning has been demonstrated by numerous studies. However, faculty demonstrate a wide range of receptiveness to incorporating active learning into their classrooms. As a result, undergraduate STEM classes, particularly in engineering, continue to be dominated by a passive lecture style. Drawing on data from a four-year study that investigated the use of five social instruction strategies in STEM classrooms, this paper explores how faculty's conceptions about active learning can facilitate or inhibit their adoption of related teaching strategies.

II. BACKGROUND

Active learning has been shown to lead to better student attitudes and improvements in students' thinking and writing [1]. Active learning strategies often involve students' participating in class in ways other than passive listening, as well as thinking about the activities in which they are engaged. Students can become more involved in learning when they are given the chance to talk, discuss, write and apply what they are learning. For example, Hake [2] examined pre- and post-test data for over 6,000 students in introductory physics courses and found significant

improvement in student performance by using interactive-engagement in classes. Redish et al. [3] also demonstrated gains in learning from active engagement strategies, showing that such improvement derived from active student engagement rather than from extra time spent on learning basic physics concepts. Clearly, considerable support for the benefits of active learning exists, whether in engineering, other STEM fields, or elsewhere. Introducing active learning strategies into lectures can significantly improve information recall and increase student engagement which, in turn, can have other benefits for the student experience.

However, active learning strategies are not widely or frequently used in STEM instruction. As Prince [4] observed, the topic of active learning "frequently polarizes faculty," and while there are many advocates of active learning, "skeptical faculty regard active learning as another in a long line of educational fads." Faculty may also be concerned that content will have to be reduced from contact hours in order to add active learning, that pre-class preparation time will be higher, and that active learning is not appropriate for large classes [5].

In an attempt to better understand why more active learning is not successfully integrated into the STEM classroom, this study uses qualitative research methods to examine how faculty view active learning. A deeper understanding of faculty's perceptions of active learning may provide insight into unsuccessful or unsustainable attempts at incorporating active learning into the classroom, and into the barriers that cause faculty to revert to more traditional, passive lecture practices.

III. FRAMEWORK

This study draws on pedagogical frameworks of active learning that emphasize (a) what students *do*, and (b) what students *think* while they are engaged in active learning.

A. What Students Do

The engineering education literature emphasizes viewing active learning in terms of what students *do*. Thus, we draw on the engineering education literature to assess faculty's views of active learning as something students *do*. Prince's [4] review of engineering education literature identifies the four types of active learning most frequently discussed in that literature: active learning (defined broadly as active student engagement); collaborative learning;

cooperative learning; and problem-based learning (Table I). This view of active learning focuses on what students are doing in their courses.

TABLE I. WHAT STUDENTS DO IN ACTIVE LEARNING [4]

| Type of Active Learning | Description |
|------------------------------|--|
| Active Student Engagement | "[A]ny instructional method that engages students in the learning process. ... The core elements of active learning are student activity and engagement in the learning process." |
| Collaborative Learning | "[A]ny instructional method in which students work together in small groups toward a common goal. ... [T]he core element of collaborative learning is the emphasis on student interactions rather than on learning as a solitary activity." |
| Cooperative Learning | "[A] structured form of group work where students pursue common goals while being assessed individually. ... [T]he core element...is a focus on cooperative incentives rather than competition to promote learning." |
| Problem-Based Learning (PBL) | "[A]n instructional method where relevant problems are introduced at the beginning of the instruction cycle and used to provide the context and motivation for the learning that follows. ... PBL typically involves significant amounts of self-directed learning on the part of the students." |

B. What Students Think

In contrast, the K-12 literature tends to define active learning in terms of what students *think*. Therefore, we have chosen a framework from the K-12 literature to structure our interpretation of how faculty view active learning in terms of students' thinking. This framework, called Fostering Communities of Learners (FCL), is a highly successful intervention that has been nationally demonstrated at the K-12 level [6,7,8]. The FCL framework characterizes classroom activity in terms of students being *motivated*, *aware* of what they should be learning and why, and *strategic* about learning (Table II). All three components of FCL are necessary to make active learning both successful and sustainable in the classroom.

TABLE II. WHAT STUDENTS THINK DURING ACTIVE LEARNING [4]

| FCL Characteristic | Description |
|--------------------|---|
| Motivated | The student is self-motivated to learn, driven little by external motivators. |
| Aware | The student is aware of his or her learning style and how it applies to the learning activity at hand. |
| Strategic | The student considers options before choosing how to solve problems. Once identifying a strategy, they invest effort into using it. |

C. Research Questions

In the context of what students *do* and what they *think* as part of an active learning experience, we seek to answer the following questions by analyzing faculty interviews on the topic of active learning.

- Research Question #1: Do faculty favor a view of active learning that emphasizes what students *do* or what students *think*?
- Research Question #2: What activities do faculty favor among what students *do* as part of active learning?

- Research Question #3: What activities do faculty favor among what students *think* as part of active learning?
- Research Question #4: What does receptiveness to active learning (or lack thereof) look like among STEM faculty?

In summary, the engineering community's definitions tend to focus on the nature of the student's activity (what the student is doing), while the FCL framework focuses on the student's approach to learning (what the student is thinking). Examining faculty perceptions of active learning through these two lenses offers insight into what may be preventing engineering and other STEM faculty from using active learning more often in the classroom.

IV. METHODS

For this study, a cross-section of 24 faculty at 4 institutions were interviewed in order to understand their attitudes toward and understanding of five social instruction strategies: Active Learning, Legitimization of Differences, Reciprocal Learning, Collaborative Learning, and Guided Instruction. The four targeted universities were chosen to represent a range of institution types: 1) a Research Institution, 2) a Teaching Institution, 3) a Private Institution, and 4) a Faith-Based Institution. Interview participants were drawn from 6 different engineering disciplines, plus computer science, math, and chemistry, in order to represent a cross-section of STEM fields.

In most cases, interviews were recorded and transcribed. When recording was not possible, extensive field notes were taken by the researcher. All transcripts and field notes were coded using the constant comparison method [9,10] in order to identify emergent themes and trends. Views of active learning were extracted from responses to the interview questions detailed in Table III.

TABLE III. INTERVIEW QUESTIONS USED TO ADDRESS RESEARCH QUESTIONS

| Research Questions | Related Interview Questions |
|--------------------|--|
| #1, #2, and #3 | How would you define "active learning"? Where does active learning belong in the classroom? To what extent can it be practically implemented in the classroom? |
| #4 | What is your ideal teaching situation? Describe your teaching philosophy. What do you see as your strengths and weaknesses in teaching? |

V. RESULTS AND DISCUSSION

All participants demonstrated an awareness of the term "active learning" in that they understood it as student participation other than simply sitting and passively listening to a lecture. However, beyond this basic common understanding of active learning, responses about what active learning actually looks like in the STEM classroom varied widely. Details of this understanding, including predominant viewpoints and persistent gaps in understanding, are addressed by our research questions and are described below.

A. Research Questions 1 and 3

In analyzing the interview data, we looked at how faculty viewed the impact of active learning on how students think, using the Fostering Communities of Learners (FCL) framework: Are students *motivated* to learn? Do they become *aware* of what they are learning and why? Are they *strategic* in their learning? Participants were not specifically prompted to discuss these three aspects, but their responses to the broad question, “Define active learning,” gave insight into whether these aspects fit into their understandings of the concept.

Our analysis found faculty most often discussed the motivational quality of active learning, but placed the least emphasis on the strategic nature of active learning. Respondents conveyed expectations that students in an “active learning” classroom should be motivated in a wide range of ways. For example:

“I expect – near demand – a high level of commitment on their part. ... When we're in the room, when we're together, I want full focus, and I will bring my enthusiasm and I will bring interesting topics to bear. They need to show up ready, active, mentally awake and prepared. And I'll harass them in that sense. I kid them, needle them, if they're not, and I'm not afraid to do that publicly.” (Engineering, Teaching Institution)

“I strongly believe in active learning, that students have to be involved in their own learning, and ideally they take responsibility for their own learning.” (Engineering, Faith-Based Institution)

Fewer respondents emphasized that active learning techniques should involve helping students become more aware of why they are learning certain concepts or skills:

“I think they need to learn to work together as early on as possible because that is the work situation that they're going into. The companies are not interested in who is the star, who is the most talented. They just want to get the job done and we teach the students to compete with each other for a grade and that the highest grade will get rewarded. In industry, that doesn't have anything to do with it. It's the team, it's working together to accomplish that.” (Engineering, Teaching Institution)

“I really work at pulling theory to practice, just constantly. If you don't-- if you only know it in theory and you can't do the practice, you don't get it. If you can only do it in practice, you can't do it in theory, you don't get it. But helping them realize the value of doing both, and then actually coming up with projects and labs that merge those and help them to see the connection.” (Engineering, Faith-Based Institution)

Consistently, however, few faculty were likely to mention the strategic nature of active learning and even

those that did, spent less time discussing it than the motivational and awareness components of how students *think* while involved in active learning. Comments regarding strategy largely had to do with students learning how to learn and taking responsibility for their own education. For example:

“I can't tell what the content will be that they need five years from now. All I can do is teach them how to think, teach them how to react, get the basic concepts together and ready.” (Engineering, Teaching Institution)

“I like to teach the kids how to learn as much as I like to teach the kids what they need to learn. So, I have them, of course, you know, listen to what I have to say, but then I also make sure that they understand that, you know, I'm only teaching them a certain amount and I really encourage them to explore other resources to get more in depth...they have to have a little bit of self initiative to go out and discover things on their own.” (Engineering, Teaching Institution)

The fact that our interview data saturated at a level that favored the motivational aspects of student learning and neglected the strategic aspects clearly speaks to a need to incorporate the strategic aspect of active learning in faculty development and teacher training efforts.

B. Research Question 2

The interview data also revealed faculty's perceptions of what students should be doing during active learning, mapping data to Prince's framework of the engineering community's definitions of active learning (Table I). This analysis found that all participants recognized that active learning means that students become visibly engaged in the learning process. This basic understanding of active learning is consistent with the first and broadest definition of active learning identified by Prince [4]. However, participants' perceptions of other, more specific manifestations of active learning varied. Participants were more likely to understand active learning as including collaborative learning (67%) than as cooperative (53%) or problem-based (53%) learning.

As noted above, all participants recognized active learning in a broad sense as leading students to become actively engaged in the learning process. For 25% of the participants, their definition stopped at the most general level, perhaps indicating a limited understanding of the concept. For example:

“Ask questions of students ... [and] encourage students to answer. If a student answer is correct, I say, ‘great’ and move on. If they know a little bit, I'll give hints and encourage more response.” (Engineering, Teaching University)

“I guess active learning is about anything other than just sitting there listening passively. ... [A]sking questions, me answering questions they ask. (Computer Science, Research University)

The majority of the participants (75%) had more detailed definitions, indicating to various degrees broader conceptions of what active learning can include and how it benefits students. For example, these faculty often mentioned classroom activities that correspond to one or more additional elements of the engineering community's framework (e.g., collaborative learning, cooperative learning, or problem-based learning).

"Active learning is where the mind is actively engaged in dealing with a subject or a problem. Not just listening but using the knowledge to do something. Now, 'do something' may be communicating to a neighbor. It may be solving a problem. It may be putting a circuit together in the lab. It may be writing a report. But it's not just sitting while the information plays to you." (Engineering Faculty, Research Institution)

"I think that active learning would be giving students enough of the basic tools, basic ground rules tools, and then presenting them with a problem where they have to apply those tools, but in addition to that, find their own tools to help solve the problem." (Engineering, Teaching Institution)

"There were some projects that we did outside of class that involved them having to do some sort of active learning and participation rather than just sitting there like a sponge. But, I learned that I need to incorporate that into the classroom a little bit more and instead of preaching to them in class, have them sit down and figure things out for themselves in class." (Computer Science, Teaching Institution)

"[Active learning is] when the students are actively using the concepts that were taught to them and in so doing solidifies their understanding of the material.... It's a way of engaging students within the classroom to either practice or reinforce something that we worked on. ... I don't use it to generate new concepts. ... It's more of a, 'This is me telling you, and now it's your turn to do.'" (Engineering, Private Institution)

C. Research Question 4

Whether defined in terms of how students think or what they do, faculty's perceptions of active learning tend to influence how receptive they are to the concept, as well as whether or not they actually use active learning in their own classrooms. Analysis of faculty responses showed that participants fell into three categories:

- Those who were not receptive to the idea of incorporating active learning strategies into their classrooms (19%).

- Those who were receptive to the idea of active learning, but had not adopted these strategies to any significant degree (31%).
- Those who were receptive to active learning and were using these strategies in their own classrooms (50%).

1) Not Receptive

At one end of the spectrum were the 19% of participants who indicated that they were not very receptive to the idea of incorporating active learning strategies into STEM classrooms. None of these participants used these strategies themselves, for a variety of reasons. For example, as one engineering professor at the Research University stated:

"I could not see the value [of active learning]. I feel a little sorry for people who need active learning in order to learn better. I think it shows their weakness...that they need to explain to somebody. It's only for those types of people. ... I think active learning serves the weaker student population."

This professor went on to describe active learning as sort of a trend or buzzword – a perception which likely impacted his decision not to use it in his own teaching:

"[Active learning] is kind of pretty; oh, that's the thing to do and you should do it. ... But active learning is, let's say, a brand, right? ... So it's just one framework that was branded. ... And I think this is where I see...one of the problems of modern education. They find a new religion, and then they expect every class to follow this religion. So currently, active learning is one of the religions. If you talk to the proponents of active learning theory, they are religiously saying that every class should have it because it's a good thing. And this is when I think it's taken too far." (Engineering, Research University)

Other participants who were not receptive to active learning made similar comments. In various ways, they indicated that they did not feel that the benefits of active learning strategies were significant enough to warrant changing their teaching styles.

2) Receptive Non-Adopters

Nearly one-third (31%) of the participants fell into the middle category: They recognized the value of active learning, at least in theory, but were not using these strategies to any significant degree. These participants perceived various barriers that prevented them from incorporating more active learning into their classrooms.

For some, the barrier was a past experience with active learning that did not go as well as hoped:

"I've tried various things. I've tried having people work together in groups a little bit and having more of an open-ended discussion. But it hasn't worked that well for me. I find I have a lot of success with pretty much explaining things in lectures." (Math, Research University)

"I've tried things like that [active learning strategies] sometimes, and I get mixed reactions from the students. There are some who really object to it...then other people find it engaging. I guess I'm not sufficiently persuasive at explaining why this is so much fun to do, and so I've gotten some pushback." (Computer Science, Research University)

Others perceived the logistics or costs of using active learning strategies as barriers:

"Well, it [active learning] is hard in the classroom because then how do you define your measurements? ... How do you evaluate who does what, or what part of it?" (Engineering, Teaching University)

"I don't do that much of those activities where students have to somehow form little groups within the classroom and do things. I have nothing against it, but it hasn't been that convenient to do it and it takes time." (Computer Science, Research University)

"[If you have a] couple hundred people in the room, give them a lecture, as opposed to breaking them into groups of five and bringing them a free, creative environment and supervise that. They would cost so much more." (Engineering, Research University)

Whether these perceived concerns are realistic or not, they are salient enough that they prevent these individuals from attempting (or re-attempting) to fit more active learning into their classrooms.

3) Receptive Adopters

At the other end of the spectrum were the participants (50%) who were not only receptive to the idea of active learning, but were actually using active learning strategies in their classrooms. This was evident in participants' descriptions of their own teaching. For example, when asked to describe his teaching philosophy, one engineering professor at the Teaching University immediately replied:

"Active learning. I do not think that the instructor needs to have all the answers, or be the expert, but put students in ways so that they can creatively find the answers themselves. ... You have to give them the basics. But then you also need to give them the opportunities to apply those and find out that the calculation doesn't always happen in the real world." (Computer Science, Teaching University)

Similarly, an engineering professor at the Private University described his "ideal teaching situation" in this way:

"I like interactive lectures. My typical strategy is to use PowerPoint, but I like to facilitate active learning and I like to activate the students. ... Work with your neighbor. We'll do multiple-choice.

From time to time I'll use the audience response systems ...the clickers...and that type of thing. ... So I like to have an active classroom. I really don't like the days where I'm just up there talking and there's no interaction." (Engineering, Private University)

An engineering professor at the Faith-Based University described her teaching philosophy in a way that suggests active learning strategies, even though she did not use that specific label:

"I do a lot of, 'Okay, let me teach you a little bit,' for maybe 15 or 20 minutes, and then I turn them loose on some problems to start working on, usually computer based. And then I walk around and answer their questions as they work through the lab. ... And if I could have an exploration on every single topic I wanted them to learn, that would be how I'd want to teach." (Engineering, Faith-Based University)

Later in the interview, when asked about the place of active learning in the classroom, this professor replied:

"I think [active learning] can be in every class. To what extent really depends on the class. I mean, ideally a class would be 90 percent active learning. I probably am achieving about 50 percent in some classes. Other times-- if I've gone a whole week and I've almost done all the talking the whole week, I'm like, 'Oh, this is a bad week. How did that happen?'"

Overall, the interview data suggest that while some STEM faculty fall at the extreme ends of the spectrum, being either strongly unreceptive to active learning or enthusiastic adopters, most faculty fall somewhere in the middle. Faculty in this middle group hold conceptions of active learning that reach beyond the most basic level, at least to some degree, and they are open to the idea of using active learning strategies. However, they may be held back from doing so by perceived barriers. It is this group to whom we propose turning our attention.

VI. DISCUSSION

Although it is encouraging to see that all of the study participants were aware of active learning and half of them reported using active learning strategies in their classrooms, those figures do not tell the full story. It is important to look closely at how faculty talk about active learning. For example, are they simply asking questions in class and labeling that active learning? Or are they utilizing other strategies, moving beyond the most basic definition of active learning? We argue that this makes a difference, and we suggest that a deeper understanding of active learning and its benefits to students are likely to lead to greater receptiveness toward using active learning strategies.

As with any professional development, understanding practitioners' perceptions and internal beliefs is essential before introducing new or different practices. Findings from this study suggest that the perceptions and beliefs that

present the most significant barriers to adopting active learning strategies are limited conceptions of what active learning means, and concerns about barriers to using active learning in class.

The complexity of instructors' understanding of active learning strategies appears to be instrumental in their decisions about how (or if) to integrate these strategies into their own classrooms. Among our study participants, those who were most receptive to active learning *and* were using these strategies gave rich, detailed descriptions of active learning, indicating a broad understanding. Conversely, respondents who were least receptive to active learning described it in more limited ways. Therefore, one key to bringing more active learning to STEM classrooms would be to enrich faculty's understanding of what active learning encompasses, both in terms of what students are thinking and what students are doing.

However, even faculty who understand active learning fairly well may not adopt it because of beliefs about logistical barriers. Thus another key strategy for moving faculty not only toward receptiveness but also toward adoption appears to be demonstrating how to manage or overcome the various perceived barriers. For example, providing suggestions or strategies for working around high costs or the challenges of large class sizes may be helpful.

We acknowledge that the interview data discussed here represent a small cross-section of STEM faculty. Therefore, rather than making broad claims of generalizability about STEM faculty, we instead propose that the insights gained by exploration of these faculty's perceptions can be used as a starting point in understanding the possible conceptions and beliefs underlying decisions about active learning, and can provide guidance for targeting faculty development efforts in more efficient ways.

If we hope to see more active learning in STEM classrooms, our data suggest that the most efficient approach would be to first target faculty who are at least somewhat amenable to active learning, but who are not yet implementing these strategies in their own classrooms due to perceived barriers. Faculty who are already doing active learning will likely continue to do so without additional interventions. At the other end of the spectrum, it may be difficult to convince faculty who are strongly unreceptive to active learning to change their practices. However, those in the middle of the spectrum are a good place to start. These faculty are already receptive to active learning, and with some guidance on strategies to overcome perceived barriers, they may be more likely to incorporate active learning strategies into their own classrooms.

VII. CONCLUSION

Our findings support previous studies that assert that STEM faculty's conceptions about active learning are diverse, and can facilitate or inhibit their adoption of active learning strategies. Most faculty already have a basic understanding of active learning, both in terms of what students are thinking (FCL) and what students are doing

(Prince). However, faculty most often view active learning in terms of what students are *doing*. This view of active learning is very important for measuring improvements in academic outcomes that result from active learning. However, a lack of emphasis on what students are thinking limits how much students are likely to carry forward and expand the use of active learning in other courses and other instructional environments.

In addition, this basic understanding appears to be insufficient motivation for many STEM faculty to use active learning strategies themselves. Therefore, broadening faculty's conceptions of active learning – including what students think and do, as well as how to fit it within classroom constraints – is critical if we hope to see more active learning in STEM classrooms. With limited resources for faculty development, it can be difficult to reach all STEM faculty and change their perceptions of active learning in such a way that they will actually bring these strategies into their own classrooms. Therefore, we propose that the most efficient use of these limited resources would be to begin by focusing efforts on faculty who indicate at least some receptiveness to the idea of active learning but who are not yet using it themselves.

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A Proposed Teaching and Learning Curriculum for COMPLEETE Based on Current National Trends

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Abstract—We propose an introductory level teaching and learning curriculum for the ASEE COMPLEETE program (*COMP*etencies in *Learning for Engineering and Engineering Technology Educators*). COMPLEETE is an initiative for a national program to build and recognize educator excellence in engineering and engineering technology at three levels. The proposed curriculum for the introductory level is compared with curricula from nine well-established existing programs. The content is specifically targeted to benefit engineering and engineering technology instructors in higher education, integrate with the values and programs already offered within ASEE, serve as a foundation for further development at higher levels, and be flexible to suit the needs of a diverse instructional community. The nine existing programs were coded under the overarching COMPLEETE criteria and then analyzed for commonalities and alignment. The proposed core competency areas were found to comprehensively represent existing programs. They are: learning theory, student development, instructional design, instructional facilitation methods, assessing and providing feedback to learners, instructional technology, and reflective practice. The proposed curriculum lays a foundation for those offering faculty development services to compare against, and challenges the engineering and engineering technology community of educators to address key competency areas all faculty should develop within 3-5 years of beginning teaching.

I. INTRODUCTION

We propose an introductory level teaching and learning curriculum for COMPLEETE. The ASEE COMPLEETE Program (*COMP*etencies in *Learning for Engineering and Engineering Technology Educators*) was described in an award winning “Best Paper” at the 2010 ASEE conference under the name SPEED (Strengthening the Performance of Engineering and Engineering Technology Educators across the Disciplines) [1]. COMPLEETE is an initiative for a national program to build and recognize educator excellence in engineering and engineering technology. This recognition occurs as the educator progresses through three levels of achievement. The proposed curriculum in this paper targets a succinct set of core competencies representing the first level of achievement, yet remains flexible to serve the needs of faculty with diverse approaches to teaching and learning. This flexibility is achieved in part by inviting a wide array

of faculty development providers to contribute to COMPLEETE programming. In other words, there may be many paths (through multiple providers) for participants to reach each level of achievement in the COMPLEETE program, but all paths must satisfy the same set of competencies.

The national debate about how to move faculty toward achieving new levels of competency in teaching and learning for the modern world (and for what purposes) is fueled by several important publications over the past decade or so. These include the revised ABET accreditation criteria published in 2000 and 2004 [2], the reports for *The Engineer of 2020* and *Educating the Engineer of 2020* from the National Academy of Engineers [3, 4], and ASEE's two recent reports on *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education* [5, 6]. The proposed curriculum responds to these calls by integrating curricula from many well-established, existing programs to form a single vision for a set of core teaching and learning competencies that all faculty can benefit from possessing, and which can move the engineering and engineering technology community of educators forward towards achieving the ideals proposed in these publications.

This work may be useful to faculty development practitioners to assist in planning curricula or individual workshop topics that are consistent with other programs and with generally agreed upon areas of competence. It may also be useful if they wish to contribute directly to COMPLEETE by offering programming that helps instructors build competence in the areas specified for the proposed curriculum. Finally, it may also be useful to educational researchers investigating instructional practices, and by instructors as a means to identify areas where they might strengthen their knowledge and skills.

Faculty development programs for which comparisons were made include STEMES [7], EXCEED [8], Pacific Crest [9], NETI [10], U-Michigan [11], Northern Illinois [12], and CIRTL's Delta program [13] within the US, plus international models from the UK [14] and IGIP [15].

These programs have informed the structure and content of the proposed curriculum, which is specifically targeted to benefit engineering and engineering technology instructors in higher education.

The COMPLEETE project proposes three levels of attainment for engineering and engineering technology educators. These are a foundational level representing critical areas of competence which contribute to building quality teaching and learning environments in any setting, a scholarly practitioner level where participants further strengthen their skills and begin to systematically investigate learning in their classrooms, and a reflective mentor level where participants contribute and give back to the engineering and engineering technology community of practice [1]. Here, we address only level one, defining the goals and outcomes associated with this level of attainment as consistent with the vision for the COMPLEETE program. We address only level 1 because the initial efforts of the COMPLEETE program will focus on this level, and further because the proposed curriculum will likely be adapted community input, implementation, and review, thus defining more detailed needs for levels 2 and 3 over time.

Level 1 – Foundations

A. *Proposed Level 1 Aims:*

- To provide an overview of teaching and learning practice and theory in Engineering and Engineering Technology Education, addressing the core knowledge and professional values educators are expected to have to be able to teach effectively and efficiently at their respective institutions.
- To begin to establish in participants a culture of reflective practice and evaluation of their own teaching practice, and of the learning of their students; and to build a broader community of practice among practitioners.

B. *Proposed Level 1 Learning Outcomes:*

Upon successful completion of Level 1 participants will:

- Have evaluated aspects of their current teaching practice within the context of learning and teaching literature (reflecting knowledge and critical understanding of the following teaching and learning activities: teaching and the support of learning; contribution to the design and planning of learning activities; assessment and giving feedback to learners; developing effective learning environments and learner support systems).
- Have gained an understanding of the learning process, drawing on recognized learning theories.
- Have developed an understanding of students, including issues of intellectual and social

development, learning styles and differences in student approaches to learning.

- Have been engaged in instructional design at lecture, module, course or curriculum level.
- Have been exposed to various methods of instructional delivery, including an overview of teaching methods appropriate for different instructional goals and environments, including both large and small classes.
- Have designed and used appropriate methods to assess student learning and give feedback to learners.
- Have developed an understanding of how to make effective use of educational technology.
- Have engaged in reflective practice and continuous learning.

The proposed curriculum which accompanies these goals and intended outcomes is built from the overarching criteria proposed in the COMPLEETE project as presented in various publications over the past three years [1, 16-19]. The curriculum revolves around seven areas of core competency which were first articulated as a synthesis of faculty development needs by an experienced faculty development expert in engineering on the original SPEED team and then revised based on discussion among others on the SPEED and, later, COMPLEETE project team. The seven areas or core competence are shown in Table 1.

TABLE I. CORE COMPETENCY AREAS

| Area | Title |
|------|------------------------------------|
| 1 | learning theory |
| 2 | student development |
| 3 | instructional design |
| 4 | instructional facilitation methods |
| 5 | assessing and providing feedback |
| 6 | instructional technology |
| 7 | reflective practice |

It is also consistent with previously proposed critical elements for successful faculty development programs at a national level in the US [20] and serves as one response to numerous call for national reform. Finally, it integrates with values and programming already present within ASEE [21], serves as a foundation for further development at higher levels, and is flexible to suit the needs of a diverse instructional community.

II. METHODS

The content of nine existing faculty development programs was coded for commonalities and alignment with the overarching COMPLEETE criteria using a qualitative methodology. This was first done individually by each of the authors. Then, two rounds of feedback among the group were utilized in order to come to greater consensus. The coding process used was based on a grounded theory approach [22-24]. The feedback process was designed to

follow, to the extent possible within a limited group of three experts, a modified Delphi procedure which has been used on other educational contexts to build consensus about complex concepts [25-28].

A. Producing initial individual rankings

The details of the process used to produce the individual ratings (before coming to consensus) in Table 1 are as follows:

1. Program materials for each "comparison curriculum" (in the form of publicly available basic program outlines that might be provided to potential participants in those programs) were assembled into a single document and distributed to each member of the rating team via email for printing.
2. Each content item listed in the program materials for each "comparison curriculum" was mapped to the "equivalent" content items in the COMPLETE curriculum using the pre-determined codes represented in Table 1. Content items in the comparison curricula could be words, sentences, or phrases present in the materials themselves. The coding process was simplified via the use of a number system to represent the codes and thus reduce writing on the "comparison curriculum" materials:

Each rater then wrote the appropriate number directly on the "comparison curriculum" materials. This process of assigning codes consisted, of course, of judgment calls, as text did not always match exactly. Rather, the general area or meaning of the wording in the comparison curricula needed to be interpreted by each rater. Further, it was possible to associated multiple COMPLETE curriculum items with a single "comparison curriculum" if needed, and vice versa.

If a "comparison curriculum" item did not match with any COMPLETE curriculum item, this information was recorded separately so a mechanism to track the items the COMPLETE curriculum did NOT cover was established.

3. Assignments for a level of agreement for the "comparison curriculum" with the COMPLETE curriculum were made. This was accomplished by ranking the relative frequency of the presence of each numbered content item and applying the matching scale defined below:

X = Not present in "comparison curriculum"

1 = Present by inference, or as subtopic of a major area

2 = present as a major aspect of the "comparison curriculum"

4. Results were recorded in a blank table with the same form as Table II.

B. Building Consensus:

Once the individual ratings were complete, a comparison table displaying the ratings from each of the three raters was produced and distributed. Two rounds of feedback were then conducted to produce a greater level of consensus.

First, a phone conference was scheduled to discuss ratings where both X and 2 appeared from different raters for the same "item" in a particular comparison curriculum (the term item here is used to represent a cell in table 1, where each cell is a comparison between one core competency in the COMPLETE curriculum with a particular comparison curriculum). There were eight items in this category. During the phone conference each rater discussed their rationale for their individual rating, and then an opportunity to change ratings was provided. Results from the discussion (along with any modified ratings) were recorded on a new spreadsheet. No items with both X and 2 remained after discussion. In other words, at least two of three raters had come to full agreement for each item, with the other rater differing by one level.

Second, remaining items where two raters agreed but a third had assigned a different level of curricular agreement were discussed. Approximately half of the items fell into this category. Discussion for these items occurred over two separate phone conferences (due to lack of time to complete the process in a single conversation). To help resolve those items where there were differences, the raters agreed that the person with a different rating than the other two should look at the materials a second time and either (a) change their rating to match the others, or, (b) write a short justification trying to convince the others why their rating (as based on their coding of curricular content) was correct. This process was completed for one rater before the first phone conference and the others at a later date. Approximately two thirds of the discrepancies were resolved in this manner.

Finally, the combined ratings for level of agreement on each item were tabulated through a simple numerical average of the three raters final scores at the end of the discussion process. In should be noted that in order to produce a numerical average, the "X" level of agreement was assigned a value of "0" for this purpose.

III. RESULTS

Table II displays the results of our curriculum comparison. The core competency areas compared are those defined in Table I: learning theory, student development, instructional design, instructional facilitation methods,

assessing and providing feedback to learners, instructional technology, and reflective practice. Results show that reflective practice and instructional technology have the lowest level of concordance with the COMPLEETE curriculum. Instructional design, and instructional facilitation and methods have the highest concordance. Also, it should be noted that the programs used for comparison vary greatly in length. A few details for each program are shown at the bottom of Table II. About half the programs are multi-day affairs where participants are together for several consecutive and intense days. Other programs consist of courses one takes during semesters over a period of one or more years (CIRTL Delta and U-Michigan), or modules to be completed either individually or with a group through various means over a period of one or more years (Pacific Crest, UK, and IGIP). This latter group is more consistent with the COMPLEETE approach where participants may progress through the level 1 curriculum over several years and continue to grow throughout their career at levels 2 and 3.

TABLE II. CURRICULUM COMPARISON

| COMPLEETE Core Module | STEMES | EXCEED | Pacific Crest | NETI | U-Michigan | Northern Illinois | CIRTL Delta Program | UK HE Certificate | IGIP |
|------------------------------------|---------------------------------|-----------------------|------------------------------|-------------------------|--|---------------------------------|--|-------------------------------------|---------------------------------------|
| learning theory | 1 | 1 | 2 | 1.7 | 2 | 2 | 2 | 2 | 2 |
| student development | 1 | 1 | 2 | 0.7 | 1 | 1.3 | 2 | 2 | 1 |
| instructional design | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 |
| instructional facilitation methods | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 |
| assessing and providing feedback | 2 | 1.7 | 2 | 1 | 1 | 2 | 1 | 2 | 1 |
| instructional technology | 1 | 1 | 2 | 1 | X | X | 2 | 2 | 2 |
| reflective practice | 1 | X | 1 | X | 0.3 | 1 | 2 | 2 | 1 |
| TOTAL | 9 | 8.7 | 13 | 7.3 | 7.3 | 10 | 13 | 14 | 11 |
| Program length | Three or more days, all at once | Six days, all at once | One year or more, spread out | Three days, all at once | Two or more semesters, consecutive or spread out | Three to five days, all at once | Two or more semesters, consecutive or spread out | Usually three consecutive semesters | Self-paced, usually one or more years |

After discussion about the overall results, the team selected a limited set of compulsory core competencies for the introductory level along with several additional optional competencies among which participants might choose to form their complete introductory level curriculum. Below, each competency (or module) is broken down into distinct components that might be addressed in single instance workshops of a half-day or less such that one might be able to piece together a complete curriculum by using a variety of faculty development resources. We derived these components from previously published descriptions of the competency areas and then refined them based on our discussions about the content of the comparison curricula. Details for the components of each core competency (or module) follow:

DRAFT MODULE STRUCTURE for LEVEL 1

The first five modules are proposed as required modules for all COMPLEETE participants. These modules are well represented in existing curricula and thus form a broad and generally agreed upon foundation of teaching and learning competencies desired for engineering and engineering technology educators.

A. Core Module 1 – Learning Theory:

Outcome: Understanding the learning process, drawing on recognized learning theories.

Narrative: A practical overview of theories of learning and teaching in Higher Education, with a focus on the disciplines of engineering and engineering technology. This includes an overview of current cognitive and constructivist learning theories with a focus on their application to undergraduate instruction.

- Understanding student learning
- Constructivism
- Approaches to learning: deep learning, surface learning, strategic learning
- The Kolb learning cycle
- SOLO taxonomy of levels of understanding
- Bloom's taxonomy of learning
- Learning styles
- Problem-based Learning
- Project-based Learning

B. Core Module 2 – Student Development:

Outcome: Understanding students, including issues of intellectual and social development, learning styles and differences in student approaches to learning.

Narrative: An introduction to understanding elements of student development which impact teaching and learning

such as students intellectual and social development, learning style preferences and approaches to learning.

- Encouraging student motivation
- Teaching and learning in small groups
- Teaching and learning in large groups
- Student supervision: one on one, e.g. projects, theses, dissertations, etc.
- Reflective practice
- Ethics

C. Core Module 3 – Instructional Design:

Outcome: Introduction to instructional design, including both course and curriculum design.

Narrative: An introduction to the theory of constructive alignment (of intended learning outcomes, learning and teaching methods and assessment) to be used in course and curriculum design.

- Organizing teaching and learning
- Outcome-based planning
- Module and course design
- Constructive alignment (Biggs)

D. Core Module 4 – Instructional Facilitation Methods:

Outcome: Instructional delivery, including an overview of teaching methods appropriate for different instructional goals and environments, including both large and small classes.

Narrative: An overview of instructional techniques that might be employed in large group or small group teaching situations, with an emphasis on approaches that might shift the environment of the classroom from teacher-centered instruction toward student-centered learning.

- Structuring lectures
- Increasing student-teacher interaction
- Managing the Classroom Learning

E. Core Module 5 – Assessing and providing feedback to learners:

Outcome: Designing and using appropriate methods to assess student learning.

Narrative: Purpose of assessment, principles of assessment, formative and summative assessment, methods of assessment, assessing groups, peer and self-assessment, devising assessment criteria, providing feedback.

- Assessment and evaluation
- Formative and summative assessment
- Methods of giving feedback

- Assessment methods/tools
- Developing rubrics

The next two modules are proposed as electives. A COMPLETEE participant would choose at least one of these two modules to attain level 1 in the COMPLETEE curriculum. Some, but not all, existing curricula address these modules in a significant way.

A. Elective Module A – Instructional Technology:

Outcome: Making effective use of technology.

Narrative: An introduction to available tools and the effective use of technology to promote learning, including principles of e-learning.

- E-learning
- Virtual Learning Environments

B. Elective Module B – Reflecting on learning and teaching:

Outcome: Engaging in reflective practice and continuous learning

Narrative: An introduction to the role of reflection in professional practice.

- Reflective practice (currently this topic remains distinct to this module, but upon further discussion will likely be distributed throughout the curriculum, with a focus reach in this elective module)
- Developing portfolios
- Classroom peer observations

IV. CONCLUSIONS

This proposal has the following implications: first, it lays a foundation for organizations/groups to compare against. When considering the needs of engineering and engineering technology educators, we have now established a comprehensive curriculum which encompasses input from many existing programs, is consistent with the literature calling for education reform, and represents a national platform for recognizing scholarly attainment in teaching and learning for engineering and engineering technology educators. Second, it lays a foundation to design levels 2 and 3 of the COMPLETEE curriculum. This curriculum is not intended to be offered as a "one and done" type of curriculum. Rather, it mirrors the journey one takes throughout their career as an educator. Third, it challenges the engineering and engineering technology community of educators to own up to what competency areas all faculty should be developing regarding their instructional responsibilities. One can sometimes improve from experience as an educator, but dramatic improvements across the entire community require mutual understanding of core competencies by everyone. In that way the entire community can work together to strengthen their skills and

foster measurable improvements in student success. Finally, we hope it extends the national conversation in this area and incites some debate. We invite comments and critique from faculty developers, researchers in engineering and engineering technology education, and individual instructors. As the COMPLETEE program moves forward we expect that the debate about how best to strengthen and recognize achievement in our community of educators will take shape at national conferences and in publicly visible space on the web. We hope you will join the conversation.

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Work in Progress: Integrating a College of Engineering Teaching and Learning Center into a Leading Position in the Institution

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Abstract - Colleges of engineering increase accessibility to higher education in the Science, Technology, Engineering and Mathematics (STEM) fields. There is often a need to promote students' learning and thinking skills in order to maintain high academic standards and at the same time avoid high rates of failure and dropout. In addition, academic staff with high pedagogical qualifications is an essential requirement. Establishing a Teaching and Learning Center (TLC) is an increasingly frequent process for achieving these goals. Such centers offer various programs for the promotion of teaching and learning in academic institutions.

This article examines the factors that influence the significant role played by TLC in an institution, and the effectiveness of its curricula. The literature refers to several factors, such as the initiation of innovative programs and participation in the institutional strategy plan. In our college, the tight linkage between teaching and learning and the involvement of faculty members in TLC programs are highly influential factors.

Keywords - teaching and learning center; faculty development; learning skills

I. INTRODUCTION

One of the main challenges of higher education in general, and of colleges of engineering in particular, is placing the promotion of teaching and learning in a central position. ORT Braude College (OBC) confers degrees in several fields of engineering, and strives to increase accessibility to higher education in Israel's northern periphery. Accordingly, its policy is to accept students from diverse and multicultural populations and backgrounds while maintaining high academic standards. This results in high dropout rates, especially among students who begin their academic studies with inadequate learning and thinking skills and insufficient knowledge in mathematics and sciences.

OBC's Teaching and Learning Center (TLC) was instituted eight years ago to promote students' learning skills and to improve the quality of instruction. Establishment of centers in Israeli academic institutions was accelerated in recent years. While earlier established centers have focused on

faculty/instruction development, TLC's programs are aimed at both Teaching and Learning.

TLC influence is greatly determined by its position in the institution. The literature dealing with TLC's policies and activities reflects several factors that determine TLC effectiveness. Our experience shows that a significant contributor to TLC leading position is the high involvement of faculty in its programs.

II. WHAT PLACES A TLC IN A LEADING POSITION?

Being a part of institutional strategic plan: Sweet and Blythe (2010) describe how they manage to insert TLC into the strategic plans of their institution through the brainstorming process involving lecturers from diverse backgrounds [1]. In the UK, several Educational Development centers were involved in setting the strategic plans in universities, an indicator of their substantial role within the institutions [2].

Engaging stakeholders in TLC's activity: In order to reinforce the leadership of the Academic Development (AD) unit, the center should work with all its key stakeholders: academic staff, university management and the wider AD community [3]. TLC directors are accountable to the university's senior executive, and TLC's success is judged by its ability to support their expectations [4].

Initiation of innovative programs for promoting teaching and learning: According to a survey of TLC directors in Australia, the most important roles of TLC are to develop and implement teaching and learning plans and to promote professional development of staff [5]. TLC is expected to be a source for initiatives and innovation in promoting teaching and learning [2, 5].

The ability of the Center to demonstrate its value: It is important for TLC to be valued by the institution community, though this goal is difficult to achieve since the assessment of its impact is complicated. The center is more acknowledged if it has evident reputation of national and international collaboration [4].

III. LINKING TEACHING AND LEARNING - GUIDELINES

In OBC, linkage between learning and teaching is elaborated through the following guidelines:

- Involvement of faculty from different academic departments in the various stages of forming new programs for the promotion of teaching and learning.
- Professional long-term training courses for instructors are often dedicated to acquiring knowledge and skills for the purpose of integrating the instructors in the center's activities, not merely for general enrichment.
- Documentation and evaluation of activities to build a teaching-learning knowledge body (e.g. gaining insights into sources of students' difficulties).
- Creation of channels for reciprocal information flow between the engineering departments and the TLC staff.

To achieve its goals TLC operates several programs involving college faculty in each of them:

Courses for learning and thinking skills, compulsory for all freshmen students, are taught by lecturers from the engineering departments.

Students' peer-led workshops guided by exceptional students ("leaders") accompany courses with high failure rates, and focus on active learning and small-group and collaborative problem-solving. Leaders are trained and supervised by course instructors [6]. Workshop evaluations show satisfaction and improved performance of student participants. In addition the workshops contributed to the leaders and course instructors.

In a unique **procedure for supporting underachieving students**, their difficulties are examined and each student is advised of support tools suitable for his own needs. This program involves the Dean for Academic Affairs, academic advisors and department heads. Evaluation research shows that the program enables over 40% of the students, who are candidates for dropping out, to continue their studies.

Academic personal coaching for students with poor learning skills, carried out by college lecturers who have completed a professional training course.

A holistic **procedure for induction of new lecturers** through peer-support and training is especially valuable for those who have arrived at college directly from a career in research or industry.

Projects are initiated and designed by TLC committees comprised of faculty from each of the academic departments: Steering Committee, Faculty Development, Students' Learning, and Research on Teaching and Learning. The discourse that takes place and the interaction between lecturers generates mutual learning fostering discussion of issues raised within the departments, and the spread of perceptions and ideas from the committees to each department.

IV. RESEARCH AND EVALUATION

Over the past several years, data has been collected, using questionnaires and semi-structured interviews, to evaluate: (a)

the effectiveness of TLC projects as they relate to students' learning and achievements, and (b) faculty's perceptions of the influence of TLC's activities on their instructional development and on institutional culture.

Instructors reported that involvement in TLC's activities made them more aware of teaching methods that enhance students' thinking skills, gain a deeper understanding of students' difficulties, and develop skills such as interpersonal communication and management of instructional objectives.

Lecturers' satisfaction with the program is circulated throughout college, and as a result, additional lecturers request to participate. About 40% of college faculty is involved in TLC's programs and committees. An increased number of teaching-learning initiatives are referred to the center by students and faculty.

TLC program evaluation research is encouraged and supported by college management, as a basis for decision-making in college teaching and learning issues. Research outcomes are frequently introduced in management meetings and conferences.

V. SUMMARY AND FUTURE WORK

TLC's position at the institution is reflected by its growing number of programs, faculty participation and additional requests by the engineering departments for TLC's involvement in pedagogical issues. Evaluation research has been carried out for each of TLC projects. Until now focus has been mostly directed at students' achievements and instructors' acquisition of professional and personal skills that influence their teaching.

For further evaluation of overall influence of TLC and its position in the college, we would like to expand our examination to different stakeholders such as department heads and college administration.

We believe that the above-mentioned guidelines for linking teaching and learning can be adapted to other small and medium sized academic institutions, and to faculties/schools inside large academic institutions.

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Mobile Communications Anytime, Anywhere:

The Impact on Work-Life Balance and Stress

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Abstract— Mobile communication technologies have fundamentally altered the concept of going to work. Work has been transformed from a place you go to a function you perform, whenever and wherever you are. Laptops, smartphones, and tablets enable users to transition seamlessly between work and personal activities anytime and anywhere. The effect of this capability on an individual's ability to balance their work and personal life and manage personal stress remains under study. One thing is clear. Modern societies are still in the early stages of this transformation. While 88% of Americans have cell phones, only 46% have Smartphones and just 19% have Tablet PCs. These devices are fast, powerful, and quickly become integrated into our lives as constant companions. This paper presents the results of a survey of engineering and technology students at a Midwestern university. No significant relationship between laptop use and personal stress was found and work-life balance was only negatively impacted when usage exceeded 3 hours on days off. While significant percentages of smartphone users reported increased stress, similar percentages felt the accessibility of the smartphone reduced their stress levels. Users overwhelmingly responded that smartphones improve their ability to balance their work and personal life.

Keywords- *mobile communications; smartphones; work life balance; stress; cell phones; laptop computers*

I. INTRODUCTION

The new reality of the world of work is any day, any time, any place. Mobile communication technologies have fundamentally altered the nature of work forever and workers, families, and employers are struggling to adapt to this change. Long gone are the days when you went to work, put in a full day's effort, and returned home to rest and relax until the next work day. For many workers, advances in mobile communication technologies (MCTs) have transformed work from a place you go to a function you perform, whenever and wherever you happen to be when a call, email, or social networking device reveals the next urgent assignment.

Laptop computers, smartphones, and tablet PCs are proliferating as the constant companions of young and old alike. They are no longer simply work tools utilized to polish a presentation or stay in touch while traveling. Instead, they are quickly becoming fully integrated into our personal lives and our dependence on them to manage our personal and work life is growing [1-3]. They are small, fast, convenient, and always close at hand as we move fluidly between personal and work activities throughout the day [4, 5]. Mobile communication technologies blur the boundaries between work and personal time enabling us to quickly switch between work and personal tasks at will. While employers and employees agree MCTs offer productivity benefits [5-7], the impact of this transformation on employee personal lives remains under considerable study.

We are still in the early throes of this transformation and there is little consensus on how these technologies impact employee work life balance. Further, the current generation is growing up in a world where universal accessibility and constant availability is assumed. College students in particular are often juggling school, work, and personal life commitments with 70-80% working at least part-time while enrolled in classes [8]. Various studies have identified the benefits of MCTs including increased flexibility, increased control of where and when work is performed, and increased productivity [1, 5-7, 9]. However, these and other studies also find increasing concerns over conflicts between an individual's work and personal commitments [1, 4, 10], increased expectations of availability and time greediness by employers [9, 11], and employees working during vacations and personal time off [1, 12, 13]. But what is the impact of this new reality on the personal lives of workers and their families? Does this rapid movement between personal and work activities increase or inhibit our ability to meet work and personal commitments? Many find it difficult to shut down these technologies after work and several studies have found workers consider personal time more malleable than work time further increasing pressure on personal and family commitments [1, 12-14].

II. PROBLEM STATEMENT

The effects of the proliferation of MCTs on work-life balance and personal stress are still being studied. It could be expected that the impacts are not uniform and that individuals balancing multiple major life events may be more impacted than those balancing simply their work and individual life. This study focuses on college students who have full or part-time jobs and may have family commitments as well. The constant multi-tasking required to balance these competing demands may lead to increased stress or difficulty achieving work-life balance.

III. SIGNIFICANCE

The importance of understanding the impact of MCTs on work-life balance cannot be overstated. In the U.S. while over 88% of adults have cell phones, only 46% currently have smartphones [15] which enable much closer ties to work activities. The iPad brought the tablet PC into the mainstream with 15 million sold since 2010 [16] and tablet ownership overall nearly doubled between mid-December 2011 and early January 2012 [17]. This device makes it even easier to perform personal and work activities anytime, anywhere. The impact of MCTs on society and individual work-life balance is just beginning. Employers need to understand the impacts so they can develop policies and work-life initiatives that benefit both employers and employees [9, 18]. Employees need to understand the impacts to develop strategies for managing the increased accessibility of MCTs while still enjoying the flexibility over working arrangements they provide [4, 9, 14]. Educators also need to understand the impacts as the number of traditional-age undergraduates working full and part-time jobs continues to increase [19]. Families must understand the pressures MCTs bring to students and impacts on the family. One study has found MCT users feel their families understand their need to work on holidays, weekends, and work nights [1] but a study among family members wasn't performed.

IV. LITERATURE REVIEW

The following literature review is divided into four sections beginning with the scholarly literature on MCT usage and how the concept of the work place and work time is changing. The next section reviews studies examining work-life balance, role conflicts, and boundaries between work and personal commitments. The third section examines studies that evaluate the relationship between MCTs and their impact on work-life balance and stress. The summary highlights areas where the literature is incomplete and additional research is needed.

A. Mobile Communication Technology Usage Patterns

Many companies now have extended work hours to support production goals and increased customer services into the evenings to serve customers. As a result company work hours are extended and MCTs enable employees to stay connected at any time and any place. Roberts [20] observed that once it is possible for an employee to be reached for work during weekends and time off, it can easily become an expectation and other studies have found that some employers now have that expectation [1, 5, 11]. MCTs make it easy for the work environment to spill over into the personal lives of workers, a phenomenon the literature refers to as the "blurring of

boundaries" [1, 5, 21, 22]. Working from home has been experimented with and MCTs seem an ideal tool to facilitate that work arrangement. However, a recent study found that workers fail in their attempts to separate their work and home life. 100% of respondents stayed connected during breaks, 92% remained contactable during the evening, and 76% were connected all weekend [22].

Other studies have found that MCTs have an undeniable impact on employee concept of working hours. Smartphones in particular are used to fill small gaps of time on the bus or waiting in line further blurring the lines between work and personal time [23]. Karlson et al., [13] found respondents checking email as the first thing they did upon waking up and made work email a higher priority than personal email. Other workers report that if they wake up in the middle of the night, they check email and respond to some items immediately [13]. Middleton & Cukier [24], found similar behaviors of checking email before going to bed as well as doing email while driving, attending meetings, on the golf-course, and while on vacation. The respondents frequently rationalized their behavior and were strongly committed to their pattern of use which Middleton & Cukier [24] felt showed evidence of compulsion.

B. Work-life Balance and Personal Stress

Work-life balance can be defined as having a healthy balance between work and home with a minimum of role conflict [6]. Role conflict occurs when simultaneous pressures from one role make it difficult or impossible to fulfill the demands of another role [4]. The literature contains a number of studies where workers enacted various strategies in an attempt to maintain a satisfactory work-life balance [1, 4, 6, 9, 14, 22] and those employees with role overload report higher work stress [25-27]. One study found the problem so severe that it described mobile email usage patterns as dangerous and anti-social while also infringing on work-life boundaries [24]. However, other studies suggest the problem is overstated and report workers show little interest in making a distinction between work and their personal life and add there is no uncontested evidence of increased work hours [28]. Other researchers agreed and argue that the feeling of being pressed for time is caused by "work intensification" or "time compression" rather than the number of work hours [3, 20]. This intensification could be a side effect of modern technology's ability to complete tasks more quickly which rather than increasing free time has instead lead to an increase in the number of tasks that must be completed [1]. However, Wajcman [3] feels MCTs may be the solution rather the source of time pressures and concludes that the separation between work and home is under reformulation and harnessing the possibilities of MCTs may aid our efforts to manage our time.

C. The Impact of MCT Usage on Work-life Balance and Personal Stress

A 2001 national work-life balance survey in Canada found over 25% of respondents believed technology had increased their ability to balance their work-life with about the same percentage reporting it decreased their work-life balance [5, 27]. The study concluded that MCTs can support or hinder work-life balance depending on the user. Towers, et al. [1], had similar results from a survey of Canadian Federal

Government employees where BlackBerrys were used by 89% of the sample. Among these users 46% said BlackBerrys increased their ability to manage their work-life balance while 38% said it decreased that ability [1]. A 2007 national survey in Australia was conducted to understand the social impact of the mobile phone on work-life balance. This survey found 51% of respondents believed mobile communications devices helped them balance their work and family lives while only 4% reported a negative impact [29]. They concluded that fears of work intruding into home life are exaggerated even though there was evidence of work intensification among men [30].

Concerning the impact of MCTs on personal stress, the Canadian national survey found 50% of respondents felt technology had increased their stress levels [5]. A separate study that analyzed the same data found that 25% felt work interfered with their ability to meet their responsibilities at home and 33% reported high levels of job stress [25]. In contrast, the Towers, et al [1] survey found 66% of respondents indicated no impact on their stress levels due to MCT and about the same number reported increased stress as those reporting decreased stress. The Australian survey also found that mobile phones did not dramatically increase stress levels. They found 61% believed their mobile phone did not affect their level of stress and 75% of those that reported an impact said it reduced their stress level [29]. A separate study of the same data concluded that the strategies mobile phone users establish to control when and how to interact with mobile messages is the key to reducing stress levels [31].

D. Summary

While these studies have begun to evaluate the impact of MCTs, it is clear there is much left to explore. There are few quantitative studies evaluating the relationship between MCTs and work-life balance and stress. The data that has been gathered are from surveys performed between 2001 and 2007 when smartphones were still novelties and tablet PCs were virtually non-existent. The literature suggests the impacts are changing over time and additional research to evaluate those changes is necessary. Finally, none of these studies were conducted among college students whose usage may represent how the next generation will integrate MCTs into their lives.

V. PURPOSE STATEMENT

The purpose of this quantitative survey study is to examine the relationship between the use of mobile communication technologies for job-related work activities and the individual's perception of their ability to maintain healthy work-life balance and stress levels.

VI. METHODOLOGY

This research used an on-line instrument to survey undergraduate and graduate students at the Purdue School of Engineering & Technology at IUPUI in Indianapolis with the primary focus on students that also have jobs.

A. Survey Design

The survey instrument utilized in this research was a modified version of a survey developed by Towers, et al., [1] and permission was obtained from Dr. Linda Duxbury to use the survey tool for this research. One question was added with

permission from Professor Judy Wajcman from a survey conducted in 2008 [29] which asked users how much they would miss their MCT device if it was taken away.

B. Survey Population

The survey was sent to 2,426 undergraduate and graduate students at the Purdue School of Engineering & Technology during the spring semester 2012. This population was chosen since a high percentage of college students are users of mobile technologies, reaching 100% in one study [32].

C. Survey Variables

The focus of this study was on the relationship between time spent using MCTs and the impact on stress and work-life balance. Table I details the variables and associated research questions used to gather this information.

TABLE I. SURVEY QUESTIONS RELATED TO THE INDEPENDENT AND DEPENDENT VARIABLES

| Variable Name | Research Question |
|---|---|
| Independent Variable 1: Time spent using a MCT device on work days. | On a typical WORKDAY, how many hours do you spend on your laptop computer (cell phone/smartphone/tablet PC) for job-related email and other applications? |
| Independent Variable 2: Time spent using a MCT device on non-work days. | On a typical NON-WORKDAY, how many hours do you spend on your laptop computer (cell phone/smartphone/tablet PC) for job-related email and other applications? |
| Dependent Variable 1: Stress | What impact has the use of your laptop computer (cell phone/smartphone/tablet PC) had on your stress level? |
| Dependent Variable 2: Work-Life Balance | What impact has the use of your laptop computer (cell phone/smartphone/tablet PC) had on your ability to balance your work and home life? |

VII. RESULTS

A. Demographic Summary

There were 468 completed surveys representing a 19.3% response rate. There were 325 responses from students who held jobs and used MCTs, representing 69.4% of all completed surveys. The age groups of the respondents were similar to the Engineering & Technology student population in 2011 [33]. However, working females comprised 24% of the sample as compared to only 10% of the overall population and graduate respondents were 19% as compared to 10% of the population. Laptops were used by 60% of employed students, while 68% used smartphones, 29% used cell phones and 18% owned tablet PCs. Only 2% of employed students did not use any MCTs.

B. Chi-Square Analysis Results Summary

A Chi-Square Test of Independence was calculated for each of the independent and dependent variables listed in Table I. Responses were grouped to ensure that no group had expected frequencies less than 5 as required for a valid analysis [34]. There were insufficient responses from users of cell phones and tablet PCs to achieve the minimum expected counts required for the Chi-square test, so they could not be conducted.

1) Laptop computer results summary

A chi-square test of independence was calculated comparing the work day and non-work day hours using a

laptop computer for work activities and the perceived impact on student stress and their ability to maintain work-life balance. No significant interaction was found between Laptop workday usage and stress ($\chi^2(2) = 1.396$, $p < .05$), laptop non-workday usage and stress ($\chi^2(2) = 2.839$, $p < .05$), or laptop workday usage and work-life balance stress ($\chi^2(2) = 0.033$, $p < .05$). Those relationships appeared to be independent. However, a significant relationship was found between laptop non-workday usage and work-life balance ($\chi^2(2) = 9.186$, $p < .05$). Students that performed work activities on their laptop more than 3 hours per day on non-workdays were more likely to report a decreased ability to balance their work and personal life than students who performed work activities on their laptop less than 3 hours per day. Twenty-nine percent of students in this group reported a decreased ability to balance their work-life as compared to 11% of students with usage less than 3 hours.

2) *Smartphone results summary*

A chi-square test of independence was calculated comparing the work day and non-work day hours using a smartphone for work activities and the perceived impact on student stress. A significant interaction was found between smartphone workday usage and stress ($\chi^2(4) = 42.650$, $p < .05$). Students that used their smartphone on work-days for more than an hour per day were more likely to report a change in stress levels than students who used their smartphone less than an hour per day. Thirty percent of these students reported an increase in stress while 29% reported decreased stress levels. A significant interaction was also found between smartphone usage on non-workday usage and stress ($\chi^2(4) = 46.733$, $p < .05$). Students that used their smartphone for work activities on non-work days were more likely to report a change in stress than students that did not use their smartphone on non-workdays. Twenty-eight percent of students that used their smartphone from 1 to 60 minutes reported increased stress compared to 21% who reported decreased stress. Twenty-four percent of students with usage over 1 hour reported increased stress compared to 27% who reported decreased stress.

Finally, a chi-square test of independence was calculated comparing the work day and non-work day hours using a smartphone for work and the perceived impact on a student's ability to balance their work-life. A significant interaction was found between smartphone workday usage and work-life balance ($\chi^2(4) = 27.419$, $p < .05$). Students that used their smartphone for work activities were more likely to report an increase in their ability to balance their work-life than those that did not use a smartphone for work. Eighty percent who used MCTs less than 1 hour for work and 83% who used MCTs more than 1 hour reported no change or an increase in work-life balance. A significant interaction was also found between smartphone usage on non-workdays for work activities and impact on work-life balance ($\chi^2(4) = 34.179$, $p < .05$). Students that used their smartphone for work on non-workdays were more likely to report an increase in their ability to balance their work-life. In this case, 82% who used MCTs less than 1 hour for work and 75% who used MCTs more than 1 hour reported no change or an increase in work-life balance.

A. *Demographic Observations*

The relatively high percentage of survey responses from female and graduate students compared to the overall student population may influence these results. It may also indicate MCTs are having more impact on these groups generating more responses. Over 98% of students on this campus had a smartphone or cell phone, a result similar to what was found in another college campus study [32]. Over 62% had smartphones as compared to 46% of American adults [15] but 68% of students that work had smartphones as compared to only 48% of unemployed students. Laptop use in this sample was 70% overall but 95% of unemployed students had laptops compared to only 60% of employed students. This may reflect the new trend among college students since 86% of unemployed students in this survey were aged 24 or less.

When working students were asked how much they would miss their MCT device if it "disappeared today", 61% percent of laptop, 63% of smartphone, and 55% of tablet users reported they would miss their device "often" or an "extreme" amount. This demonstrates how integrated these mobile devices are into their work and personal lives. One student commented that "I use my android smartphone and tablet a great deal, to the point that it would be considered an addiction. If I don't have the phone on me, I feel that I'm missing a limb." These extreme feelings closely aligned with the results of a 2007 survey in Australia where over 50% of respondents said their daily lives could not proceed as normal without their mobile phone and the overwhelming majority of this group would miss their mobile either 'often' or 'an extreme amount' [31]. In this study however, working students were much less enamored with their cellphones as 54% said they would only miss it "sometimes" or "not at all". Smartphones obviously provide users greater benefits and are more integrated into the lives of students.

B. *Laptop Computers*

Among engineering and technology students, the laptop computer was viewed as a useful tool that increased flexibility of when and where to perform work. It was mostly viewed as a positive communications and work tool to help balance work and personal life. The number of hours used did not seem to have any significant impact on users stress and only a nominal impact on work-life balance. Only when the laptop was used for work activities more than 3 hours per day on non-work days did users begin to report a significant negative impact on their ability to balance their work and personal life. Even then only 29% of that group reported a negative impact compared 39% who reported the laptop made it easier to balance their work and personal life. One laptop user observed "The technology tools themselves are not necessarily the point of increased stress for home/work; rather my increased stress and productivity challenges stem from expectations and higher demands of immediate communications from others (24/7)." This was consistent with the findings of Wajcman, Bittman, & Brown [31] who found job characteristics and working hours had a greater influence on work stress than mobile communications.

C. Smartphones and Stress

When students used their smartphone for work activities during the workday, they reported significant impacts on their stress levels. While 60% of students that used their smartphone for less than an hour reported no change in their stress, 22% of this group reported increased stress with about the same percent reporting decreased in stress. These results were similar to what Wajcman, Bittman, Johnstone, et al. [29] found in their survey, where 61% responded the mobile phone had no impact on stress. In their study however, only 9% reported increased stress versus 22% in this study. One key difference may be that their study did not distinguish between cell phones and smartphones which were less common when their data was gathered. Remarkably, when students used their smartphone more than 1 hour per day, those reporting increased stress rose from 22% to 30% but about the same percent reported a decrease in stress. When the data was broken down between full-time (>25 hours/week) and part-time workers a shift in responses was seen. The percent of part-time workers who reported increased stress rose from 5% to 28% when usage surpassed an hour, whereas for full-time workers the percentage actually declined from 37% to 30%.

A similar pattern occurred for those that used their smartphone on non-workdays for work activities. Once part-time workers began using their smartphone on non-workdays for more than an hour the percentage reporting increased stress rose from 6% to 18%, whereas it fell from 42% to 27% among full-time workers. Students that work full-time and used their smartphone infrequently during days off tended to feel increased stress when they utilized their MCT. However, those that worked full-time and used their smartphone frequently (> 1 hour) on days off were less likely to report increased stress and were just as likely to report a decrease in stress. These students tended to view the increased connectivity and capabilities of smartphones and laptop computers as the solution rather than the problem. About 28% of the student comments discussed the productivity benefits of their mobile devices with observations like "...it has allowed me to better manage my time, accomplish tasks at a faster pace and during periods of time that would have normally unusable." It seemed the more they used the device, the more they adapted to its intrusion into their personal life and felt less stress as a result.

D. Smartphones and Work-Life Balance

The impact of smartphones on work-life balance for students was also significant. The more working students used their smartphone on workdays the more likely they were to say it made balancing their work and personal life easier. Thirty-three percent of students that used their smartphone between 1 and 60 minutes during the work day indicated it was easier to achieve work-life balance. For those whose use was more than an hour a day, this percentage increased to 51%. These results were again consistent with the findings of Wajcman, Bittman, & Brown [31] who found that 54% of respondents believed that the mobile phone helped them balance their work-life. Towers et al. [1] also found 46% of Blackberry users felt it increased their ability to achieve increased work-life balance. The responses for working students were similar for non-workdays where 80% of students that used their smartphone for work between 1 and 60 minutes reported no change (42%) or

an increase (40%) in their ability to achieve work-life balance. For those whose usage was over an hour on non-workdays, this percentage declined slightly to 75% and those who reported an increased ability to balance work-life actually rose to 46%. It seems clear that student workers viewed the ability to connect to their personal lives as a significant benefit even when balanced against the possibility of work activities intruding into their personal life. Further, the more they used their smartphone for work activities, the more likely they were to view them as a positive influence in balancing their work-life.

IX. CONCLUSION

While the increased accessibility provided by MCTs have the potential to increase stress and negatively impact work-life balance that is clearly not always the case. Most students in this survey embraced the connectivity of MCTs and felt they increased their ability to balance their work and personal life. While some smartphone users felt increased stress as usage increased, similar percentages felt smartphones provided reduced stress. These results have a number of implications.

A. Implications for Employers

Employers should recognize that MCTs are now integrated into the lives of their workforce and can be a tremendous productivity tool. Over 30% of the comments student workers made in this survey discussed the productivity benefits of MCTs. Some studies found workers prefer the peace of mind this connectivity provides which enables them to perform work activities during times that would normally be "unusable" [13]. Employers should make these devices readily available to employees as work tools and encourage employees to utilize them to balance both work and personal commitments.

B. Implications for Educators

Educators should recognize that students carry these devices 24x7 and consider ways to enhance the educational experience through them. Web pages, systems, and class resources should be formatted to support access via smartphones and tablets. The tablet will quickly become the tool of choice for the majority of students who will desire books, class materials, and on-line collaboration projects to be accessible on their tablet. Users can become frustrated with systems that do not support transitions across devices [23]. Investments in on-line capabilities and state-of-the-art access may be the best way to attract the top students of the future.

C. Implications for Families

Families of student workers should recognize the demands placed on students attending classes while working. Some students felt increased levels of stress, in particular those that used smartphones related to their work activities. Stress is most often driven by personal life issues rather than work issues according to some studies [18, 35] but they also have an impact on work which is why many companies are providing work-life support resources [10, 26]. Families should take advantage of those resources to mitigate the potential impacts.

D. Implications for Students

Students embrace MCTs as a way to balance their busy lives and are early adopters of new technologies. As one student commented "Life is better and easier with a smart

phone!" However, there is some cause for concern when 30% of those using smartphones more than an hour during a typical workday reported increased stress. Currently, the benefits seem to outweigh the risks in the minds of students since 44% of smartphone users responded they would miss their phone "an extreme amount". However, students need to develop strategies to manage MCT use. While studies have started to explore some potential strategies [6, 14] more are needed to identify solutions to this likely problem.

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Using eReaders and Tablets in the Engineering Classroom

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Abstract—The use of eReaders, and Tablets is increasing dramatically by engineering students. As engineering and science textbooks become more available for these devices at costs significantly below the costs of traditional printed textbooks, even more students will use these devices. In addition to the text, students often use a professor's slides, handouts, assignments, laboratory exercises, and supplemental material as part of their studies. While some is prepared by the publisher, the material is more often locally prepared by the professor. Having this material available on the students' eReader or Tablet would significantly enhance the students' use of their device. During the past academic year, we have begun to develop supplementary materials for several courses for use with a Kindle or Tablet. In this paper, we will describe the techniques needed, beginning from the straightforward transfer of purely textual materials, to developing materials with highly mathematical and graphical content for display on the devices. In addition, we will describe how these techniques can be used to produce material for these multiple uses without placing a significant additional burden on the faculty member. The paper will report the results of a pilot project where students in several Fall 2011 and Spring 2012 Electrical and Biomedical Engineering courses were loaned Kindles and all material beyond the texts for the courses was produced for the devices. The results of the students' surveys on their use of the material and the eReaders will be presented and discussed.

Keywords—eReader, handouts, Kindle, Nook, preparing course content, tablet

I. INTRODUCTION

College students are beginning to use eReaders and small tablet computers in increasing numbers. Surveys show that roughly 1/3 of college students currently own a Kindle, Nook, or other eReader. The surveys also report that as soon as books for their courses become available in eReader format at a reasonable cost, students will immediately purchase an eReader. Additionally, the studies [1], [2], [3] have estimated the growth of eReader use to be almost exponential.

In addition to the course text, engineering (and science) students often receive handouts of lecture slides, supplemental materials, and problems sets (and associated solutions) and laboratory handouts as part of their courses. Laboratory assignments often require data sheets and instrumentation operating instructions and software requires manuals and possible sample programs. While much of this material is still handed out in printed form, it has become almost universal that such material be converted to pdf or another appropriate format and posted on the web or made available on the

institution's course management software such as Blackboard. The challenge then for the faculty is to make their material available to students while not dramatically increasing their lecture preparation time.

While it is straightforward to convert purely textual content to a form that it can be viewed on a eReader, most engineering (and science) content is both highly mathematical and contains substantial amounts of graphics. This poses challenges to a faculty member attempting to produce content for the eReaders. To complicate the situation, due to quirks in individual eReaders, content that looks totally acceptable on one eReader at times looks like gibberish on another eReader.

Finally, whatever method is used to create content, the lecture material must be available for projection in the classroom, and use on larger tablets (such as an iPad), on a PC, and be able to be printed by printing by normal methods. The challenges in creating content then include adding equations and mathematical symbols, graphics, taking into consideration the different aspect ratios of the tablets, dealing with the nuances for the various pdf rendering methods.

Since content needs to be transferred to the eReader in a seamless fashion, it would be useful if the eReader could directly connect with the institution's course management software like books are currently downloaded. Barring that, it should be straightforward to move the material to the students' eReaders.

In subsequent sections of this paper, there will be a brief overview of the characteristics of the eReaders, how to create purely textual material for an eReader, creating content using OpenOffice sWriter, and LaTeX, Creating Slides using Impress and Beamer, transferring material to the eReader and linking with course managements software. This work will conclude with the results of pilot trials of eReaders during 3 courses during the Fall 2011 semester.

II. CHARACTERISTICS OF EREADERS

While there are a plethora of eReader type devices available on the market, the devices used in this work are confined to three devices that could be purchased in June 2011, two eReaders, Amazon's Kindle, Barnes and Noble's Nook and a similarly sized Android tablet, the Dell Streak 7. By the time this work was written the two eReaders have been replaced with updated models. However the techniques used to generated content and the students' opinions are not likely to

change much by the technology evolution. Each of the devices are book sized devices that have a display with diagonal dimension of between 6 and 7 inches. The overall dimensions of the devices are about 5" x 8" and between 1/4" and 3/8" thick. They range in weight from 10 to 12 ounces. Thus, they are smaller and lighter than an iPad, a traditional tablet computer, or a laptop.

All of the devices come with USB ports that can be used for file transfer and charging. All have internal WiFi that can be used to connect to a majority of WiFi networks. The Kindle has a 3G version which automatically connects to 3G Wireless Networks without any additional costs or data plan. This allows data transfer without connection a WiFi connection. Most Android tablets, like the Dell Streak 7 have enhanced versions that connect to a data network. These are normally sold through a wireless provider and require an additional data plan.

Most eBooks are distributed in the mobi format. Most eReaders dynamically reformat the page based upon the font size chosen by the user. This allows the easy display of textual material, although it sometimes results in the page numbers on the eReader being different from those in the printed work.

In addition, all of the devices used have the ability of view a wide variety of other file types, including the .doc and .docx for word processed documents, .xls for spreadsheets, .ppt for presentations, .txt, and portable document files (.pdf).

In rendering pdf files, the default mode of most eReaders is to shrink the page to the width of the eReader display. Thues, depending on the aspect ration of the original document and the eReader, a single document page might be displayed or spread over multiple pages. By experiment however, it was found that not all pdf pages are rendered according to this algorithm, especially those will graphical content. Graphics are often rendered to exceed the normal width of the display and essentially wrap over to a new page. This was most noted in the display of PowerPoint slides that have been converted to pdf.

Most eReaders rotate the page as the eReader is physically rotated from the portrait to landscape mode. Therefore, it might seem possible just to rotate the eReader and display a slide in the Landscape mode with the eReader rotated. However, this does not always happen because the aspect ration of the eReader screen is likely different from the aspect ration of a typical PowerPoint slide and the scaling of the displayed file does always change as desired when the device is rotated.

In Table I below, the properties of the displays of the Knidle, Nook, Streak 7 are summarized and compared to paper and several types of books.

TABLE I. ASPECT RATIOS

| | Page Width | Page Height | Aspect Ratio |
|---------------|------------|-------------|--------------|
| Kindle | 3.56 | 4.75 | 1.44 |
| Nook | 3.6" | 6.25 | 1.74 |
| Dell Streak 7 | 3.6" | 6" | 1.67 |
| Letter Paper | 8.5" | 11" | 1.29 |

| | Page Width | Page Height | Aspect Ratio |
|---------------------|------------|-------------|--------------|
| Kindle | 3.56 | 4.75 | 1.44 |
| Letter 3/4" margins | 7" | 9" | 1.36 |
| Letter 1" margins | 6.5" | 9" | 1.38 |
| Couch [4] | 5.25" | 6.75" | 1.29 |
| Ingle/Proakis [5] | 5.5" | 6.75" | 1.22 |
| Trade Book [6] | 6" | 9" | 1.5 |

In some eReaders, although the documentation states that the page size is changed as the content is rotated, experimentally we have found that wrap occurs unless the aspect ratio of the eReader is less than the aspect ratio of the page it is trying to render. The pages of material thus are converted to two pages on the display.

III. CREATING CONTENT AND PORTING IT TO EREADERS

A. Converting Files to eReader formats

Purely textual material can be converted to the .mobi or other eReader formats by a program like Calibre. [7] [8]. Indeed it is straightforward enough that there are several how-to-do books on self-publishing one work to an eReader [9], [10], [11], [12]. A major caveat of these methods is that they apparently work well for textual material that can be generated in a pure text (.txt).

On the other hand, the online documentation for Calibre states while conversion of pdf files is possible, it is not recommended because, depending upon the complexity of the graphics and special characters in the pdf file, the ultimate rendering on the eReader is not guaranteed and the quality of the rendering will vary among eReader types. None of the guides mentioned above were particularly helpful in preparing highly mathematical content, content containing images, or powerpoint slides for the eReaders.

Another methodology for authoring is an automatic system as described in [13]. The infrastructure required for that system was beyond what was desired for this work.

B. Creating Engineering Content with Open Office sWriter

To develop textual material with limited graphics and equations a standard word processor such as Microsoft Word or OpenOffice [14] can be used where the document is displayed as is on the computer screen can be used. By proper formatting, the pages can be displayed on the eReader without magnification or wrap around. The goal in formatting is to create a document that, when saved in pdf format and displayed with the eReader its parameters are such that when the eReader is set to scale to page width, the pages will not overlap be cutoff either vertically or horizontally.

The most straightforward way to create a document that is easily viewable on an eReader is to set the word processor page size to the eReader screen size (for the Kindle 3-9/16" by 4-3/4"). The margins are then set to 1/4" on each side and the document is created. The document can then be saved as a pdf

and transferred to the eReader. Pages of the document will be displayed as single pages on the eReader and may be advanced using the Kindle page buttons or swiping on other eReaders.

To choose font sizes it was noted a direct mapping of font sizes was not possible. However, by experimentation, it was found that 12 point is rendered that most people feel is acceptable for reading at a moderate distance. Magnification of page on the eReader can be used if the reader desires a larger typeface. However the magnification would often cause overlapping and was not as convenient as documents saved in an eReader format.

Graphics that were included in the document were constrained to the page width which often resulted in them at times being too small for easy use. While a graphic could be rotated and displayed in a larger format, unless the eReader was configured not to rotate the page when the eReader was rotated, the rotation of the image was not satisfactory.

Content prepared in this form could be printed by insuring the option of "fit to printable area" was chosen. Thus, the handouts could be printed to serve students without an eReader without significant additional effort by the faculty.

C. Creating Content with LaTeX

The Gold Standard mathematical text processing program is LaTeX. LaTeX was developed by Donald Knuth in the late 1970s as a way to computer typeset mathematics and has gained almost universal acceptance [15]. Because Latex use proportional fonts, ligatures, and auto-hyphenation, material prepared in LaTeX looks like a fully typeset document. More importantly for Engineers (and Scientists) is the fact that LaTeX can typeset complex mathematical equations and structures easily. Most current LaTeX distributions output LaTeX documents as pdf files.[16]

There are several default page sizes for LaTeX. If a document is chosen to be set as a letter-sized document, then the scaling of the pdf file by the eReader often leaves the material unreadable.

To better create pdf files for viewing on a Kindle the page size had to be chosen to be the screen size similar to that used in sWriter. Unlike work processors, Latex, does not use absolute margins, rather one sets the upper margin, left hand margin and the text width. While not natural to those of us who regularly use WYSIWYG Word Processors, this choice of parameters is derived from how a classical typesetter sets up a page. With some experimental work with PCTex [16], it was found that the following parameters produced an appropriate looking page. When viewed by students, most agreed that the quality was acceptable.

TABLE II. LATEX PARAMETERS

| |
|--|
| <pre> \setlength{\paperwidth}{3.5in} \setlength{\paperheight}{4.75in} \setlength{\hoffset}{-.9in} \setlength{\voffset}{-.9in} \setlength{\textwidth}{3.3in} \setlength{\textheight}{4.in} </pre> |
|--|

IV. CREATING PRESENTATIONS FOR THE EREADER USE

A. Lecture Sildes

Lecture slides and handouts are likely to be the most created content for Engineering (and Science) courses next to problem assignments. The key to adding such content to an eReader is to make it straightforward and simple to create this content in eReader format. In addition, many texts include sample slides as aid to the instructor, often removing the need to scan text images.

B. Creating Content with Open Office Impress

Impress is the Open Office presentation program which is analogous and in most cases functionally equivalent to PowerPoint. In addition to saving to a plethora of file formats, Impress can directly output pdf files.

Since current presentation methodology is to use Landscape Mode, it might appear reasonable to create the presentation, then have the eReader rotate it, then rotate the eReader to view the slides in the landscape mode. However, this does not work for several reasons. The primary one is that most eReaders do not rescale the presentations when the display is rotated. Even if one disables the auto-rotating on the eReader, it still keeps the scaling as too small for ease of viewing. On some, eReaders, the slide is wrapped to 2 pages which makes it very inconvenient to use.

One workaround is to create a presentation using a page size with the same dimensions as the eReader screen, as was done for textual material in Section III but in the Landscape orientation. The presentation may be saved as a pdf file. The pdf file can be then opened in Adobe Acrobat, the pages rotated counterclockwise 90-degrees, and the file re-saved. The resulting file can then be displayed on the eReader and will not overlap pages. However when the eReader is rotated so that the screen is in the Landscape mode, the presentation will also rotate. This can be overcome by disabling the the auto-rotate content on the eReader. The presentation can be viewed on the eReader in the Landscape orientation without any page overlap.

The original un-rotated file can be displayed on a computer using Adobe Reader in the full screen mode and projected. The projected image will appear no different than one that is created at full page size. The original version can also be made available to students who are using laptops or tablet-based computers for their work.

Rendering problems on all eReaders, however do not allow the display of all presentations generated this way. It was found that use of certain color combinations, although displayed perfectly clearly on a PC or MAC, would not display properly on all eReaders. This was particularly frustrating, since files that are displayed correctly on a Kindle might not be displayed properly on a Nook and vice-verso. What was found after preparing several courses was that it was important to keep the color style as simple as possible. Choice of background colors was important, since for unexplained reasons, on some eReaders and for some background colors, the background color choice covered up the text and graphics. None-the-less, edited slides produced from sample powerpoint presentations

prepared by textbook, software, and hardware manufacturers were used with minimal problems.

C. Creating Content with Beamer

The Beamer style of LaTeX is the Gold Standard for creating presentations with significant mathematical content [17]. While not as flexible in adding graphics to a What-You-See-Is-What-You-Get presentation such as ImPress, LaTeX's ability to create slides with complex mathematical formulae, makes is a choice for many applications. Like ImPress, Beamer creates pdf files.

Beamer slides can be created with a variety of presentation backgrounds. In general, it was found that for unexplained reasons, the eReaders were much less sensitive to background color schemes for presentations created using Beamer than for presentations created using ImPress.

It was found, however, that because of the default font choices made by Beamer, if one takes the Beamer created pdf file of the full sized slides, rotated all pages by 90-degrees counterclockwise, and re-saved them, the resulting file could be displayed on all the eReaders without overlapping or page-wrapping. This meant that slides created for projection in class could be converted to the eReader format in a very short time, conserving valuable faculty time. Similar to ImPress, the original pdf file could be projected in class, viewed on a PC, or printed as hardcopy handouts.

V. TRANSFERRING MATERIAL TO THE EREADER

To successfully integrate the use of eReaders in the classroom, there should be an integrated method of transferring material to the eReader, just like books are transferred to the eReader. The University of Hartford currently uses the Blackboard platform for course management. When this work was initialed, no mobile apps for Blackboard were installed. Therefore, the students had to log into Blackboard, download the files to a local computer, and then transfer the downloaded files to their eReaders using a USB cable..

While each of the eReaders has some form or Web Browser implemented, primarily for logging onto the seller's site to purchase content, the browsers are by no means a full implementation of browsers that are expected Because Blackboard uses a significant number of popup windows, if the browser implementation does not full implement these, it will be difficult or nearly impossible to connect. The Kindle had the most difficult time with Blackboard and eventually most Kindle users decided to download the files to a PC and then connect the Kindle to the PC via the USB port to load files.

Another issue arose with the connection of the eReader to the University of Hartford wireless network. The failure to connect was identified as a multi-stage problem. The first dealt with the choices that were made by the eReader designer on what parts of wireless security to actually implement. The second was the Browser implementation and how it responded to the request for authentication by the University network. The final problem dealt with a conflict between the security certificate choices made by the University of Hartford network administrators and the security certificates implemented on the

eReader. Even with assistance from Computer Services, it was not possible to connect the Kindle to the campus WiFi network, although the Kindle connected seamlessly with networks in many other locations.

VI. USE IN COURSES

During the Fall 2011 Semester, materials for courses Bio-instrumentation, BE 401, Digital Signal Processing, ECE 440, and Communications Engineering, ECE 423 were prepared for use on the eReaders. Students who did not own personal eReaders were loaned Kindles. Each of the students was requested to fill out evaluation forms for each item used. No all studnets in the courses had access to or used eReaders.

The results of the survey administrated are summarized in the Table III below. Responses were collected in a 5 point Likart Scale, from Strongly Disagree, 1, to Strongly Agree, 5. 16 students participated in one (or in several courses two or more) courses. Because of the relatively small number of students and the desire of the Institutional Review Board to keep the survey anonymous, the data could not be broken out by gender or year.

TABLE III. STUDENT SURVEY

| Question | Weighted Response |
|--|-------------------|
| The textual material (as opposed to charts and graphs, etc) was clear and readable | 4.31 |
| The figures displayed were clear and readable. | 4.56 |
| Use of eReader helped me understand my Class Notes. | 4.38 |
| The material on the eReader helped me to better understand the key concepts. | 4.25 |
| Using the eReader enhanced my classroom experience. | 4.63 |
| Using the material on the eReader helped me complete an assignment. | 4.18 |

From these results, it was clear that a majority of the students who used eReaders concluded that having the course material on the eReaders enhanced their classroom experience. For one of the courses, Bio-instrumentation, the publisher loaned us copies of the text in pdf format which the students also loaded to their eReaders. In their reviews, the students were very satisfied that they could have all the course materials available on their eReader.

When asked what additional material the students would like on their eReaders, most students indicated that they added manuals or guides to the course software packages (MATLAB or LABVIEW). Several replied that having the software manual or guide on their eReader helped them even when they used the package on their laptops, since most of the time they carried both their eReaders and laptops with them

The main negative comments from the students dealt with the difficulty of transferring material to their eReaders and the occasional glitches in rendering pdf files, especially slides made with Open Office with colored backgrounds.

VII. SUMMARY AND FUTURE WORK

In this work I have outline the methods to produce engineering content in a form that can be displayed on various eReaders and Tablets in addition to Laptops, PCs and iPads. I have also investigated the integration of these devices with our Course Management Software. The work has shown that using readily available software, it is possible to format lecture handouts and slides in a format that can be displayed on the eReader without adding a significant burden on the faculty member. It was also shown that the students enjoy having the material available on the eReaders.

Future work will include evaluating updated eReaders as they become available and working to provide more seamless integration of the eReaders with the course management software to simplify the student's ability to receive the material.

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Undergraduate Hands-on Senior Capstone Project Experience on Emerging Mobile IPv6 Technology

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Abstract – In this paper, we detail how a senior student's desire to pursue a challenging Senior Capstone project in networking and mobility paved the way to the development of a networking environment where hands-on research at the undergraduate level on topics, such as, Mobile Internet Protocol version 6 (MIPv6) is readily feasible. Undergraduate students face many obstacles when pursuing hands-on projects requiring laboratory equipment not readily available in undergraduate laboratories. We describe how Open Source Software and Virtualization platforms were configured and deployed by a student and his advisor to successfully complete a MIPv6 hands-on project. The environment was developed using Linux, VMware, and GNS3. In addition to the technical aspects of this project a second unintended, but important, outcome is described. At the onset, the student and his advisor assumed that the student had the prerequisite Linux knowledge and skills necessary to create the technical environment required to complete this project. When it became clear, despite the student's best efforts, that his Linux knowledge and skills were insufficient to complete the project, the advisor, with no prior Linux Kernel related experience, had to learn it and provide guidance to the student. The student saw firsthand how his advisor, an experienced researcher, had to overcome a problem in a domain outside his core expertise as a normal part of the research process.

Index Terms – Hands-on, Undergraduate Research Experience, IPv6, Mobile IPv6, Open Source, Virtualization.

INTRODUCTION

A key goal of the Integrated Science and Technology (ISAT) program at James Madison University [1] is to prepare students to be professionally well equipped when entering the workplace or enroll in graduate programs. This is accomplished by developing students' ability to be problem solvers who are able to investigate local, national, and global issues not only from a science perspective but also from a technology and social context perspectives. The program provides students with a unique hands-on research experience through its Senior Capstone Project by requiring each student to partner with ISAT faculty to pursue a challenging undergraduate level project. The ISAT Senior Capstone project normally spans three semesters. The Senior Capstone program begins the 2nd semester of junior year for ISAT

majors' junior year; by then students have had the opportunity to declare a specific concentration among their top three sectors of study.

The major objective of the ISAT Senior Capstone project is to provide a constructive research and hands-on experience for students at the undergraduate level. Once a student has identified a number of potential projects that interest him/her, the next step is to seek out one or more ISAT faculty members who would be willing to become the student(s) advisor(s). The project requires at least one faculty member but can often include multiple ISAT faculty members if it is cross-area based project. Once a project team has been formed, a Memorandum of Understanding (MoU) is drawn and signed by all parties including the advisor(s).

The literature on capstone project experiences is fairly robust particularly in terms of the diversity of the approaches explored. Recently, at Miami University, a capstone project [2] engaged an alumnus as a co-advisor and a fund raiser. A team at Ohio Northern University (ONU) asserted in [3] that students who get involved in extracurricular design activities instead of the mandatory senior Capstone Projects tend to be highly motivated, gain the Engineering and Technology experience they need but at an earlier stage in their college careers and have better chances in finding jobs upon graduation. This paper focuses on the approach that an undergraduate student and his advisor adopted in the face of working on a high risk project, Mobile Internet Protocol version 6 (MIPv6) [4], where both the student and the advisor had limited familiarity. Consequently, it demanded an innovative approach in implementing a network test environment. It highlights how high motivation, reliability, and commitment of the student to take his networking skills to the next level compelled the advisor to accept the challenge and take on the project as a new experiment in Problem-Based Learning (PBL) [5] and research at the undergraduate level.

This paper documents our experience and approach creating a complete Mobile IPv6 test environment prototype with intensive use of network virtualization tools. The prototype constructed is easily portable, as the MIPv6 network test environment is fully virtualized. We share the details of how a collaborative and trusting relationship between a student and his advisor played a crucial role in the successful completion of this project. Finally, we cover major highlight and key learning by both the student and the advisor whose role started as a coach and transformed as a co-researcher.

This paper is organized as follows. The mobile environment and mobile IPv6 section provides a brief

background on IP Mobility with emphasis on current deployment and both commercially available and open source MIPv6 tools. In the next section, the objectives, the proposed mobile IPv6 environment solution and the methodology of the senior capstone project are described in details. The technical results section presents the Mobile IPv6 virtual test environment that was developed. The final two sections summarize our experience and propose future work.

MOBILE ENVIRONMENT AND MOBILE IPV6

Unlike 3G, which is based on two parallel infrastructures consisting of circuit switched and packet switched network nodes, respectively, 4G is based on packet switching only. Verizon Wireless claims that *"The performance and capabilities of 4G LTE will be unmatched in the marketplace; allowing customers to do things never before possible in a wireless environment"* [6]. Long Term Evolution (LTE) [7] is a 4G mobile specification for multimedia application designed to provide multi-megabit bandwidth, more efficient use of the radio networks, latency reduction and improved mobility. One of the advantages of 4G is the LTE's inherent support for Internet Protocol version 6 (IPv6) addressing.

IPv6 became a reality at the end of the 90s [8, 9]. Mobility support for IPv6, known as, Mobile IPv6 (MIPv6) [10] is an IETF RFC standard that has added the roaming capabilities of mobile nodes in IPv6 networks and thus permits an IPv6 node to roam across any IPv6 network without changing its address. In other words, the mobile node always appears to be connected to its home link even though the user is actually visiting many networks. In the heart of LTE is mobile support for IPv6 and more precisely Proxy Mobile IPv6 (PMIPv6) [11]. Mobile IPv6, along with fast-handoffs and context transfer mechanisms will be essential for the large scale deployment of real-time services, such as, Voice over IP (VoIP) and IP multicast services, such as, IP Television (IPTV). With more and more connected people, smart-phones, improved support of mobility and more, IPv6 has become the key for the next generation of mobile networks. 4G and LTE rely on IPv6 to provide enough addresses, and to support mobility.

A number of projects such as, KAME [12] and USAGI [13] were launched in the late 90s and early 2000s to make Mobile IPv6 accessible and improve its stack's quality and security on Linux Platforms. One specific implementation of Mobile IPv6 for Linux that was adopted for the project described in this paper is UMIP [14]. Together, these efforts led to the availability of Mobile IPv6 functionality as part of recent Linux Kernels. In addition to the introduction of Mobile IPv6 on Open Source Platform, commercial products such as Microsoft Windows Server 2003 [15] included Mobile IPv6 in 2004 and IPv6 Mobility has been supported on Cisco routers since IOS 12.3(14)T [16].

SENIOR CAPSTONE PROJECT

Objectives

The primary goal of the Senior Capstone project described in this paper was to demonstrate MIPv6's

capabilities in providing a mobile host with seamless transition as it migrated amongst different networks. To accomplish this goal, we had to first delve into the specifics of IPv6 [4], a topic not typically covered in depth at the undergraduate level. Second, we had to design and construct a MIPv6 network environment prototype in support of demonstrating how customers with IPv6 enabled devices can hold seamless Voice over IP (VoIP) conversations or data exchanges while roaming from their home network to other networks.

Proposed Mobile IPv6 Network Environment Solution

In light of resource limitations, the prototype was architecturally designed and constructed using Open Source platforms, such as Linux (Desktop and Servers) and Graphical Network Simulator Dynamips/(GNS3) [17] that allows simulation of complex network elements including Cisco routers. In addition, we used virtual network tools such as VMware Workstation [18] and/or Oracle VirtualBox [19] to facilitate the creation and management of virtual machines targeted at server, desktop, and embedded systems. This prototype has enabled us to demonstrate a number of other IPv6 features such as neighbor discovery, address auto-configurations in addition to advanced MIPv6 capabilities, such as, route optimization [4].

We selected Ubuntu [20] which is a computer operating system based on the Debian Linux distribution and distributed as free and open source software, for this project due to the ease of implementing the other required software tools in a Linux environment. Virtual Machines (VMs) [18, 19] were created from Ubuntu desktop 10.04 and 11.04 International Organization for Standardization (ISO) release images and were run primarily on VMware Workstation. Some of the Linux based VMs were configured as Mobile Nodes and others as Linux based Routers. VMware Workstation is a virtual machine (VM) software suite/environment that allows users to run multiple VMs simultaneously on top of a host Operating System (OS) such as Windows or Linux. Equally important, VMware allows these VMs to be interconnected in a variety of different complex network configurations.

In addition to the use of Linux based VMs to emulate MIPv6 Routers, we experimented with Cisco's emulated Internetwork Operating System (IOS) images. Dynamips/GNS3 was used to emulate Cisco Routers IOSs (these were provided by Cisco). We were also successful in integrating Mobile Node (Linux based VMs) with the emulated Cisco Router on GNS3. By adopting virtualization through Dynamips/GNS3, VMware, and Open Source OSs such as Linux, the project which would have required 5 to 6 network hardware nodes was successfully implemented using a single laptop or desktop. With this highly portable architectural approach, students in educational institutions that have limited access to real Cisco routers and desktop hardware can still perform high quality projects with minimum financial requirement.

Key features of the virtualization environment worth highlighting are "suspend/resume", "snapshots" and "network

team". The suspend and resume feature is useful to save the current state of a virtual machine and continue work later from the same state, even if you quit VMware Workstation in the interim. The "suspend" and "resume" feature provides the ability to conduct research virtually anywhere; all that is required is a laptop and an external USB drive. Multiple successive snapshots [21] of an operating system running under VMware Workstation can be taken and the virtual machine can be restarted in the state it was in when any snapshot was saved. Furthermore, VMware Workstation includes the ability to designate multiple virtual machines as a team. Through the team feature, users can configure an entire virtual network with multiple VMs grouped together in one single team, saving valuable time.

Overall, the virtual environment we constructed has been extremely effective and practical in allowing us to achieve and accomplish our ambitious objectives. It also allowed us to test mobility scenarios over a number of different network configurations all inside and on one *single* Linux or Windows machine, avoiding the investment and management complexity needed to create them using real hardware. It is worth noting that few weeks prior to our project's completion we identified another research group that had built a similar platform known as Virtual Network User Mode Linux (VNUML) [22]. Unfortunately, the VNUML project development and maintenance effort had been abandoned in favor of a new version of the tool Virtual Networks over Linux (VNX) [23]. The main reason stated for the migration was to overcome the following limitations of the VNUML tool identified by the VNUML team as its inability (1) to interact with the virtualization capabilities of the host (that is, the machine hosting the VMs) and (2) to integrate with Dynamips/GNS3 router virtualization platforms. This statement confirmed that our approach in building a virtual environment using Open Source VMs, VMware and GNS3 described above has been architecturally sound and viable for multiple purposes including teaching and research.

Methodology

To ensure that the project remained on course, the major milestones of the project were identified for the fall and spring semesters. At the beginning of each semester, the primary milestones and their associated tasks were revisited and reprioritized through the use of a running action items register. The student and his advisor met on a weekly basis. A weekly status report prepared by the student included a description of what he had accomplished during the week and provided a proposed activity plan for the following week. Each status report and the specific milestones that were completed were reviewed by the advisor. Tasks that were incomplete were reevaluated and reprioritized for the following week along with other newly assigned tasks. One of the major highlights of the weekly meetings was the push for "Demos", demonstrations of hands-on incremental building blocks that taken together comprised a final polished demonstration of the entire project.

In the early stages of the project the weekly status report methodology helped ensure the identification of issues where the student and the advisor had difficulties, particularly in areas where they had limited expertise, such as, IPv6 and expertise in recompiling a Linux Kernel from scratch. Some of these difficulties were mitigated when the advisor recommended the student to try certain networking arrangements using a more familiar IP addressing scheme, that is, IPv4. This traditional approach guaranteed that completed tasks were thoroughly documented and tracked as the weekly status report updates were uploaded onto the online Blackboard (BB) course tracking system. On a weekly basis, the advisor posted a grade on BB to ensure that the student received clear feedback on his progress.

At the end of the first month of the final semester (spring 2012), it became clear from the list of tasks remained unaccomplished for longer than 3 weeks that the student was facing issues beyond his current skill levels. In light of these challenges, it was necessary to decide on a new path forward. The student and advisor agreed to put aside the status report/action item register approach and focus instead on resolving the major issues stymieing progress. There were two major issues: (1) patching and re-compiling specific Linux Kernel releases with the Mobile IPv6 features and (2) figuring out how to accomplish the mobility functionality excluding the security measure that was tightly coupled in most recent implementations. Since neither the student nor the advisor had experience patching and re-compiling the Linux Kernel with the Mobile IPv6 features, the advisor took on the challenge of learning how to do so [24]. Once the advisor was successful accomplishing this task, he provided guidance to the student to do the same. Then it was a matter of searching for clearly documented scenarios of MIPv6 implementation without security. Within a week the student and his advisor were able to identify a number of scenarios, but ironically the scenarios [25, 26] were written in Spanish; an issue we resolved using Google Translate.

TECHNICAL RESULTS

Before constructing a virtual MIPv6 environment first intensive research on IPv6, IP Mobility and Internet Security (IPSec) was conducted to determine the scope of the project. In contrast to the 32-bit address space provided by IPv4, IPv6 has a 128-bit address space that allows it to support up to 2^{128} new devices requiring access to the Internet. IPv6 also provides auto-configuration which is a mechanism by which a node can be allocated an IPv6 address automatically whenever it attaches itself to a new network [4]. After gaining a solid foundation of IPv6 addressing scheme, the next step was to design the virtual MIPv6 environment which supported the mobile capabilities of IPv6 as shown in Figure 1A.

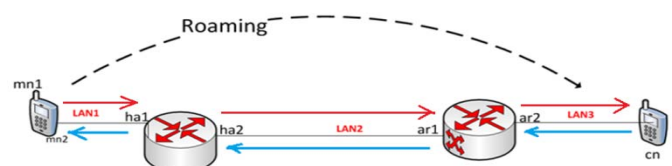


FIGURE 1A
VIRTUAL NETWORK TOPOLOGY

Figure 1A represents the network topology adopted in the implementation of a MIPv6 virtual test environment. Each node is a single Linux Ubuntu OS VM. To ensure all nodes have the same IPv6 and MIPv6 capabilities, a base VM was first created. Next, IPv6 and MIPv6 settings on the Linux Kernel of the base VM were selected (enabled). Following the kernel configuration, it had to be re-compiled [24]. The recompilation task had to be repeated a number of times due to missing dependencies. Once the Linux Kernel recompilation was successfully completed, the Router Advertisement (radvd) [27] and the MIPv6 daemons were installed unto the base VM. Following this preparation, the base VM was cloned through VMware Workstation to create a Mobile Node (MN), Home Agent (HA), Access Router (AR), and the Correspondent Node (CN) VMs. The network interfaces on these VMs were then configured according to Table I [28].

TABLE I
NETWORK INTERFACES

| Interface | Static IPv6 Address |
|-----------|------------------------------|
| mn1 | 2001:1:1:1::fcfd:ff:fe00:101 |
| mn2 | 2001:1:1:3::fcfd:ff:fe00:102 |
| ha1 | 2001:1:1:1::fcfd:ff:fe00:201 |
| ha2 | 2001:1:1:2::fcfd:ff:fe00:202 |
| ar1 | 2001:1:1:2::fcfd:ff:fe00:301 |
| ar2 | 2001:1:1:3::fcfd:ff:fe00:302 |
| cn | 2001:1:1:3::fcfd:ff:fe00:401 |

While the Mobile Node (MN) is attached to its home network, a stateless auto-configuration takes place where the Home Agent (HA) sends a Router Advertisement (using radvd

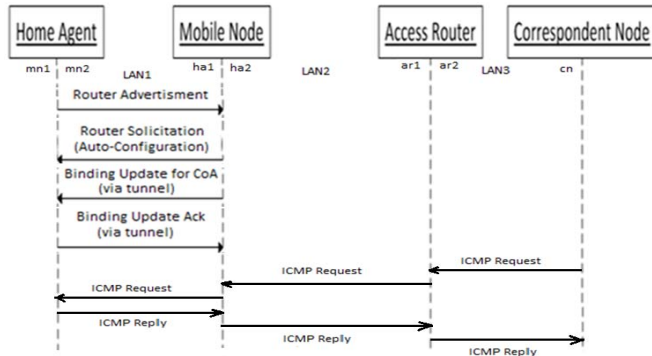


FIGURE 1B
SEQUENCE DIAGRAM FOR BINDING UPDATE

daemon) to announce the presence of its network. Through router neighbor discovery, an MN sends a router solicitation to automatically receive an IPv6 address [27] as shown in the first two steps in Figure 1B.

Once auto-configuration was setup and MIPv6 features were enabled in the proper order; first on the HA and then on the MN, a tunnel is automatically established between the HA and MN as depicted in the last two steps in Figure 1B. The binding update message sent from the MN consists of a Care

of Address (CoA) that the MN sends to the HA. Care of Address (CoA) is also a mechanism by which the HA can forward packets to the MN, no matter where it is located. The original binding update sent by the MN to the HA is then acknowledged by the HA through a binding update acknowledgement message as seen in Figure 1B.

When the MN moves to another network, be it the one the CN is attached to (that is, LAN3) or entirely different from LAN1 and LAN3, the MN sends a binding update message to the HA which confirms that the already established tunnel between the MN and HA as shown in Figure 2A along with the previously defined CoA are to be used for communications between HA and MN while MN is away from its Home network.

With an IPv6 tunnel setup between the HA and MN to provide a mechanism of communication, the CN sends packets to the MN's home network as shown in Figure 2B whenever it needs to communicate with MN. Figure 2C shows the path the pinging packets take from the CN to MN. All packets intercepted from the CN destined for the MN are forwarded to the CoA of the MN by the HA. As can be seen in Figures 2B & 2C, the communication is not always efficient as there are three pinging (ICMP) request messages before the packets from CN reach the MN at its new location and three more ICMP reply messages.

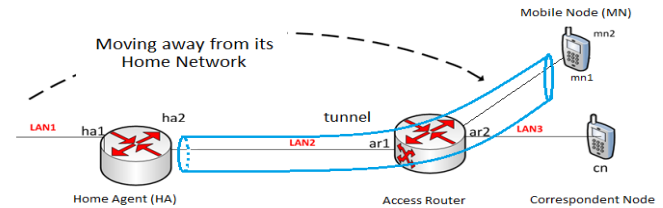


FIGURE 2A
MN TO HA TUNNEL AFTER MN MOVED TO LAN3

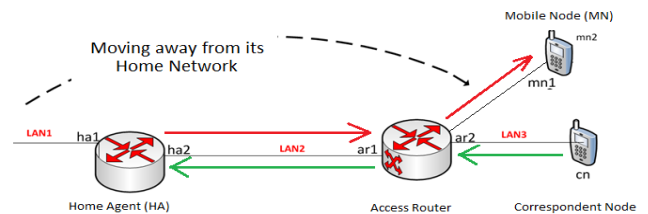


FIGURE 2B
CN TO MN COMMUNICATION VIA HA

To make communication more efficient, the MIPv6 daemon can be launched also on the CN with the route optimization option enabled. This triggers the establishment of a tunnel between the CN and MN. This allows direct communication between the two entities, initiating what is known as route optimization [29, 30] as shown in Figures 3A and 3B

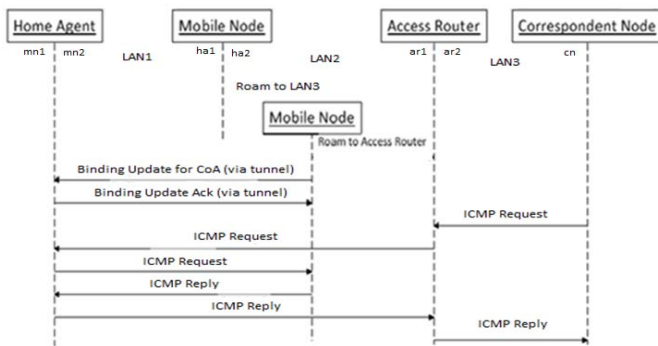


FIGURE 2C
SEQUENCE DIAGRAM OF CN TO MN COMMUNICATION VIA HA

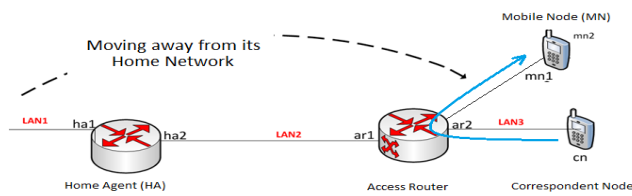


FIGURE 3A
COMMUNICATION VIA ROUTE OPTIMIZATION

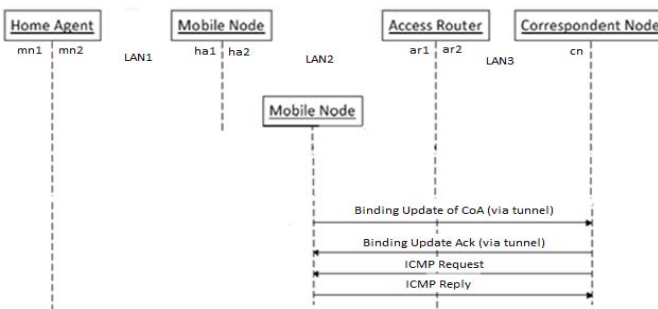


FIGURE 3B
SEQUENCE DIAGRAM OF ROUTE OPTIMIZATION

The results obtained using the virtual network environment described in this paper were consistent with those achieved in other environments such as the VNUML [22] and the test bed in [29]. For example, we verified that the launch of the MIPv6 daemon on the CN was necessarily if direct communication between the CN and MN is required.

SUMMARY OF OUR PROJECT EXPERIENCE

To properly configure an IPv6 capable network, routing was another challenging concept that had to be understood before a virtual network could be established with full end to end connectivity. To achieve full control over the virtual network, static routes were established on the virtual routers and hosts. Despite the early challenges faced while setting up static routes and establishing the virtual test environment, the most challenging of all was the configuration, recompilation, and installation of the MIPv6 enabled Linux Kernel. This was definitely the biggest challenge faced as it required much time and effort in both understanding and undertaking a task never

attempted before by either the student or his advisor. To achieve this task, the USAGI-Patched MIPv6, known as, UMIP was adopted as it had the most up to date version of MIPv6 for Linux [14].

The procedures documented by the UMIP organization in the implementation of MIPv6 required a higher level of experience with Linux and a deeper understanding of mobility for IPv6. Therefore, it took many weeks for the key obstacles to be clearly identified and resolved. This delay was partially due to the approach taken at first where the advisor allowed the student to research and implement the prototype without the advisor's hands-on involvement. Certainly, this provided the student ample opportunities to learn how to troubleshoot, especially in cases such as compiling small and simple applications which is a totally different task when compared to recompiling a Linux Kernel.

When it became clear, in spite of the student tenacity and willingness to do whatever it takes, that the issues facing the student exceeded his current Linux skills, a new approach was taken. The Linux Kernel compilation was done in parallel by the student and advisor on two different Linux Kernel releases to maximize the chances for success. The student ended up reconfiguring and recompiling the Linux Kernel on Ubuntu 11.04 while the advisor did the same on Ubuntu 10.04 release. During this process the advisor intentionally withheld certain information from the student in order to incent the student to find answers on his own.

MAJOR HIGHLIGHTS AND FUTURE WORK

From an innovative perspective, this project brought about a novel approach to undergraduate research and hands-on projects. The adoption of an Open Source and Virtualization network test environment enables undergraduate researchers to tackle major network research projects that otherwise would demand resource investments and management beyond most institutions' financial means. This environment enables budding researchers to complete major projects in a shorter time span and have better chances in finding jobs upon graduation.

One major benefit of this project is its potential to offer wide audiences at early levels of education, such as, high school a virtual appliance that can be downloaded on demand with very minimal configuration. This appliance would be comprised of a single VM team made up of four VMs networked to emulate the mobile capabilities of IPv6, in a portable virtual environment. The appliance can be made available to instructors and students, allowing them to conduct Mobile IPv6 projects in their own virtual lab environments, through the use of VMware Player or Workstation.

In this project, there were many learning opportunities for both the student and advisor. For example, this project was an excellent example of how high risk projects (typically excepted of graduate students) can be accomplished at the undergraduate level. This effort was a major undertaking for an undergraduate student. It was also a valuable learning experience for the student to witness firsthand how an

experienced faculty researcher approached and resolved an issue in a domain outside of his core expertise.

In terms of future work, a solid foundation has been established to enable junior students to explore IPv6 mobile capabilities on smart phones platforms. A natural next step is to secure the MIPv6 tunnel between the Mobile Node and Home Agent by making use of IPv6 built-in IP Security (IPSec). With the LTE-based 4G service being rolled out, it would be very timely to also explore and enhance the platform to incorporate the Proxy Mobile IPv6 (PMIPv6) capabilities. An extension to the PMIPv6 is to apply the constructed virtual environment in testing new IPv6 based services such as VoIP and Video Multicasting in support of IPTV. Yet another is to enhance the virtual prototype environment with the Return Routability (RR) and IPSec to protect the location information of a MN described in [31] and the Fast Mobile IPv6 (FMIPv6) [32] aiming to minimize MIPv6 handover latency.

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Work in Progress: Using Smart Mobile Tools to Enhance Autism Therapy for Children

Anthony Ellertson

Abstract – Autism and related communicative disorders in children are major issues facing parents, school districts, and government institutions. Autism now affects one in eighty-eight children in the United States, and treatment requires significant resources – time, expertise, and financial. This project seeks to enhance the reach of therapeutic efforts through a family of smart mobile tools created to assist therapists working with autism and communicative disorders. The system uses cloud services and a knowledge automation expert (artificial intelligence) engine to track patterns in treatment and visually display those patterns for clinicians, schools, and parents, thereby creating a space for cross-communication between parties that is tailored to the treatment needs of each child.

Index Terms – Autism, Communicative Disorders, Mobile Development, ABA or Speech Therapy

INTRODUCTION

In this work in progress, I describe the development of a grant-funded “smart” mobile application project to enhance therapeutic interventions and track biometric data for improved therapeutic intervention for children with autism and related communicative disorders. This system was developed to address in part the increasing challenges related to delivery of services for autism and communicative disorder therapies in the field.

Autism is the fastest growing developmental disability in the United State [1], and the Center for Disease Control currently estimates that 1 in 88 children between the ages of 3 and 17 have an autism spectrum disorder [2]. To date, 36 states have mandated some form of treatment coverage for autism therapy. It is expected that more states will follow as large numbers of children begin needing services. Most of the coverage goes for early intensive interventions, with the average cost of those treatments reaching \$60-70,000 per child per year. [3]. Although costly, early intervention is actually more economical for the states and medical insurers when considering that the average cost in social and medical services for a person on the spectrum is \$3.2 million over the course of their lifetime; 60% of those costs are in adult services. It is estimated that the cost of life-long care can be reduced by 2/3 with early diagnosis and intervention [4].

The intention of this project is to enhance training for therapists and educators in the field while also providing a space for cross-communication between professionals on treatment teams.

METHODS

This project arose from needs identified through observation of home-based intensive autism therapy services. These needs included more robust training for front-line therapists, more comprehensive tracking of therapy data for senior therapists overseeing a child’s program, and integration of multi-faceted treatment approaches.

Funded by the Wisconsin Technology Foundation in collaboration with industry partners, students from the Web & Digital Media Development program and I created a family of four mobile applications: Charting Dashboard, Video Behavior Recording, Video Conferencing, and Data Entry App.

Using a knowledge automation expert (AI) engine in conjunction with Cloud services, our family of mobile applications:

- Captures implicit knowledge of senior therapists to make their expertise more available to new therapists/educators in the field
- Creates enhanced inter-rater reliability for therapists through thick and descriptive multimedia data
- Identifies patterns in the interventions to improve treatment
- Facilitates collaboration between therapists, medical doctors, and parents in the treatment of children with autism and other communicative disorders
- Tracks both biomedical and therapeutic interventions

FAMILY OF SMART MOBILE TOOLS

The purpose of this project is not to provide applications for the delivery of therapy, but rather a suite of applications for evaluating the effectiveness of therapy and enhancing the real-time training of therapists in the field. Our project differs from most in its approach because it uses a knowledge automation expert system to track treatment, identify patterns in that treatment, and provide guidance on the best next steps based on each child’s needs. In addition, our applications are media rich and mobile ready, allowing parents, therapists, and medical doctors to record, track, and observe actual behavior in real time through interactive charting, video sharing, and video conferencing.

Currently, children undergoing intensive therapeutic interventions for autism are monitored almost daily by therapists, parents, or medical professionals. Behaviors such as social-cue tracking, sleep patterns, and reactions to medications are being recorded to help therapists and doctors tailor treatments for each child. Unfortunately, much of these data are still stored in paper formats that are difficult to share or track. Our family of mobile tools allows therapists/parents/medical professionals to securely enter data via mobile or desktop device. Once entered, these data can be charted, combined, and shared instantly between all parties working with the child.

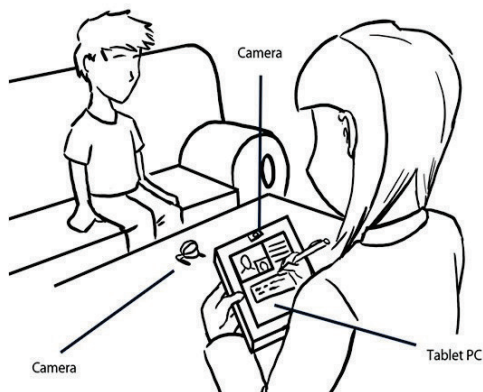


FIGURE 1
EXAMPLE OF THERAPIST USING TABLET

Figure 1 represents how the system currently is accessed and tracked by professionals treating the child. Using a combination of tablets and smart phones, patient behavior is recorded instantly into the cloud in natural environments such as the patient's home or school. Once recorded, these data can be tracked and shared among various professionals to help identify patterns of behavior and treatment.

Additionally, through tools like the Video Behavior Recording app, greater inter-rater reliability can be achieved by using the device to record actual behavior in real time so that all on the team can observe, identify, and agree on what the behavior is and means. For example, therapists will be able to agree on the criteria for what makes a particular child's behavior aggressive versus perseverative. Further, using a mobile device means that recording is convenient and can be done in real time. Figure 2 shows the Video Behavior Recording application in use. The application stores video of patient behavior into the cloud and allows the therapist to add cue points with behavior comments during significant portions of the recording. These cue points can then be charted so that when significant trends in the behavior are noted, the therapist also will have access to all videos related to that identified trend.

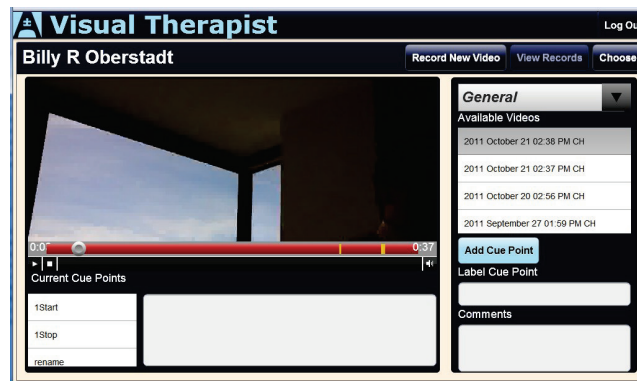


FIGURE 2
EXAMPLE OF VIDEO BEHAVIOR RECORDING

In addition to storing information and video into the cloud, all four apps are connected to our knowledge expert automation (AI) engine. The AI engine is currently being populated with rules from senior therapists and team leads in the field to enable the system to track changes and recognize patterns in real time. Once patterns are recognized, suggestions will be immediately fed back to the mobile applications so that front-line therapists/parents/medical professionals working in the field will be immediately alerted to avenues of treatment based on the experience and expertise of seasoned professionals.

FUTURE DIRECTIONS

Currently, we are field testing the suite of tools in conjunction with industry and academic partners. These field studies will help refine the rules in the AI engine, test usability, and hasten the training of new therapists thereby enhancing the treatments available for each child.

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Work in Progress: Application Design on Touch Screen Mobile Computers (TSMC) to Improve Autism Instruction

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Abstract— This study identifies the areas of autism therapy that can be enhanced by using a touch screen mobile computer (TSMC) device to facilitate autistic children's learning experience. At an affordable price range, the simple touch screen of a TSMC has an immediate cause and effect response that enables these students to be more independent during the learning process. These key factors make the TSMC an ideal supplement for autism therapy in the classroom and for skill reinforcement at home. However, to identify a correct starting point is crucial for the success of this research. Our study aims to explore the most effective application design areas using a TSMC as an instructional tool for autistic children. To determine this direction, four main steps were identified. These steps include reviewing current literature on autism deficits, evaluating the interaction design of the TSMC, analyzing existing TSMC applications currently available, and designing a prototype application for evaluation. This paper reports our model of information processing interruption in autism learning, our target zones of instruction based on the literature review of autism deficits, and introduces our implementation plan of the application design to enhance autism therapy.

Keywords—autism therapy; computer aided instruction; instructional technology; cognitive deficits; cognitive information processing; application design; Touch Screen Mobile Computers

I. INTRODUCTION

Autism spectrum disorders (ASDs) are a group of developmental disabilities characterized by atypical development in socialization, communication, and behavior [1–3]. The significant increase in the prevalence of ASDs has led to an increase in research of related treatments. Currently, there are a wide range of assistive technology devices available that can be implemented by teachers, parents, and/or therapists. These items range from the low level visual cue cards to the high level computer assisted instruction (CAI) devices. Among the many assistive technology options, CAI provides the educational advantage of providing consistent and predictable feedback that can be repeated many times to reinforce skills. For such use, TSMCs stand out because of their potential price affordability, accessibility, and usability. The research topic of developing new applications for autism therapy on the iPad was inspired by Rasche's collaborative design experience with

Purdue University's EPICS (Engineering Projects in Community Service) program. The team was developing a suite of iPad applications to be utilized as communication aids for children with autism and other special needs [4]. The success of these applications encouraged us to go one step further – conducting research upon what autistic children most need to improve their current learning condition, investigate possible paths to satisfy these needs with TSMC technologies, identify patterns through our design experience, and then encourage involvements from the design society to improve the education resources for autistic children.

Our research started from reviewing psychology literature to understand cognitive deficiencies associated with ASDs to determine instructional needs. Through integrating these findings with human cognitive information processing model, we drafted an interruption model to illustrate the problematic regions. Reviewing different TSMC devices provided an understanding of their interaction strengths and weaknesses in relation to being an effective tool for different ASD deficits. The comparison table of the cognitive deficits and TSMC potential will help us to locate target instruction zones and prospective paths that are suitable for application design on the TSMC. These steps pave the way to provide credibility to our possible designs. The goal of this thesis research is to create an interaction design framework to explore the potential, boundaries, and directions of developing TSMC applications for autism therapy.

II. ENIGMA OF COGNITIVE DEFICITS

According to the literature review, we started to realize that ASD cognitive deficits constructed an enigma instead of an explicit list - every child diagnosed with autism will have a wide range of disabilities at many different capacities. Therefore, it is impossible to clearly list all the disabilities for all children with autism because it varies for each.

The summary of deficits list may be apparent in many, but not all of the individuals with an ASD with variable capacity. Therefore, it is necessary to have a detailed register of deficits for autism disorders that can be considered an area for needed focus in therapy instruction based on the individual's needs. The three general areas of cognitive deficits are theory of mind,

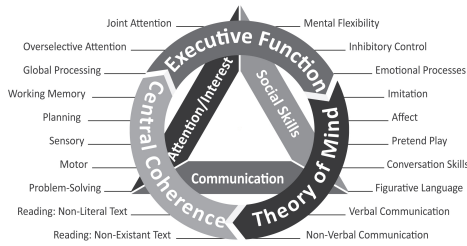


Figure 1. Target Zones of Instruction

executive function, and central coherence. These three deficit areas lead to the three most common areas of disabilities: communication, social skills and attention/interest. As shown in Figure 1, the deficits and disabilities create a long list of possible target zones of instruction.

Although, it is important to note that there is a connection between these deficits that can cause an increase or decrease in the capacity of the other disabilities. In other words, these deficits are linked, overlapped, and influence each other directly. To understand it further, we focus on the specific cognitive skills related with these deficits areas.

- Theory of Mind (ToM) can be described as an ability to understand the mental state of oneself and/or others [1], [5], [6]. ToM deficits are evident in children with ASDs as having difficulty understanding the perspective of others.
- Executive Function (EF) is the ability to make planning strategies to reach goals and having the flexibility to modify goals as necessary [1], [7], [8]. EF deficits are noted in children with ASDs as a strict coherence to routines and patterns.
- Central Coherence (CC) can be described as the ability to process information to achieve a whole, coherent meaning. Children with ASDs show exceptional skill at processing details, but the capacity to grasp inferred meaning in language and social settings is difficult [1], [8].

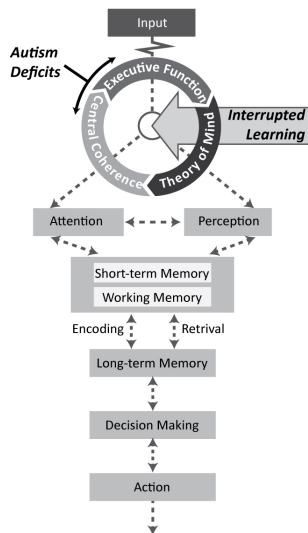


Figure 2. Information Processing Interruption Model

As a whole, it is clear that the cognitive deficits associated with autism cause an interruption in the processing of information [9]. As we illustrated in Figure 2, these deficits make attention and perception difficult to achieve and directly affect learning. Thus, the interruption in the processing of information reduces the amount of input translated to memory that can be later accessed to make appropriate decisions.

III. CONCLUSION

We are currently reviewing TSMC devices to understand their interaction and examining available applications. Early research is showing a weakness in social skill instruction with the TSMC. This skill is best taught with one on one behavioral therapy approaches. Communication and attention are two areas that show a lot of promise. In fact, the research we saw with the communication application indicates that it draws more attention for effective information processing. The outcome of the final evaluation of the research studies and reviews will determine the application design direction. According to the develop plan, the first round of design and prototyping will start in July. This phase will include an evaluation of the prototype application with students, their families, and their educators through GLASS (Greater Lafayette Special Services) [4]. We aim to develop TSMC applications that will help supplement ASD instruction and connect family members to the child's learning experience at home with the help of digital media.

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Work in Progress: How Differences in Student Motivation Characterize Differences between Engineering Disciplines

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Abstract— The limited impact of many engineering education reforms may be due in part to treating engineering as a single monolithic discipline. We are using student motivation to characterize differences in engineering majors in order to inform educational practices and differences in student learning. Here we report on differences in student attitudes towards their engineering majors, elucidated through the use of survey data collected from first year students and longitudinal data on their majors 2 years later. We provide a detailed picture of the complexity of the engineering population, which will help direct more in-depth qualitative research to examine possible correlations between student motivation and learning in different engineering majors.

Keywords- attitudes; motivation; engineering disciplines

I. OVERVIEW

Studies of student retention and learning in engineering have been made in comparison to other majors and colleges within the university system [1]. Such studies are often used for implementation of evidence-based educational reform, but one factor limiting the success of such reforms is treating engineering as a monolithic discipline. Differences between cultural dimensions of engineering disciplines, such as a “newer” (software engineering) versus a more established discipline (electrical engineering) have been noted [2]. Although studies have identified differences between student attributes in engineering disciplines [3], research on the differences between factors that characterize them in terms of attitudes, behaviors and practices is lacking.

We are using achievement motivation as a theoretical framework. Achievement motivation, which can shape engagement behavior, examines students’ attitudes about their abilities and the value they place on tasks as indicators of their motivation to pursue academic and career goals. This study seeks to understand the fundamental differences between engineering disciplines in terms of student motivation, because motivation affects choice, persistence and performance [4].

II. RESEARCH ENVIRONMENT AND ACTIVITIES

A Likert-scale survey (Motivations, Attitudes and Expectancy Survey (MAE)) was developed to assess students’ attitudes related to their engineering studies. More information on the survey can be found in Morkos and Benson (J Engr Ed,

under review). The survey was developed based on the Expectancy x Value theory of motivation [4]. Survey constructs were analyzed for reliability and validity, and survey responses were collected for a single cohort of freshman engineering students ($n= 494$) at a southeastern land grant university. Additional data was collected on enrollment of these same students in engineering disciplines the following two years. This data was further analyzed to examine whether differences in student attitudes during their first year in engineering were observed based on their engineering major two years later.

Through factor analysis, three survey constructs were demonstrated to be reliable, with values for Cronbach’s alpha ranging between 0.85 and 0.92. Content validity analysis identified constructs as: Expectancy [4], attitudes about present tasks/goals in engineering (“Present”), and attitudes about future tasks/goals in engineering (“Future”). The latter two constructs are supported and explained by the Future Time Perspective theoretical framework [5]. Binomial regression of survey data was used to correlate constructs and persistence in engineering.

Students’ attitudes about their future was found to be a significant predictor of continued enrollment in engineering two years later by a factor of 2 ($\beta = 2.01$). However, the capability of student attitudes to characterize different engineering majors is limited, as no significant differences between chosen majors were found for any construct. Majors were grouped as traditional (mechanical, electrical, civil, chemical, and industrial) and interdisciplinary (material science, environmental, computer, ceramic, biosystems, and bioengineering). Traditional majors are well-established and have a well-defined canon of knowledge [6]; interdisciplinary majors draw from a more emergent body of knowledge. Differences in specific survey items for different types of engineering majors were analyzed to glean information for more in-depth future studies. Significant differences were found between traditional and interdisciplinary groups of majors for three items within the Expectancy (E) construct and one item within the Future (F) construct (Table 1). These results provide some insight into how student motivation might contribute to persistence in a major, but they do not provide enough insight to explain differences in motivation that may affect student choice of major.

Another source of insight on student motivation was data from administrations of an informal beginning of semester survey (BOS) given in freshman engineering courses at the same southeastern land grant university, which included questions about reasons why students chose engineering. Students self-reported the importance of factors for seeking to major in engineering (see examples in Table 2). The BOS data indicated differences in student perceptions about benefitting society, doing interesting work, and designing and building things (Table 2). The combination of differences observed between majors for specific MAE and BOS items, a clearer picture of differences in student motivation based on engineering majors emerges.

TABLE I. MOTIVATION, ATTITUDES, AND EXPECTANCY SURVEY RESULTS, ON A SCALE FROM -2 (STONGLY DISAGREE) TO 2 (STONGLY AGREE). SURVEY ITEMS FROM FUTURE (F) AND EXPECTANCY (E) CONSTRUCTS SHOWED SIGNIFICANT DIFFERENCES BETWEEN TRADITIONAL AND INTERDISCIPLINARY ENGINEERING GROUPS. * $p < 0.05$

| Construct | Survey Item | Traditional | Interdisc. |
|-----------|--|-------------|------------|
| E | I am struggling with my college courses. (Reverse coded) | 0.274 | 0.587* |
| F | I will use the information I learn in this engineering course in the future*. | -0.162 | 0.130* |
| E | I am having to work harder than many of the other students in my classes*. (Reverse coded) | 0.928 | 0.685* |
| E | I believe I will receive an excellent grade in this engineering course*. | 0.639 | 0.902* |

TABLE II. BEGINNING OF SEMESTER SURVEY RESULTS. STUDENTS WERE ASKED TO RANK THE FOLLOWING REASONS IN RESPONSE TO THE QUESTION, "PLEASE RANK THE FOLLOWING REASONS YOU WANTED TO PURSUE ENGINEERING, ON A SCALE OF 1-5, WITH 1 = NO INFLUENCE, 5 = TOP REASON." * $p < 0.05$, ** $p < 0.001$

| Statement | Traditional | Interdisciplinary |
|-----------------------------------|-------------|-------------------|
| More scholarship money available | 1.638 | 1.837* |
| Opportunities to benefit society | 3.554 | 3.753* |
| Engineers do interesting work | 3.864 | 3.692* |
| I like to design and build things | 4.097 | 3.515** |

III. DISCUSSION AND FUTURE WORK

We are applying achievement motivation as a framework for characterizing differences in engineering populations by discipline. The findings of the MAE show that students in newer, more interdisciplinary majors struggle less in their courses, value introductory courses less, do not feel they work as hard, and expect better grades than those in established, traditional majors. These results, while important, are limited. The MAE survey was developed to inform student persistence in engineering, and thus its constructs are not as useful for informing differences in choice of engineering major. Additional insights from the informal BOS showed the importance of making a difference and the availability of scholarship money for students in interdisciplinary majors, while engineering work and designing and building things were valued less than for students in traditional majors. Despite the limitations of the informal BOS, items in this survey can help identify appropriate frameworks such as intrinsic and extrinsic value (scholarship money), identity formation and possible selves (I like to design and build), and goal orientation (benefitting society). Our results also demonstrate the limitations of Likert-scale surveys to fully assess the complexity of student motivation. These findings will help direct more in-depth qualitative research (i.e. developing interview questions and quasi-experimental designs). Further elucidation of motivational differences between engineering disciplines will allow for examination of how these differences manifest themselves in terms of student learning.

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Care Ethics in Engineering Education

Undergraduate Student Perceptions of Responsibility

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Abstract—Engineering is not known to be a particularly caring profession, scoring significantly lower than science in this regard according to a poll of the American public. However, engineers have many opportunities through their work to show care and concern for both people and the ecosystem, such as by choosing to work on humanitarian or environmental issues and taking responsibility to ensure these issues are meaningfully addressed. When engineers do their jobs uncaringly, people and the environment often suffer. In this paper we argue that care ethics should be a part of engineering education and explore how care is reflected in student work. Specifically, we examine empirically how undergraduate engineering students care for others, as expressed through their writing about engineers taking responsibility for the adverse impacts on the environment and public health created by e-waste recycling in the developing world. We find that in our sample, most engineering students associated engineers with responsibility for this problem, but that many appeared to lack an appreciation of both the complexities that must be addressed, and the broadly interdisciplinary and collaborative approach necessary to meaningfully address them.

Keywords—ethics; ethics of care; humanitarian engineering; social justice; environmental justice

I. INTRODUCTION

One might claim engineering to be a caring profession by its very nature as a service profession, arguing that engineers apply their knowledge of math and science to solve human problems. However, care and concern for others has not traditionally been an explicit topic in the engineering curriculum as it has in other service professions such as social work, medicine, and nursing. Emerging engineering disciplines such as bioengineering and human-centered design & engineering appear to be fertile ground for care in engineering, but even the more abstract fields of electrical or computer engineering offer opportunities to manifest care through the application of their work to important issues such as studying climate change or enabling communication in post-disaster situations. Unfortunately, not everyone sees engineering this way. According to one study summarized in [1], the American public perceives engineers as being significantly less sensitive to societal concerns and less caring about the community than are scientists.

In the modern day, where technology is a critical element in addressing a wide range of global issues, bringing care to the forefront of engineering education and curricula is important

for ensuring that technology serves to improve social and ecological justice for all, rather than serving the few at the expense of the many (a coarse distillation of the basic argument for engineering and social justice made in [2]). Care may also hold a key to recruiting and retaining broader demographics to the engineering profession, which is a crucial step for increasing diversity of thought and perspective needed for reframing and addressing complex issues such as social justice, climate change, and many of technology's unintended consequences. As learning theory reminds us [3], understanding how to teach care and incorporate it into engineering courses and curricula requires pedagogical content knowledge comprised of both, in this case, what it means to care, as well as what students bring to the table in terms of their own knowledge and understanding prior to any formal instruction in care. Toward these ends, we present in this paper, findings from a study in which writing samples from sophomore and junior level engineering students in several engineering disciplines are analyzed in order to explore how an ethic of care might be manifest in engineering.

The “ethics of care” or “care ethics” is a normative ethical theory that has developed over the past few decades [4] and can be concisely defined as emphasizing “the importance of responsibility, concern, and relationship over consequences (utilitarianism) or rules (deontology)” [5]. Care ethics provides a conceptual framework for understanding both what it might mean to care in engineering and what students bring to the table in terms of care and concern for others. Specifically, we seek to understand how undergraduate engineering students care for others as expressed through their thoughts on taking responsibility (as engineers) for impacts on the environment and public health created by the “backyard” recycling of electronic devices that occurs in developing countries. Since these devices have historically been designed in, used in, and disposed of primarily by wealthy, industrialized countries, the problem framing employed to collect this data explicitly introduced a humanitarian and social/ecological justice context.

II. LITERATURE REVIEW

In the engineering education-related literature, care and care ethics have not attracted much interest to date. Perhaps the earliest mention of care ethics and engineering appeared as recently as 1995, when electrical engineering professor G. Moriarty, publishing in the field of professional ethics, highlighted the importance of care tempered with objectivity, to create a balanced notion of both good engineering and the

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good engineer [6], [7]. Similarly, in 1997, civil engineering educators T. Broome and E. Peirce, stressed “caring” principles as the motivation needed for engineers to become good, responsible, and even “heroic” in their practice [8].

In a 1999 Ph.D. dissertation [9] and a later journal article [10], civil engineer R. Hyde addresses the need for educating engineering students for environmentally sensitive practice by developing an “ethic of caring” for the ecosystem that involves assessable attitudes and behaviors of caring. Also in 1999, civil engineering professor M. Pantazidou, in collaboration with professor of engineering & public policy I. Nair, showed how care ethics is relevant to engineering in general [5]. They highlighted the service-oriented nature of engineering and demonstrated care ethics’ applicability to engineering design and problem-solving methodologies by mapping aspects of these methodologies to elements of Tronto’s [11] framework for care ethics (described in the following subsection). In 2005, professional structural engineer D. Kardon, building on Pantazidou and Nair’s work, conceptualized care as a “standard of care” that essentially serves as a measure of ethical adequacy of the exercise of the engineer’s professional duties [12]. Kardon illustrated the application of Tronto’s framework to engineering using multiple ethics case studies on topics of engineering failure and liability. In 2008, engineering professor D. Riley provided a brief exposition of the importance of care ethics in relation to engineering and social justice [2].

Finally, while not focused on care ethics, but more broadly on conceptions of care and empathy, a collaboration of education and engineering education researchers, led by professor of engineering education J. Strobel, recently performed a systematic review of the literature on these topics, searching databases of research in education, social science, engineering, nursing, medicine and counseling [13]. They indicate a variety of ways in which care is conceived, even within engineering, and are optimistic about the prospects for more explicitly incorporating care in engineering. In the spirit of building on the existing literature, this paper, contributes insight into the student conceptions by looking at particular aspects of care as viewed through a theoretical framework of care ethics.

A. Tronto’s Framework of Care Ethics

As one of several significant contributors to the ethics of care, political scientist J. Tronto has demonstrated how care applies to not only the interpersonal micro-ethical situations we commonly think about in regards to caring, but to larger political/societal macro-ethical situations as well [11]. Tronto describes four interconnected and frequently overlapping phases of the care process: caring about, taking care of, care giving, and care receiving. These phases correspond to four moral elements of care: Attentiveness, Responsibility, Competence, and Responsiveness, respectively. In this paper, only the first two phases are utilized and discussed in detail, but for the sake of completeness, a brief description of the remaining phases is also given below.

Tronto’s first moral element of care, Attentiveness (c.f. caring about), involves awareness of the needs of others and makes the claim that neglect and even ignorance, be it willful or inadvertently habitual, are moral failings. Here Tronto

describes, as an example, the failure of many wealthy people in industrialized countries to notice (in spite of worldwide information technology and diverse media coverage) how “activities spurred by a global capitalist system results in the starvation of thousands” [11, p. 128]. Tronto’s second element, Responsibility (c.f. taking care of), involves the care-giver taking responsibility for involvement in the care relationship (be it voluntary or not). Here Tronto makes the point that responsibility differs from obligation, in that responsibility is contextual rather than universal, is more ambiguous, and may or may not be associated with prior actions of the care-giver. Tronto points, as an extreme example, to the benevolent actions of Europeans during the second World War who, at great peril, tried to rescue Jews from Nazi persecution because they felt responsible simply by virtue of being human [11, p. 132].

Tronto’s third moral element of care, Competence (c.f. care giving), indicates that the work of meeting an objective need must be not only performed, but it must be done competently so that the need is in fact met. Tronto’s fourth element, Responsiveness (c.f. care receiving), deals with the response of the care-receiver to the care-giver and includes consideration of the problems of inequality and vulnerability. To these four elements/phases of care, Tronto adds a fifth meta-level component, known as the Integrity of Care, through which the four phases must fit together as an integrated whole in a way that is sensitive to context and addresses the conflict that is inherent in any situation with moral implications. The interested reader is encouraged to refer to other sources, such as [11] for a fuller treatment of these concepts or [14] for a brief but helpful introduction.

III. DATA & METHODS OF ANALYSIS

A. Description of Data

A sophomore level electrical engineering class was given an optional extra-credit assignment to write a one-page paper in response to reading selections from a journal article [15] on the health and environmental impacts of waste electrical and electronic equipment (e-waste) in China and India. The writing assignment was scaffolded with prompts for three brief essay questions to guide and constrain the responses. The first essay question drew attention to a figure in the article depicting the ecological cycle and fate of pollutants generated by e-waste recycling and asked the students to discuss what concerned them the most about this figure and why. The second essay question asked the students to discuss the impacts on humans and the environment of that aspect of e-waste recycling identified in the first question. The final essay question, which is the focus of our analysis, asked:

“What do you think modern engineers producing these electronic technologies should do as an ‘ethical’ response to the waste electronics recycling dilemma? Comment specifically on how far in scope engineers should go to limit this impact.”

While the assignment was not designed with Tronto’s framework explicitly in mind, her phases/elements of care are useful for interpreting and perhaps even assessing the resulting student work. Reading the journal article on developing-world e-waste recycling in conjunction with the first two essay

questions set the stage to ensure Attentiveness to a problem that requires some level of ethical caring, while the third essay question served to prompt students to discuss what they felt to be appropriate levels of care-ethical Responsibility. Furthermore, from the students' conceptions of ethical responses to the problem, we gain insights into their potential for care-ethical Competence. Thus, our findings focus on the nature of the notions of Responsibility and Competence that undergraduates bring into the engineering classroom without prior study of or instruction in care ethics.

B. Sample Selection

Data analyzed in this study were collected in a course offered in 2010 at a large, public research university. 133 students enrolled in the course, primarily in the majors of bioengineering, electrical engineering, and pre-engineering. For this paper, data from a random selection of 19 of the 73 students who completed the assignment were analyzed. While a more purposive sample would have been preferred given the study's qualitative and interpretive nature, resource constraints necessitated a random sample.

C. Inductive Coding Approach

Inductive, data-driven coding was performed on the writing samples to extract the entities these students associated with responsibility for the e-waste dilemma. Using elements of phenomenography similar to those used in [16], the purpose was to discern the range of entities that students associated with responsibility for the e-waste dilemma. Coding was performed iteratively by a single coder using ATLAS.ti qualitative data analysis software, and verified by a second researcher. For further methodological details on phenomenography in general, see [17], [18], or the concise introduction in [19].

IV. FINDINGS

A. Entities Associated with Responsibility for the Problem

Table I summarizes the entities (mostly stakeholders) that students associated with responsibility for the proliferation, disposal, and/or improper handling of waste electronics. The number of students associated with each code is intentionally not provided because the purpose of this phenomenographic-style analysis is not to essentialize or reduce the codes to the most common responses, but to discover and "map" the entire range of responses. The first column of the table indicates codes that are "close to the data" (i.e., assigned with minimal interpretation of data and given names that match or closely resemble relevant wording where possible). The second column describes the meanings of the codes in more detail. The third column groups the grounded codes by higher-level categories. These are the phenomenographic categories of description that emerged from the data, labeled Business, Citizen, Government, Technical, Collaboration, and Non-responsibility (all described in the following paragraph). The fourth column gives example quotations from the students' essay question responses, which are numbered for ease of reference.

The Business category of Table I includes all stakeholders that are specifically economic- or business-related, including

businesspeople, design companies, companies that profit from toxic products, recycling-plan departments with a company, manufacturers, and recycling facilities, as well as the less tangible "market forces". The Citizen category comprises stakeholders who are unaffiliated, ordinary people, including consumers in developing countries, unspecified consumers (likely those in industrialized countries given the context, but both could also be intended), and people who live/work in developing countries. The Government category comprises stakeholders and entities associated with government or regulations, including governments of both industrialized and developing countries, international laws, unspecified governmental bodies, and politicians. The Technical category comprises stakeholders in the technical fields, including engineers, individual designers, innovators, researchers, and scientists, as well as the less tangible, drive of "technology". The Collaboration category is a meta-level category that captures indications of engineers working together with other stakeholders, including politicians, businesspeople, and recycling facilities. The Non-Responsibility category, unlike the other categories, is not an indication of responsibility but an explicit denial or strong limitation of engineers' responsibility.

B. Conceptions of Breadth of Responsibility

Table II depicts a mapping of the six categories of responsible entities from Table I to the responses contained in each student's essay, where each checkmark (✓) represents a unique entity the student associated with responsibility for the e-waste problem. The table is sorted by breadth of considerations as reflected in the number of categories covered. A number of observations can be made of these findings. First, the technical entities, including engineers, researchers, and scientists, are the most prevalently indicated. This was expected, given the focus of the essay question prompt on engineers' responsibility. In fact, only one of the students (Student 8) absolved engineers of all responsibility (a fact that is somewhat obscured by the table, which does not visually distinguish among codes within the Technical category to indicate engineers).

What was not expected was the relatively large number of other entities students associated with responsibility. The fact that the Business, Citizen, and Government columns of this table are not blank for a substantial number of students is encouraging because it indicates a more realistic conceptualization of the distributed nature of responsibility for this problem than if students simply indicated that the problem was solely an engineering problem. Less encouraging, however, is the Collaboration column, which indicates that only a few students appear to recognize the need for engineers to take a collaborative approach with non-technical entities to meaningfully address this complex problem. Mitigating the effects of e-waste recycling on health and the environment will require more than just minor technical changes in design or materials, as it involves politics, transnational relationships, market forces, and globalization. For example, as Student 19 indicated in quote (9) above, "Engineers, politicians, and businessmen must work together to develop solutions ..." and Student 7 even provided a concrete way that engineers might collaborate with others:

TABLE I. ENTITIES INDICATED AS ASSOCIATED WITH RESPONSIBILITY

| Grounded Code | Code Meaning | Category of Description | Example quotations |
|--|---|---------------------------------|---|
| Businesspeople | Businesspeople (non-specific) | Business | “Companies ... designing electronics that will one day end up in recycling facilities should set up funds to aid in the modernization of [those] facilities.” –Student 13 (1) |
| Companies that Design | Companies that design e-devices | | |
| Companies that Profit | Companies that profit from toxic products | | “However the market is driven by mass consumerism – in which customers are encouraged to buy new technologies even if there are only slight modifications to the previous versions. Nuances such as these are out of the hands of an engineer.” –Student 12 (2) |
| Company Policy | Company policy (e.g., on planned obsolescence or recyclability of products) | | |
| Recycling-Plan Department | A new department within a company charged with planning for recyclability of each product | | “An ethical response would always look to be greener however it is important not to overlook the root of the problem, uncontrolled [e-waste] recycling sites.” –Student 3 (3) |
| Manufacturers | Manufacturers of e-devices (may be implied e.g., by use of the word “manufacturing”) | | |
| Market Forces | Market forces or economics | | |
| Recycling Facilities | E-waste recycling facilities in the developing world and/or their owners | | |
| Activists | Activists raising awareness of the e-waste problem | Citizen | “Probably the most helpful would be if every person would try and go out of their way to recycle their old or unusable electrical equipment.” –Student 15 (4) |
| Consumers in Dev. Countries | Consumers of e-devices in developing countries | | |
| Consumers (unspecified) | Consumers of e-devices (location unspecified) | | |
| People in Dev. Countries | People living/working developing countries | | |
| Government of Industrialized Countries | Governments of industrialized countries or regulations mandated thereby | Government | “Local governments like in China and India should be made more aware of the waste electronics recycling dilemma and decide how to proceed themselves.” –Student 18 (5) |
| Government of Dev. Countries | Governments of developing countries or regulations mandated thereby | | |
| International Laws | International laws or regulations | | “... I think a more effective strategy would be to subsidize research in recycling processes. If a strict limit is placed on individual products dictating what can and cannot be used it will very likely hinder the advancement of technology...” –Student 14 (6) |
| Government (unspecified) | Unspecific government or regulations (may be implied e.g., by use of words “tax”, “subsidize”, “regulations”, “rules”, “law”) | | |
| Politicians | Politicians (non-specific) | | |
| Designers (Individuals) | Individual designers of e-devices | Technical | “Engineers should do as much as they can to help reduce the amount of hazardous byproducts, and if they could change the design of electronics so that they are easier to recycle, there might be less ‘backyard’ recycling.” –Student 1 (7) |
| Engineers | Modern engineers | | |
| Innovators | Innovators of new e-devices | | |
| Researchers | Researchers of materials or recycling process (may be implied by use of the word “research”) | | “It is apparent that it is not easy to simply switch the materials for every electronic device known and that there are probably some essential electronics that can only function with the toxic materials, but it is very important that research go into finding as many alternatives as possible.” –Student 7 (8) |
| Scientists | Scientists involved in research of materials or the recycling process | | |
| Technology | Technology itself | | |
| Collaborations | Collaborations of engineers with other stakeholders, including, politicians, businesspeople, and recycling facilities | Collaboration | “Engineers, politicians, and businessmen must work together to develop solutions to this problem...” –Student 19 (9) |
| Not Engineers ^a | Explicit indications of engineers having limited or no responsibility | Non-responsibility ^a | “I think that this dilemma is more of a regulation problem, rather than an engineering challenge. When engineers design a product, they do so with the expectations that it will be used and disposed of in a reasonable manner. For engineers to consider all of the ways a product could be disposed of could seriously hamper product development.” –Student 8 (10) |

a. Unlike the other codes and categories in this table, this is not an indication of responsibility, but one of denial or strong limitation of responsibility.

"It is also essential that the engineers communicate with the recycling plants to develop the best ways to transition from a used device to recycled parts." –Student 7 (11)

Student 17 is unique in indicating alternative ways that engineers might work together with others:

"... although the engineer could be active in community awareness or community policy or could help develop a proper policy for the company the engineer works." –Student 17 (12)

Another observation that can be made from Table II is that some students even resist or deny that engineers have responsibility for the e-waste recycling problem. In spite of the clear expectation built into the essay question prompt that engineers have some responsibility, Student 8, for example, was particularly keen to point the finger elsewhere in quote (10), placing responsibility on others and indicating that it is acceptable for engineers to expect devices "will be used and disposed of in a reasonable manner," since product development is paramount. This student then goes on to discuss the need to regulate e-waste recycling and concludes with a statement that businesses could opt to go green if they wanted to and thereby create a good public image:

"Even though I believe the onus of protecting people's safely should be placed on government, companies can chose to be eco-friendly in their product development decisions. This can be an ethical choice by those in charge of the company or their stock holders. This...can help a company stand out by showcasing their integrity and commitment to the customer." –Student 8 (13)

Other students in the Non-responsibility category were more moderate in their disavowal of responsibility by indicating the limits and boundaries of the engineer's purview:

"The engineers should not be held to responsibilities outside of their own duties of development and design, but must do their part to help in this situation as much as they can in their sector of the modern technical industry." –Student 4 (14)

"I believe that modern engineers have little responsibility for these improper disposal and recycling practices... One way engineers could limit the negative consequences of their products is to put more pronounced labeling on their packages. Engineers should not go much further than this, as their role is not political." –Student 18 (15)

V. DISCUSSION

As the findings above on the entities associated with responsibility for the e-waste dilemma (Table I) indicate, these students are collectively aware of a variety of responsible stakeholders and systems, beyond engineers. While this is encouraging, individual coverage is actually quite spotty: indeed, only two students indicated all five categories and many covered less than three. We can also observe that the empirically derived categories of description are incomplete with respect to possible entities/stakeholders of importance. For example, no mention was made in this sample of non-profit or non-governmental organizations (NGOs), such as humanitarian aid organizations, schools, or education in general.

TABLE II. BREADTH OF RESPONSIBILITY INDICATIONS

| Student | Category of Description ^a | | | | | | Qty of Categories ^d |
|---------|--------------------------------------|---------|------------|------------------------|---------------|---------------------------------|--------------------------------|
| | Business | Citizen | Government | Technical ^b | Collaboration | Non-responsibility ^c | |
| 17 | ✓✓✓ | ✓✓ | ✓✓ | ✓ | ✓ | | 5 |
| 19 | ✓✓ | ✓ | ✓ | ✓ | ✓ | | |
| none | | | | | | | 4 |
| 13 | ✓✓✓✓ | | ✓✓ | ✓✓ | | | 3 |
| 2 | ✓✓ | ✓ | | ✓✓✓ | | | |
| 14 | ✓✓ | | ✓ | ✓✓✓ | | | |
| 8 | ✓ | ✓ | ✓✓✓ | | | ✓ | |
| 7 | ✓ | | | ✓✓✓ | ✓ | | |
| 12 | ✓ | ✓ | | ✓ | | ✓ | |
| 18 | | ✓ | ✓ | ✓ | | ✓ | |
| 3 | ✓ | | ✓ | ✓ | | | |
| 6 | | ✓ | ✓ | ✓ | | | |
| 15 | ✓ | ✓ | | ✓ | | | |
| 5 | | | ✓✓ | ✓✓✓ | | | 2 |
| 9 | ✓ | | | ✓ | | | |
| 1 | | ✓ | | ✓ | | | |
| 16 | | ✓ | | ✓ | | | 1 |
| 11 | | | | ✓✓ | | | |
| 4 | | | | ✓ | | ✓ | |
| 10 | | | | ✓ | | | |

a. For each student, a ✓ represents a unique entity associated with responsibility for the e-waste problem.

b. All students except one (Student 8) associated engineers with responsibility for the e-waste problem.

c. This category is not an indication of responsibility, but denial or strong limitation of responsibility.

d. The Non-Responsibility category is excluded from these counts (see footnote c).

It is also important to understand the distinction between awareness of the responsibilities of other entities and recognition of the need for engineers to collaborate with those entities. In other words, it is one thing to conceptualize responsibility as distributed but view others' responsibilities as independent from and unassociated with one's own responsibility, versus recognizing the need to coordinate and work together in ways that competently enact what is ultimately a shared responsibility. As the findings on breadth of responsibility (Table II) indicate, most of these students appear willing to take responsibility as engineers for solving the problem of e-waste recycling in the developing world. From the perspective of Tronto's second element of care ethics, most would appear to get high marks for the Responsibility element. However, most students gave no indications of the need for engineers to work collaboratively with others in understanding and addressing the problems. This points to a potential problem for caring engineers who wish to work toward saving lives and helping the environment: their effectiveness at doing so (Tronto's Competence) is seriously in question if they neglect consideration of the responsibilities and competencies of non-engineers or constrain themselves to technical actions when technical fixes would be inappropriate or ineffective. As [14] aptly explains this element of Tronto's framework, "competence means that one has the necessary knowledge, skills, and ability to assess the situation and carry out the chosen act(s) to fill the care needs". Complex problems like the e-waste recycling dilemma and the associated issues of neoliberalism, globalization, and environmental pollution are diverse, broadly interdisciplinary, and require that engineers collaborate with non-engineers in order to care competently.

VI. IMPLICATIONS AND CONCLUSIONS

This work has several implications on teaching and learning engineering. It shows a need to help students better understand and appreciate the complexity of the e-waste recycling problem, and to recognize the need for cross-disciplinary collaboration to address complex problems. Our application of Tronto's care ethics framework sheds light on serious inadequacies for ethical caring for many of the students in our sample. This work has value in making clear what elements of care engineering undergraduates can already exhibit and the extent to which they do so. It also points to what elements educators need to attend to in explicitly helping students learn to become more effective care givers in society. This work also provides a concrete example of how care ethics, which we have argued elsewhere [20] as a neglected dimension in traditional engineering ethics curricula, might be instantiated in the classroom. Furthermore, this work suggests that care ethics, as operationalized by Tronto's framework, may be useful for assessment purposes, i.e., that care ethics is not just abstract and feel-good philosophy but has practical use as a concrete way to think about stakeholders and their responsibilities, competencies, and interactions. Finally, given the recent initiatives and interest in situating engineering education in real-world contexts (e.g., problem-based learning and service learning), care ethics provides a way to articulate and leverage the educational benefits that real-world context can offer. Such context can help re-humanize engineering education by providing the learner with an important intrinsic motivational factor: the opportunity to care about the people engineers aim to serve and the environment on which we all depend.

The implications of this work also go beyond engineering education. For example, from a researcher perspective, this work shows that Tronto's framework can be a useful operationalization of care ethics that deserves further exploration and development. From the perspective of engineering practice, educating engineers to be attentive, responsible, and competent in their work will help to create a more ethical and caring workforce that is better able to engage in addressing modern issues, such as climate change, globalization, and social justice.

Additional work is in progress and includes performing a similar analysis of additional student essays, and examining indications of what engineers and other stakeholders should do in order to exercise their responsibility. Future work will also look at other data sets, such as capstone design project reports, in which other elements of Tronto's framework, such as Competence and Responsiveness, can be examined.

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Work in Progress: Does Motivation Matter for Conceptual Change?

Exploring the Implications of “Hot Cognition” on Conceptual Learning

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Abstract—This Work in Progress paper describes a five-year study where we apply a *hot cognition* framework to analyze the perspectives, experiences, and practices of faculty and students with regard to conceptual learning. Although this project focuses specifically on thermal sciences, the results are expected to be generalizable across engineering conceptual domains. The project involves three sequential phases, each guided by research questions and leading to five measurable outcomes that contribute to the understanding of intentionality and conceptual change.

Keywords— *conceptual understanding; intentionality; engagement; hot cognition; teaching strategies*

I. INTRODUCTION

One critical challenge facing engineering education is to develop graduating engineers with the extensive technical expertise needed to lead innovation. This challenge demands a robust understanding of how engineering students learn in order to create environments that best support technical mastery through deep, conceptual understanding of core concepts. Researchers and educators alike know that engineering students enter undergraduate programs with misconceptions about critical engineering concepts. We also know that some students effectively engage in learning and correcting misconceptions, while for others the misconceptions persist – often through graduation and into their professional careers [1,2]. To address this issue, educators need to better understand how students learn, and particularly how they engage in conceptual learning. “*Hot cognition*,” which merges traditional cognitive approaches with a robust exploration of learner’s *intentionality* – i.e. why and how they choose to engage in learning – provides a critical framework to span this gap. This powerful, holistic approach will enhance our existing understanding of students’ misconceptions and maximize the impact of on-going efforts to promote conceptual learning in engineering.

First introduced by Pintrich, Marx and Boyle in 1993 [3], *hot cognition* moves away from “cold” approaches that consider only knowledge structures to add intentionality, recognizing that learners make choices about whether to engage in learning and which learning strategies to use. In positing *intentional conceptual change*, Pintrich argued that “learner’s intentions can determine the likelihood of knowledge change” [4, pg iX]. While research among K-12 students has confirmed the importance of intentionality in conceptual

change [4-6], we know comparatively little about students’ motivation and the learning approaches they choose (i.e., learning strategies) in relation to conceptual understanding at the college level, and more specifically in engineering classrooms [7]. We know even less about what teaching strategies would support motivation to engage in intentional conceptual change.

Consistent with the idea of intentional conceptual change, Linnenbrink and Pintrich proposed a framework (Figure 1) to explain how *hot* conceptual change occurs [4]. The core precept of their model is that motivation for conceptual change determined how the learner will approach the task of learning. This model starts with a primary categorization of students’ motivation under *Achievement Goals* then considers *Other Motivational Beliefs* and the associated *Learning Strategies* as contributing to *Intentional Conceptual Change*.

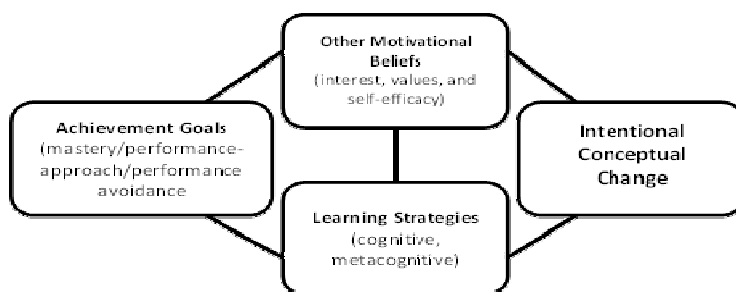


Figure 1: Framework for Intentional (*Hot*) Conceptual Change

II. PROJECT RESEARCH PLAN

The project involves three sequential phases, each guided by research questions ultimately leading to five measurable outcomes. Each phase is discussed in further detailed.

A. Phase I

1) Research Questions:

- What are the intentionality factors (i.e., student motivation and learning strategy choice) and relationships among these factors that lead to successful conceptual change? (RQ 1)
- What are the faculty beliefs about students’ intentionality in conceptual change and what teaching strategies do they use to promote conceptual change? (RQ 2)

2) *Data Collection and Analysis:* Data will be collected through a nationwide survey deployment (pre/post) that will measure student motivation and learning strategies (instruments such as, but not limited to, the Motivated Strategies for Learning Questionnaire (MSLQ) survey) and conceptual understanding using the Thermal and Transport Concept Inventory (TTCI) from an estimated 2,000 students (<http://thermalinventory.com/>) [8]. Survey data will also look at faculty beliefs about student motivation, learning strategies, conceptual understanding, as well as faculty teaching strategies from an estimated 60 faculty members. To gain deeper information from survey responses, follow up interviews will be conducted with approximately 35 students and 15 faculty members.

3) *Outcomes:*

- Identification of student intentionality factors and resulting synergy that leads to successful conceptual change
- Identification of faculty beliefs about students' intentionality in the conceptual change process and the teaching strategies used to promote conceptual change

B. Phase 2

1) *Research Questions:*

- What regular daily and/or critical incidents (instruction/learning experiences) precipitate conceptual change in a one-semester thermal sciences engineering course (RQ 3)
- What daily and critical classroom teaching and learning experiences do students say help or hinder development of conceptual understanding (Sub RQ 3a)
- What daily and critical teaching experiences do faculty say help or hinder development of conceptual understanding? (Sub RQ 3b)

2) *Data Collection and Analysis:* Data collection will consist of using real-time data collection methods through smart phone applications and online tools. Data from Phase 1 surveys and interviews will be used to inform the survey development for Phase 2. This data will be collected at 10 case study sites that will be determined from data collected in Phase 1. Sites will be chosen to provide for a variety of experiences from students and faculty members participating in Phase 1. Approximately 100 students and 10 faculty members will participate in Phase 2.

3) *Outcomes:*

- Descriptions of regular student learning experiences contributing to conceptual change.
- Categories and classifications of critical teaching and learning incidents contribution to conceptual change

C. Phase 3

1) *Research Question:*

- What teaching practices, based on Phase 1 and 2 outcomes, support and encourage conceptual change? (RQ 4)

2) *Data Collection and Analysis:* Using five test sites identified from Phase 2, teaching strategies will be developed

and implemented with the help of faculty partners. Pre/post surveys will be given to evaluate the effectiveness of each method. Surveys will be developed using motivation scales (like, but not limited to, the MSLQ) and TTCI survey instruments (<http://thermalinventory.com/>) [8]. This will be a quasi-experimental design when combined with Phase 2 data. An estimated 250 students (approximately 50 students from each site) and 5 instructors (1 from each site) will participate in Phase 3.

3) *Outcomes:*

- A list of tested strategies to promote intentional conceptual change

III. SUMMARY

A critical challenge of engineering education is to develop engineers with the technical expertise needed to meet industry demands. Many students graduate with an engineering degree with misconceptions on critical engineering concepts. Past research has focused on only knowledge structures when studying conceptual change. This study seeks to add students' intentionality in learning to develop a better understanding of why students engage in the classroom to move towards conceptual understanding. At the conference, we will present pilot data from surveys and interviews from Phase 1.

IV. ACKNOWLEDGEMENTS

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Work in Progress: Development of Computer Modules to Improve Student Metacognition and Motivation Strategies

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Abstract—This project aims to advance personalized learning by helping students to understand and regulate their own learning. The project is designed to equip students with the knowledge, skills, and attitudes of self-directed lifelong learning. We developed two online modules—one on learning styles and the other on motivation. We have begun to test the effectiveness of the modules in two mechanical engineering classes—a sophomore manufacturing class and a junior design class. The modules themselves record data such as preferred learning style, MSLQ scores, pre and post knowledge on topics presented in the module, and module evaluations. In addition, we administered brain dominance and lifelong learning readiness instruments to control and intervention groups. We intend to monitor the changes in brain dominance and lifelong learning readiness over time for the control and intervention groups.

Keywords—lifelong learning; e-learning; learning styles; motivation strategies

I. INTRODUCTION

Given the pace of technological change, engineering graduates of today must be prepared for a lifetime of learning and adaptation. Some argue that the skills they learn at the university are already outdated by the time they graduate. For this reason, the ABET outcome “a recognition of the need for and an ability to engage in life-long learning” may be one of the most important outcomes for a BS engineering graduate. However, few curricula explicitly teach life-long learning skills. Our approach is to develop computer modules that help teach these skills.

Personalized learning must take into account individual differences in learning style and motivational factors. Although no learning style classification scheme has 100% acceptance among educators, several classification schemes have achieved some degree of prominence. The Kolb learning style inventory measures a learner’s strength in four learning modes: concrete experience, reflective observation, abstract conceptualization and active experimentation [1]. Another instrument—the learning styles profiler—includes the effects of temperament and character and is used in work as well as educational settings [2]. Most familiar in engineering education is the work of Felder and Silverman [3] who proposed four learning style dimensions: active vs. reflective, sensing vs. intuitive, visual

vs. verbal, and sequential vs. global. The VARK learning style questionnaire identifies four primary learning modes: visual, aural, read/write, and kinesthetic [4]. The Barsch Inventory is similar to the VARK and identifies four learning styles: visual, auditory, tactile, and kinesthetic [5].

Even when learning and teaching styles are well matched, no learning will take place without the motivation to learn. Motivation comes from a variety of sources and is affected by a number of factors. Two primary aspects of motivation are value and expectancy [6]. The 81 question motivated strategies for learning questionnaire (MSLQ) probes the sources of motivation and includes questions in the areas of intrinsic goal orientation, extrinsic goal orientation, task value, control beliefs, self-efficacy, and test anxiety [6]. Teaching tips that correspond to each of the questions in the MSLQ have been developed [7]. These can be recast as strategies that students can apply themselves.

Pintrich identifies four areas for self-regulation: cognition, motivation/affect, behavior, and context [8]. The self-regulation cycle includes four phases: planning, monitoring, control, and reflection. This project focuses on the first two areas (cognition and motivation) and the middle two phases (monitoring and control). Our objective is to develop and test e-learning modules that raise student awareness of their own cognition and motivation and subsequently provide strategies for improving learning.

II. E-LEARNING MODULES

We developed two computer modules, one on metacognition (specifically learning styles) and the other on motivation. As shown in Figure 1, the metacognition module begins with the Barsch Learning Style Inventory, which could be used free of charge with permission. It proceeds to two biology tutorials (on mitosis and Punnett square). We chose two topics that most mechanical engineering students would know little about. At random, one of the two topics is presented in the most preferred learning style while the other is presented in the least preferred style. This gives students a first hand experience of the influence of learning style. Next, the module presents strategies that correspond to each learning style, and it concludes with reflection and module evaluation questions.

| Metacognition Module |
|--|
| <ul style="list-style-type: none"> • Barsch Learning Style Inventory • Pre-test on mitosis (or Punnett square) • Tutorial on mitosis (or Punnett square) using least (or most) preferred learning style (visual, auditory, tactile, or kinesthetic) • Post-test on mitosis (or Punnett square) • Pre-test on Punnett square (or mitosis) • Tutorial on Punnett square (or mitosis) using most (or least) preferred learning style • Post-test on Punnett square (or mitosis) • Present the results of Barsch Inventory to the student • Tutorial on strategies for different style learners • Post-test on learning style strategies • Questions asking students to reflect on the learning experience and to evaluate the module |

Figure 1. Content of metacognition module

| Motivation Module |
|---|
| <ul style="list-style-type: none"> • Motivated Strategies for Learning Questionnaire • Task value manipulation <ul style="list-style-type: none"> ○ Pre-test on osmosis (or northern lights) ○ Tutorial on osmosis (or northern lights) ○ Post-test on osmosis (or northern lights) ○ Repeat the above with northern lights (or osmosis) ○ Reflection questions on task value • Control beliefs manipulation <ul style="list-style-type: none"> ○ Pre-test on photosynthesis (or aluminum can manufacturing) ○ Tutorial on photosynthesis (or aluminum can manufacturing) with high or low complexity content ○ Post-test on photosynthesis (or aluminum can manufacturing) ○ Repeat the above with aluminum can manufacturing (or photosynthesis) ○ Reflection questions on control beliefs • Present the results of the MSLQ to the student • Tutorial on motivation strategies • Post-test on motivation sources • Questions asking students to reflect on the learning experience and to evaluate the module |

Figure 2. Content of motivation module

The motivation module, outlined in Figure 2, begins with the Motivated Strategies for Learning Questionnaire (MSLQ). To manipulate task value, the module presents tutorials on osmosis and the northern lights—topics chosen to elicit different levels of student interest. After reflection questions on task value, the module presents two topics that should differ in difficulty for mechanical engineering students. To further manipulate control beliefs, the module informs the student that many mechanical engineers find photosynthesis to be a difficult topic. Also, two versions of each control beliefs tutorial were created that differ in complexity level. In other words, there is a low complexity version and a high complexity version of both the photosynthesis and manufacturing tutorials. This is

followed by reflection questions on control beliefs. The module concludes with motivation strategies and evaluation questions.

III. DATA COLLECTION

In the spring 2012 semester, students in two classes participated in a study of the effectiveness of the e-learning modules. Early in the semester, a group of 137 students took a brain test that measures left and right brain dominance and a lifelong learning readiness test. Later in the semester, 56 students completed the metacognition and motivation modules. At the end of the semester, most of the 137 students re-took the lifelong learning readiness test. We are beginning to analyze the data from the spring 2012 semester. To determine how well the modules demonstrate the importance of learning styles and motivation, we will look at changes in test scores from pre to post as well as the student reflections. For example, we expect that material presented in the preferred learning style will lead to greater improvement in test score. We also expect students to report more difficulty in learning material when their motivation level is low. The results of this analysis will lead to improvements in the modules. In the longer term, we will continue to collect data on lifelong learning readiness from both the control and intervention (took modules) groups and monitor changes over time from the second to fourth years of the student's program.

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Work in Progress: *Building a K-12/University Biotechnology Learning Community*

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Abstract— In 1992, Boston University School of Medicine launched CityLab, its innovative biotechnology education outreach program that has been disseminated across the country. CityLab serves students in grades 7-12 and their teachers. Since CityLab's founding, approximately 200,000 students have participated in hands-on, discovery-oriented investigations and more than 2,000 teachers have attended professional development workshops at Boston University. As is typical for most STEM outreach projects, CityLab has developed extensive partnerships with public and private schools that are located near its main location. Recently, CityLab expanded its scope by forging a unique partnership with high school students and teachers from an under-resourced rural area in North Carolina located 1000 km from Boston. Through this experience, we have explored how to create, nurture, and sustain a long distance K-12/University partnership. Herein, we share the lessons learned from this project.

Keywords- *K-12; university; partnership; biotechnology; laboratory investigation*

I. INTRODUCTION

Since CityLab's inception twenty years ago, it has focused on improving students' interest in and understanding of the biological sciences through hands-on laboratory experiences. CityLab is housed at Boston University School of Medicine and its facilities include three on-site laboratories for students and MobileLab, a mobile laboratory that brings state of the art biotechnology experiences to students and teachers at their schools. CityLab has authored its own curriculum supplements and disseminates them widely. To date, more than 500,000 middle and high school students and teachers have worked with CityLab materials.

CityLab has always worked closely with public and private schools in its cachement area. Teachers have collaborated with CityLab staff on curriculum development efforts and have piloted new materials in their classrooms. CityLab has also offered professional development workshops for teachers who are interested in biotechnology. As is typical of most collaborations between institutions of higher education and K-12 school districts, the participants are located within commuting distance of one another. This geographical proximity facilitates early morning or late afternoon face-to-face meetings.

CityLab has provided assistance to university faculty throughout the U.S. and abroad who want to develop CityLab

programs on their own campuses. While CityLab remains in contact with these satellite programs, no on-going collaboration between the groups has emerged from these interactions.

In 2009, CityLab was contacted by members of the Bertie County, NC community who were not directly affiliated with the local schools. They recognized that student achievement in the sciences was inadequate and they sought assistance. The three authors of this paper traveled to Bertie County to meet with community and school district stakeholders. The Bertie-CityLab collaboration is CityLab's first attempt to establish a long distance K-12/University partnership.

II. DEVELOPMENT OF THE PARTNERSHIP

Most science education partnerships between university faculty members and K-12 teachers are formed through direct interactions of the participants rather than as a result of agreements made by senior administrators of the collaborating institutions. The NC-CityLab partnership is unique because the K-12 science teachers did not pursue the collaboration; a few science and mathematics teachers were invited to attend CityLab's presentation to the district's senior administrators that described CityLab and proposed possible collaborative efforts. Interestingly, the teacher who has been most engaged in this collaboration was not present at the initial meeting.

During the initial discussion, CityLab proposed that NC students and teachers come to Boston to participate in CityLab's SummerLab, a week-long inquiry-based program that provides students with an opportunity to learn and apply fundamental biotechnology concepts through an immersive biotechnology laboratory experience. For the NC-CityLab partnership, we coupled SummerLab with academic enrichment and an exploration of the college admissions process. The NC students and teachers lived in Boston University undergraduate dormitories and experienced college life.

Financial considerations were an immediate concern for this fledgling partnership. The NC students might not have participated if they had to pay for the program. Fortunately, a generous grant from the Biogen Idec Foundation provided funds to cover the travel costs, room and board, and tuition for the NC students and their teachers to come to Boston.

During the summer of 2010, eight students and two teachers from Bertie County, NC spent three weeks at CityLab. After the one-week SummerLab program in which students

learned about bacterial transformation, protein purification, and other recombinant DNA laboratory techniques, the students spent two additional weeks in Boston and explored additional topics in experimental science and mathematics as well as attended college preparatory seminars. During the same three-week period, the Bertie teachers learned the content, pedagogy, and logistics of using laboratory investigations to teach biotechnology to their classes.

We refined this program for the summer of 2011 and implemented an integrated two-phase program for the students and teachers from Bertie and neighboring counties in NC. The first phase was identical to the first week of the 2010 program and consisted of student and teacher participation in the SummerLab program. However, in 2011-2012 we eliminated the second and third weeks in Boston and instead launched an academic year program in NC that consisted of monthly meetings to explore advanced molecular biology topics. These sessions were led by a teacher who participated in the teacher program in 2010 and 2011 at a Bertie County high school.

In order to provide on-going professional development for the teacher in NC, we scheduled conference calls via skype (web-based video conferencing). These calls give the teacher a chance to ask questions about the laboratories and also provide an opportunity for additional content and pedagogical support.

III. EVALUATION RESULTS

Preliminary results from the first phase of the partnership were assessed using pre/post tests of content understanding, a survey of students' understanding of science and scientific inquiry (SUSSI)[1], and student focus group responses. Due to the small number of participants (n=8), statistical analysis was not performed, but the data show that students achieved small gains in their understanding of science content at nominal, structural, and functional levels of literacy. Students also valued the opportunity to modify protocols and design/perform their own experiments. This finding suggests that future programs incorporate additional opportunities for students to think and act independently in the lab.

A fortuitous re-alignment of teaching responsibilities for the key Bertie teacher allowed her to spend 2011-2012 building a biotechnology laboratory in her classroom. This made it possible to offer a monthly biotechnology enrichment program in NC. She also used this classroom laboratory to develop and teach a biotechnology class to her students.

IV. LESSONS LEARNED

While many scientists and teachers have opined about the characteristics of successful local or regional K-12/university partnerships to promote STEM achievement, there is a dearth of research on the characteristics of successful collaborations, whether local or long distance distances [2]. A recent attempt to assemble a comprehensive database of organizations involved in science education partnerships has resulted in the creation of the STEMconnector database. This resource, launched in November 2011, is available at www.stemconnector.org/stemdirectory and lists state by state STEM activities. The STEMconnector database is "a tool to establish partnerships with a broad cross section of

organizations working in STEM Education [by increasing] reach and connectivity in regions through working relationships" [3]. This effort focuses on local partnerships but fosters the development of long distance collaborations.

Four recent reports discuss the obstacles that are commonly encountered by science education partnerships [2, 4-6]. Among the most important challenges that need to be overcome are finding common ground and mutual understanding, creating a partnership that will last and evolve over time, aligning the activities to meet the needs of the participants, and allocating time to interact with one another. Garnering the support of school/district administrators is often thought to be essential for the success of the partnership [5].

Science education partnerships are fragile, even when they exist in one's neighborhood. Sustainability and persistence are integral to the success of a long-distance partnership, as are flexibility, good humor, and genuine rapport. We have learned that because schools are in flux- students, teachers and administrators move or are re-assigned frequently- it is important to involve those who want to participate and empower them to serve as ambassadors for the partnership. People who are part of the community are best suited to advocate for the partnership.

Moreno describes several models for partnerships including the Superman model, in which one partner single-handedly tries to rescue the other, and the Batman and Robin model in which a more experienced partner mentors or guides a less experienced partner [5]. She indicates that Superman-style partnerships rarely succeed but Batman and Robin-style partnerships are more likely to succeed. In many sense, the NC-CityLab partnership has evolved from a Superman to a Batman and Robin partnership.

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Utilizing Reflection in Projects for Increased Metacognition and Enhanced Learning

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Abstract— Active and project-based learning (PBL) strategies provide a great means for students to enhance their learning and further develop critical engineering skills. In order to guide students to a higher level of learning, a critical reflection process has been incorporated into upper level and graduate civil engineering classes that utilize PBL. This paper presents a model for classroom practice for enhancing student skill development through critical reflection as part of PBL that is based on existing theory on learning.

Keywords: active learning, reflection, critical thinking

I. INTRODUCTION: BACKGROUND AND MOTIVATION

Active and project-based learning (PBL) strategies provide a great means for students to enhance their learning and further develop critical engineering skills. PBL provides complex tasks based on challenging questions or problems that involve the students' problem solving, decision making, investigative skills, and reflection [1-8]. The activities are student centered and focus on real-world problems and issues, which further helps motivate students to learn. However, students still struggle with making decisions between approaches and when not given exact procedural steps want the reassurance they are "doing the correct thing" to meet the project requirements [2, 4, 9]. Higher-order thinking by students involves the transformation of information and ideas. This transformation occurs when students combine facts and ideas and synthesize, generalize, explain, hypothesize or arrive at some conclusion or interpretation. These skills are valued because they better prepare students for the challenges of professional practice and daily life, as well as for advanced academic work. Bloom's revised taxonomy is a multi-tiered classification system for learning that identifies six cognitive process categories in increasing complexity. Research indicates that PBL can frequently and reliably get students to reach the Applying level, student's struggle with the Analyzing and Evaluating levels, and frequently do not reach the Creating level of the taxonomy.

There is a need within engineering for our students to reach these higher levels of Bloom's on a more consistent basis. The importance of effective critical thinking skills has been recognized by many employers and educational institutions. The U.S. Department of Education stated as a goal that "the proportion of college graduates who demonstrate an advanced ability to think critically, communicate effectively, and solve

problems will increase substantially [10]." This goal was then incorporated as part of the "Goals 2000: Educate America Act" passed by Congress [11]. The importance of preparing students to think critically has also been advocated by educators at all academic levels [12-16], and a report from the American Association of Universities indicated the importance of preparing people to think critically and to solve problems were essential for college success [17].

The need for these skills are directly tied to the learning outcomes specified by the Accreditation Board for Engineering and Technology (ABET) [18], as well as desired outcomes specified by professional engineering societies, such as the American Society of Civil Engineering's Body of Knowledge [19]. This report defines twenty-four outcomes that make up the knowledge, skills and attitudes necessary to practice civil engineering and utilizes Bloom's taxonomy to outline the necessary level of achievement for each of them. However, intellectual development towards higher levels of thinking requires careful planning and is a slow process [20-23]. Research has shown that learning activities need to engage students in taking ownership of their own learning as well as address multiple learning styles to be effective at getting students to reach higher levels of thinking [24-40].

In order to guide students to a higher level of learning, a critical reflection process has been incorporated into upper level and graduate civil engineering classes that utilize PBL. When learners reflect, they thoughtfully consider (or reconsider) an event or experience. If the reflection is critical, it challenges the customary ways of understanding or explaining an experience.

Using reflection to improve thinking is not a new idea; Dewey stated, "Reflection involves not simply a sequence of ideas, but a consequence—a consecutive ordering in such a way that... 'thinking,' in its best sense, is that which considers the bases and consequences of belief" [26]. This definition of reflection was revised a couple decades later to "Active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusion to which it tends [26]." This definition fits well with the description of critical thinking by Diane Halpern: "Critical thinking refers to the use of cognitive skills or strategies that increase the probability of a desirable outcome. Critical thinking is purposeful, reasoned, and goal-

directed. It is the kind of thinking involved in solving problems, formulating inferences, calculating likelihoods, and making decisions [41].”

Dewey defined the educational process as a "continual reorganization, reconstruction and transformation of experience [27]." The ideas espoused by Dewey led Kolb and others toward a model of experiential learning, a model where learning occurs in a cycle of concrete experience, reflective observation, abstract conceptualization, active experimentation, and repetition [36, 37]. The processing of knowledge lies on a continuum between active experimentation (doing) and reflective observation (watching), and the perception of knowledge lies on a continuum between abstract conceptualization (thinking) and concrete experience (feeling). Reflection seems for many students to be a missing link in the learning process.

Critical reflection questions meanings and looks at assumptions. The opportunity to reflect on experiences develops critical thinking skills and helps students to learn things for themselves. However, students are not born knowing how to reflect on experiences, critically or otherwise. It is important to structure prompts that guide students to make in-depth considerations of their thinking process, including assumptions, various alternatives for the solution process, and how to improve their future work.

The outcomes of this process, as shown in prior research, include:

- **enhanced motivation:** to improve the quality of both the learning process and the ability to give (and receive) constructive feedback;
- **improved cognition and social outcomes in learning:** to encourage deeper level or higher-order thinking, and to develop collaborative skills;
- **an increased sense of responsibility for one's own learning:** to enhance ownership of the learning process and the constructed knowledge; and
- **improved metacognitive skills:** to enable students to reflect more critically on their learning.

This paper presents a model for classroom practice for enhancing student skill development through critical reflection as part of PBL that is based on existing theory on learning. Evidence of the effectiveness of this strategy is presented, through a qualitative assessment of student reflective essays. Additional results will include student perceptions of the process and its value.

II. IMPLEMENTATION

The critical reflection was incorporated as part of a project-based learning experience that incorporated a technical review of work-products by other students in the course. The technical review was performed prior to the critical reflection assignment, giving students a different perspective on the project prior to asking them to critically consider their own process and final product. This approach was implemented in a range of courses from junior through graduate levels.

For all courses the technical review required students to evaluate the available choices, with an emphasis on the rationale and impact of the engineering decisions made. The decisions include both modeling and analysis options as well as design alternatives and choices. Due to the variability built-into the projects, no single solution key is possible and should not be given to the students even in cases where a unique solution may be achievable as grading is not the goal. Students need to be guided on how to perform a critical evaluation of the technical content and provide meaningful feedback.

The critical reflection assignment then explicitly asked students to consider learning that occurred during the assignment. To guide students through the process, questions and prompts were given. While the details of the questions varied slightly to emphasize the specific course, they had the following common bases:

- What are the strengths of the work you submitted? Weaknesses?
- What assumptions did you make? What (other) assumptions did you consider?
- What (other) methods did you consider for analyzing this situation?
- How do you know your answer is the best available solution?
- If applicable, at what point in the process did you realize that there was an error in your process or solution? How did you get “stuck” working on the project tasks? How did you and your group get “unstuck?”
- How could you have approached the problem or situation differently?
- What made this exercise/problem/project easy/difficult?
- What lessons will you take with you to the next problem/project?

III. ASSESSMENT RESULTS

A. Analysis of Reflective Essays

A qualitative analysis of reflective essays was undertaken in order to gain an understanding of the student’s perspective on their learning. These were divided into three subcategories: (a) personal learning experiences, (b) learning experiences relating to skills and (c) professional learning experiences.

1) Personal Learning Experiences

Students reported that the technical review and reflection process resulted in personal learning experiences which they interpret as personal growth.

“The project served as a test of handling grand intricate tasks. It was an exercise which taught me how to systematically approach a daunting problem. In the little amount of time and in a midst of a heavy course load, this project was a show of time management.” (graduate dynamics)

Students also think that they obtain additional perspectives on the projects.

“Through the review process, I was able to see different methods used to generate an approximate SDOF (single degree of freedom) model. This led me to consider the pros and cons of their models and the one our group chose.”
(graduate dynamics)

“Seeing how other groups solved the same problems in different ways and having to comment on what they did took more thought than I had anticipated. When you see an alternate process, you naturally call your own process into question. So in order to give meaningful commentary, you actually have to go back and clear up any uncertainties in your analysis.” (graduate dynamics)

2) Learning Experiences Relating to Skills

Students gain many technical skills throughout a PBL experience. When multiple solutions and/or approaches are possible, reviewing the work of a peer allows students to more readily perceive alternatives. They also become more cognizant of the strengths and weaknesses of each approach, and how various skills must be integrated to solve a task.

“While performing the reviews I learned a great deal about various methods to performing a push-over analysis. The two groups that I reviewed as well my own group all solved the push-over analysis using a different method. One group used a completely linear push-over analysis, in which they would remove members from the model once they had failed, until they perceived that the building had reached failure. The other group used SAP’s push-over analysis by force-control option, while my group used SAP’s push-over analysis by displacement control option. From reading all three reports, I learned that no matter which method was used, it was always difficult to determine when your building had actually failed.

In all three cases failure of the building was based on engineering judgment of the results. In no method does SAP tell you when your building has failed. Throughout my studies, my professors have lectured on the importance of structural engineers to be able to understand how a building should act under prescribed loads. After performing my own push-over analysis and reading the other reports, I firmly believe this to be true if I want to be a good engineer. I would rate my learning” (graduate finite element)

3) Professional Communications

In this category, students reported about learning experiences regarding how communicating ideas and processes was critical to how their work was perceived.

“I realized how important it is to be completely clear when presenting an idea... If a classmate cannot understand the concept, a client will definitely not be able to understand.”
(undergraduate design)

“While reviewing others’ work, I continually thought, “We could have done a better job on our report had we considered

this,” or, “this would have been a better way to communicate this concept in our report.”” (graduate finite element)

“It is important to present your information in a way that is understandable for someone who literally just picks up your report and has no idea what you are doing initially. Anyone can make stacks and stacks of analysis and output, but until you present it in a manner that is easy to understand it literally means nothing to anyone outside your project group.”
(graduate dynamics)

“One paper that I analyzed referred to tables and figures much later than the figures and tables were presented. I found that it is much easier and effective to follow a paper if the tables and figures are shown immediately after they are described. I was unaware of how much a disorganized paper distracts from the analysis being presented prior to analyzing other groups.” (graduate finite element)

B. Faculty Perceptions

Most students can do a meaningful technical peer-review (even of a broad civil engineering project), while they are limited in what they can do in grading – they do not have the experience to judge partial credit well, they provide very good feedback and assessment). As they reflect on what they learned through doing the technical assessment of peer work as well as reviewing their own submission, students also gain insight into what makes a good (or bad) project; they learn what is required of an adequate description and realize how easy it is to detect lack of effort. Finally, the review process provides peer pressure to raise the bar.

“I also learned that it is painfully obvious when a report was rushed” (undergraduate design)

“I literally could compare my group’s work with others that were better or worse off than ours and how much effort some had put to create their memos” (undergraduate design)

“After reviewing other’s work, I could find out a lot many things that I could have done differently and reached better results” (graduate finite element course)

“one of the reports I reviewed was well written and masterfully done... it makes me feel like such a slacker”
(graduate finite element course)

A common thread in the reflections, or self-reviews, was that top students were more critical of their own work than their classmates. In contrast, weaker students self-review was consistently higher than that of their classmates on their work. This can in part be attributed to top students being more aware of their state of knowledge and how to improve their work, which is a component of student metacognition. However, both groups of students in general were able to identify areas that could be improved through the self-review, even before receiving the comments from their classmates. As a result of

both peer and self-reviews, the quality of the final work product improved.

IV. FUTURE WORK

An issue with the reflections, or self-reviews, was that some students were less able to do reflection than others. In some cases, student reflections were somewhat superficial and focused on facts rather than reaching a metacognitive level. This problem is particularly evident in reflections by international students, where language already is a barrier. Future implementations will include additional cycles so as to provide training and calibration of the review and reflection process. This should allow even the weakest reflections to touch on a metacognitive level.

V. SUMMARY

Critical reflection of both peer and own work products develops critical thinking skills and helps students to learn things for themselves. By first reviewing peer work, students can more objectively look at the work and see what could be improved. Since they are not emotionally invested in the work submitted, they have the benefit of perspective. It is then easier to look at their own work product more objectively and be more aware of alternatives and choices that were available during the process.

An important effect of the technical peer review cycle is that of raising the bar; once students see better quality work from some of their classmates, it is more difficult to assume that they can get by with inferior results. Not only do student motivation increase and the overall quality of the student work improve; but all desired learning outcomes show an improvement as a result of the technical review activity. Additionally, professionalism, communication, and other ABET outcomes also benefit in the process. ("a rising tide lifts all boats"... often attributed to JFK, 1963). This simultaneous improvement in all learning outcomes likely results from the increases in the metacognitive and critical thinking skills of the students.

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Using Inquiry-Based Activities to Repair Student Misconceptions Related to Heat, Energy and Temperature

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Abstract— *This study examines the effectiveness of inquiry-based activities for addressing student misconceptions related to four concept areas in the thermal sciences that have been identified as both important and difficult for students to master: (1) temperature vs. energy, (2) factors that affect the rate vs. the amount of energy transferred, (3) temperature vs. perceptions of hot and cold and (4) the effect of surface properties on thermal radiation. Students' conceptual understanding was assessed using the newly developed Heat and Energy Concept Inventory (HECI). In the control sample, student performance on the overall HECI improved from 49.2% correct to a post-instruction performance of 54.4% correct. Using inquiry-based activities, the mean performance on the HECI improved from 46.6% correct prior to instruction to a post-performance score of 65.7%. Significant learning gains were found in each of the targeted concept areas when the activities were used. The study also examined the impact of the activities on near vs. far transfer of learning and found statistically significant improvements for both, but larger learning gains on HECI items involving near transfer.*

Keywords-component; formatting; misconceptions; heat transfer; inquiry

I. INTRODUCTION

There is broad recognition that meaningful learning requires that students master fundamental concepts. Understanding concepts and the connections among concepts is one of the primary distinctions between experts and novices [1; 2]. Conceptual understanding is also a prerequisite for students to transfer what they have learned in the classroom to new settings, something that is arguably among the most significant goals of an engineering education.

While there is little disagreement about the importance of conceptual learning, a wealth of evidence drawn from decades of research in the sciences [3-6] and a growing literature in engineering [7-12] demonstrates that students generally enter our classrooms with misconceptions and that traditional instruction is often ineffective for promoting sizeable conceptual change. Research, much of it in the sciences, has successfully demonstrated that a range of student-centered instructional techniques can significantly improve students' conceptual learning gains [4; 13-15] is a small but growing body of literature in engineering that supports similar conclusions [16; 17].

Several factors explain why engineering education has not yet fully capitalized on the research, primarily in

physics, for addressing student misconceptions. These factors include (1) the unfamiliarity of the relevant education literature to many engineering educators, (2) the lack of concept inventories with good estimates of internal consistency and validity that address core engineering areas and (3) the lack of tested educational materials in engineering similar to those that have been developed and tested in physics. However, significant progress is happening related to each of these issues. The lack of established educational materials specifically designed to repair important misconceptions in the core disciplines of engineering is arguably the predominant missing piece.

The study examines the extent to which inquiry-based activities promote conceptual learning gains in the four concept areas in the thermal sciences that have been identified as both important and difficult for students to master [18; 19]. Those concept areas are (1) temperature vs. energy, (2) factors that affect the rate vs. the amount of energy transferred, (3) temperature vs. perceptions of hot and cold and (4) the effect of surface properties on thermal radiation. In addition, the study examines the effectiveness of the activities for developing students' ability to transfer their conceptual understanding. Transfer relates to the students' ability to extend conceptual understanding acquired in one situation to new contexts [20]. Whether transfer really occurs is still hotly debated [21]. Resolving this debate is hindered by the confusion about how transfer is interpreted in the existing literature. Barnett and Ceci present a clear framework for characterizing transfer that was applied to the present study.

While conceptual change is difficult, a number of approaches have shown promise for promoting conceptual learning relative to traditional instruction. Most of those approaches are active engagement methods and many are inquiry-based. Bernhard [22] provides a good overview of the range of inquiry-based approaches that have been developed for physics education including Physics by Inquiry, Peer Instruction, Real Time Physics, Tools for Scientific thinking and workshop Physics. Prince and Felder [23; 24] provide extensive evidence that a variety of inquiry-based instructional methods are effective for promoting conceptual understanding as well as additional educational outcomes. The framework adopted for the activities presented in this study drew heavily on the Workshop Physics model, the defining elements of which [4] are shown in Table 1.

TABLE 1: Elements of Inquiry-Based Activity Modules [4]

- (a) Use peer instruction and collaborative work
- (b) Use activity-based guided-inquiry curricular materials
- (c) Use a learning cycle beginning with predictions
- (d) Emphasize conceptual understanding
- (e) Let the physical world be the authority
- (f) Evaluate student understanding
- (g) Make appropriate use of technology
- (h) Begin with the specific and move to the general

This approach is similar to that proposed by others [25; 26] and has extensive empirical support [4; 27]. Letters in parentheses in the following description of the activities refer to the elements of Table 1 in order to demonstrate the consistency of the approach employed here with the methods described in Table 1. Students were put in teams (*a*) and asked to predict what would happen in a number of scenarios (*c*). The students were then given physical experiments and/or computer simulations to test their predictions (*b*, *e*, *g*), after which they were asked to discuss how their thinking had changed if their predictions did not match reality. All the questions were conceptual in nature (*d*, *f*), using technology where appropriate (*g*). At the end of the specific activities, students were asked to step back and generalize what they had learned from the specific experiments and in some cases were asked to extend that knowledge to a novel application in order to determine if the learning was transferable to a new situation (*h*).

II. METHODOLOGY

This exploratory study examined the effect of eight inquiry-based activities for improving students' conceptual understanding in 4 targeted concept areas using the newly developed Heat and Energy Concept Inventory (HECI). The instrument was designed specifically to assess these specific concept areas and has demonstrated acceptable estimates of internal consistency reliability and content validity [4; 27]. An assessment of the internal consistency of the HECI was done with the entire post-test and each of the sub-post-tests using the Kuder-Richardson Formula #20 (KR #20) and split-half reliability. Estimates of the internal consistency reliability for the post-test can be found in Table 2.

TABLE 2: Estimates of Internal Consistency

| | KR #20 | Split-half Reliability |
|--|--------|------------------------|
| Total HECI (n = 740) | 0.87 | 0.84 |
| Temperature vs. Energy (n = 736) | 0.60 | 0.46 |
| Temperature vs. Perceptions of Hot or Cold (n = 736) | 0.57 | 0.44 |
| Rate vs. Amount (n = 736) | 0.79 | 0.84 |
| Thermal Radiation (n = 740) | 0.76 | 0.74 |

A quasi-experimental design with intact groups was used to assess learning gains. The two groups were a test group that were given the activities and a control group that was not. Each activity was designed to incorporate each of the elements of inquiry-based activities as defined by Table 1. There were 8 activities tested in this study, two targeting each of the four concept areas of the HECI. Students at each

institution used all of the activities. Participants completed the HECI prior to and after instruction. Measurements for the control group assessed pre/post changes on the HECI under normal conditions, that is, without the use of the activities. Student learning gains for this sample were compared to gains found for a test sample of students who experienced the activities in their heat transfer course.

Descriptive statistics examined changes in knowledge, as measured by the mean scores of participants on the entire concept inventory by activity group or control group as well as in each conceptual area sub-test. One-way analysis of variance (ANOVA) was used to examine the differences between pre and post-test scores of the two groups (e.g., difference in pre-test scores of control and test groups). Analysis of covariance (ANCOVA) was used to examine differences between the control and activities group on the post-test using pre-test scores as a covariate. Dependent t-tests were used to examine pre-post learning differences for both the control group without activities and for the test group with activities. Independent t-tests were used to study the differences between near and far transfer questions. Normalized gains were also used to compare the groups. In addition, effect sizes, using Cohen's *d*, were calculated to show the magnitude of the difference between the means of each group when t-tests were calculated and partial eta square was calculated to show the effect size when analysis of variance (ANOVA) or analysis of covariance (ANCOVA) was done. Each is the appropriate measure of effect size for those tests [28].

The HECI was administered as a pre-test of existing knowledge to a control group of 373 undergraduate engineering students at eleven different universities or colleges. The concept inventory was used in 21 course offerings, five of which were offered at the same institution in two different semesters. Of the 373 respondents, 344 completed the concept inventory again after instruction in a heat transfer course. The test group consisted of a sample of 463 students at ten undergraduate institutions. The HECI was administered as a pre-test of existing knowledge to this group. Of the 463 respondents, 392 completed the concept inventory again after instruction that included administration of the inquiry-based activities. The demographic make-up of both control and activities groups is summarized in Table 3.

TABLE 3: Demographic Information

| Demographic Variable | Control Group (No Inquiry-based Activities) | Activities Group |
|----------------------|---|---|
| Gender | 26.6% female, 73.4% male | 23.1% female, 76.9% male |
| Race | 80.9% White, next largest group, Asian/Pacific Islander 10% | 72.01% White, next largest group, Asian/Pacific Islander 13% |
| Major | 39.5% chemical engineering, 47.4% mechanical engineering, 13.1% other | 46.9% chemical engineering, 38.5% mechanical engineering, 14.6% other |
| Year in B.S. Program | Primarily junior (61.3%) and senior (30.5%) | Primarily junior (57.4%), sophomore (21.1%), and senior (19.9%) |

III. RESULTS

A one-way analysis of variance (ANOVA) showed a significant difference between the test group using the inquiry-based activities and the control group on the total pre-test scores, ($F(1, 834) = 5.37, p > .05$). The control group had a significantly higher mean score (17.70) than the activities group (16.77). Because the mean pre-test scores differed, analysis of covariance (ANCOVA) was used when examining group differences in the mean post-test scores because of its ability to compensate for differing pre-scores [29]. This analysis is also warranted given findings from physics education that indicate that differences in pre-test scores continue despite instruction. [30]. When pre-test was used as a covariate, there was a significant difference with a moderately high effect size between those who used inquiry-based activities versus those who did not on the total post-test, $F(2, 696) = 286.19, p < .01, \eta^2 = .451$.

TABLE 4. Mean Pre/Post Performance Data by Content Area, With and Without Activities

| Content Area | Mean Score, Control (no activities) | | Mean Score, Test (w/ activities) | |
|--|-------------------------------------|----------------------|----------------------------------|----------------------|
| | Pre-Test N = 373 | Post-Test N = 344 | Pre-Test N = 463 | Post-Test N = 392 |
| Temperature vs. Energy | 53.6% | 56.6%* | 52.4% | 62.2%* |
| Temperature vs. Perceptions of Hot or Cold | 61.1% | 70.4%* | 57.3% | 73.1%* |
| Rate vs. Amount | 36.8% | 42.6%* | 33.5% | 62.9%* |
| Thermal Radiation | 44.6% | 50.8%* | 40.9% | 63.0%* |
| Overall | 49.2% | 54.4%* | 46.6% | 65.7%* |

*significant change at the $p < 0.01$ level

Paired samples t-tests showed that there was a statistically significant improvement from pre- to post-test scores for both the test and the control groups. A summary of the results as assessed by pre/post measurements using the HECI for both the control and test groups is shown in Table 4. As can be seen from the table, while student learning gains in the control group were statistically significant, they were modest ($t(336) = -7.737, p < 0.01, d = 0.42$) with a moderate effect size. By contrast, the significant improvement with inquiry-based activities was larger (mean score of 46.6% on the pre-test to a mean score of 65.7% on the post-test), ($t(361) = -24.31, p < 0.01, d = 1.28$) with a very large effect size. Effect sizes of 0.50 or larger indicate important findings [29].

As can be seen in Table 4, paired samples t-tests showed significant improvement from pre- to post-test on each of the sub-tests with and without activities. However, effect sizes as measured by Cohen's d were uniformly larger for the activities group. For example, for the Rate vs. Amount of heat transferred sub-test, there was a significant difference from pre- to post-test for the control group, $t(323) = -4.328, p < .01, d = .24$ with a small effect size. For the Activities group, there was also a significant difference from pre- to post-test with a large effect size, $t(361) = -19.525, p < .01, d = 1.03$. What is also notable is that the mean score increased from 33.5% to

62.9% (pre- to post-test) for the inquiry activities group while only increasing from 36.8% to 42.6% for the control group.

One conventional measurement used in much of the conceptual change studies involving physics students is the normalized gain, defined as the improvement in student scores normalized by the possible gain. For example, the normalized gain for students in the control group is 10.4%, calculated by looking at the measured gain of 5.3% (54.4%-49.2%) divided by the total possible gain of 50.8% (100%-49.2%). This can be compared to a normalized gain of 36% with activities. A chart comparing normalized gains on the instrument as a whole as well as for each of the sub-categories of the HECI is shown in Figure 1. The data shows that the activities improved student learning gains in each of the four targeted concept areas as well as for the overall. These gains are significant, both statistically and in absolute terms.

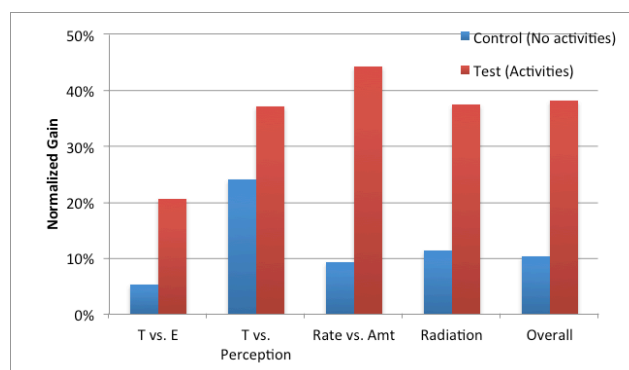


FIGURE 1: Affect of activities on learning gains

The study also examined the impact of inquiry-based activities on students' ability to transfer knowledge to different contexts. Each question on the HECI was characterized by content experts as requiring either near or far transfer of conceptual learning depending on the degree to which the question related to the inquiry-based activity. Near transfer questions were defined as those that assessed understanding using some of the same situations as those in the inquiry-based activities. Far transfer questions were those that extended concepts learned. Paired samples t-tests showed that the entire sample significantly improved from pre- to post-test on the near transfer questions, $t(668) = -20.302, p < .01, d = .79$ as well as the far transfer questions, $t(649) = -17.10, p < .01, d = .67$. However, results suggest that while the activities promoted both near and far transfer of learning gains, the activities were more effective for promoting near transfer.

There was a significant improvement from pre- to post-test on near transfer questions for both the control and activities groups. The control group had a mean pre-test score of 30.26% ($n = 307$) and a mean post-test score of 39.78% ($n = 307$); $t(306) = -6.066, p < .01, d = .35$. For the near transfer questions, the activities group had a mean pre-test score of 28.61% ($n = 362$) and a mean post-test score of 65.84% ($n = 362$); $t(361) = -24.880, p < .01, d = 1.31$. There was a large

effect size for the near transfer question improvement for the activities group.

There was a significant improvement from pre- to post-test on far transfer questions for both the control and activities groups. The control group had a mean pre-test score of 56.07% ($n = 289$) and a mean post-test score of 61.62% ($n = 289$); $t(288) = -6.948$, $p < .01$, $d = .41$. For the far transfer questions, the activities group had a mean pre-test score of 52.07% ($n = 361$) and a mean post-test score of 66.29% ($n = 361$); $t(360) = -17.103$, $p < .01$, $d = .90$.

When examining each type of question by control and activities groups, an independent t-test showed a significant difference on the post-test for near transfer questions with a large effect size, $t(645.31) = -12.647$, $p < .01$, $d = .97$. The activity group had significantly higher mean scores on the post-test than the control group. When examining the far transfer questions, the independent t-test showed a significant difference on the post-test with a small effect size, $t(691) = -3.349$, $p < .01$, $d = .26$. The mean post-test score for the activities group was significantly larger than the control group, although the magnitude of difference between the two mean scores was small.

It should be noted that near and far transfer questions are disproportionately distributed throughout the sub-tests which could impact some differences in activity effectiveness highlighted in Figure 1. For example, six out of eight questions in the Rate vs. Amount concept area are near transfer questions while none of the nine questions in Temperature vs. Perceptions concept area are characterized as near transfer questions. Therefore, it seems likely that the greater impact of the activities for promoting gains in the Rate vs. Amount concept area compared to the concept area of Temperature vs. Perception result (at least in part) from this difference in distribution of questions on the assessment instrument rather than the inherent nature of the targeted misconceptions or the construction of the activities for the given concept area. This issue needs to be examined in future work.

IV. CONCLUSIONS AND FUTURE WORK

This study builds on earlier research in a number of ways. Consistent with a large body of literature, the data from the control group demonstrates that students have significant misconceptions about heat, energy and temperature and that these misconceptions are frequently robust or resistant to change through conventional instruction. The modest learning gains found for the control group support that finding. At the same time and again consistent with a large body of literature in the sciences, it has been shown that the use of inquiry-based activities can significantly increase student performance on measures of conceptual understanding, even in those cases that are resistant to change through conventional instruction. Again, the significantly improved student performance, both in the aggregate and for each of the targeted concept areas of the HECI, supports this assertion. Taken as a whole, this work contributes to our understanding by adding to what is at present a small data-base of the effectiveness of such activities with undergraduate engineering students.

While these results are very encouraging, there is a need for significant future analysis. We are in the process of how effectively the activities promote conceptual learning gains immediately after their completion compared to student performance on the concept questions several weeks after the activity. In addition it would be beneficial to have additional measures of students' conceptual learning, drawn from additional venues such as concept maps or semi-structured student interviews.

Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced. Styles named "Heading 1", "Heading 2", "Heading 3", and "Heading 4" are prescribed.

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Examining student constructed explanations of thermodynamics using lexical analysis

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Abstract—Thermodynamics can be challenging to students, thus improving thermodynamics instruction and assessment is an important area of science and engineering education research. Constructed response assessments can reveal the complexity of students' ideas about thermodynamics. We investigate the use of lexical analysis software for examining students' constructed responses using a group of three questions related to reaction thermodynamics. These questions were administered to students in a large enrollment undergraduate introductory science course and examined learning at two levels of Bloom's Taxonomy: comprehension and application.

Our results show that students are able to identify correct statements about thermodynamics in a multiple choice context but fail to construct correct explanations using thermodynamic concepts. Lexical analysis revealed that students who provided correct explanations incorporated more correct concepts and/or made more connections among these concepts than did students with incorrect explanations. Lexical analysis provided insight into student understanding by revealing heterogeneous ideas that were masked in multiple choice versions of the assessment.

Keywords—component; lexical analysis, text analysis, thermodynamics, assessment, Bloom's taxonomy

I. INTRODUCTION

A basic understanding of thermodynamics is essential to learning in STEM disciplines in order to understand the relations between different forms of energy in physical, chemical and biological systems. Science and engineering education research has found thermodynamics concepts to be particularly challenging for students. Students have difficulty distinguishing among endothermic and exothermic reactions [1], and struggle with concepts such as entropy and reversible and irreversible reactions [2] and heat transfer [3].

The need for improved learning continues to drive instruction and assessment of thermodynamics. Current instructional research focuses on conceptual change through active learning including the use of models and simulations [3–5]. Assessment research has focused on the development of concept inventories such as the Thermodynamics Concept Inventory [6], the Heat Transfer Concept Inventory [7], and the Thermal and Transport Concept Inventory (TTCI) [8], [9]. For example, the recently developed TTCI is a 2-tiered multiple choice diagnostic test that seeks to identify student misconceptions and the reasons for these misconceptions.

Another approach to assessment in thermodynamics is the use of writing to allow students to represent their understanding in their own words and reveal the heterogeneity of their ideas [10], [11]. These written formative assessment give instructors insight into students' thinking by allowing students to generate ideas [12] and to present the heterogeneity of their ideas [13]. For example, students may hold more than one misconception along with correct ideas of a concept, all of which can be present in a written or constructed response. However, one obstacle to the use of written assessments has been the time and expense involved in grading these assessments.

The Automated Analysis of Constructed Responses (AACR) research group at Michigan State University explores student understanding expressed in constructed responses using computerized lexical and statistical analyses. Linguistic or text analysis can be conducted by vector space (such as latent semantic analysis), linguistic structure and feature-based methods [14]. We employ a feature-based approach that involves extracting and categorizing ideas from student responses, giving instructors insight into student thinking. This method can facilitate formative assessment and feedback in large-enrollment courses [15]. AACR has been exploring lexical analysis in evolution, genetics, cell metabolism and acid-base chemistry assessments [15–17].

In this study, we demonstrate the use of automated text analytics software to investigate students' understanding of thermodynamics in an introductory biology course. We examined student writing using questions targeted at two levels of Bloom's Taxonomy of the Cognitive Domain [18]: comprehension and application. This approach can be applied to other STEM disciplines and should be of interest to faculty who would like to use written assessments in large enrollment courses.

II. METHODS

A. Study Questions

Our study was conducted in an introductory cell and molecular biology course. At least one semester of general chemistry is required as a prerequisite for the course and students were expected to have a basic understanding of thermodynamics. We have collected thermodynamics data

using different questions over several semesters. Data for this study was collected from questions administered during Fall semester 2008 and Spring semester 2012. Prior to receiving this assignment, the students also revisited this topic in their current course. Students were given online homework assignments including a set of three questions relating to reaction thermodynamics – two closed-form items followed by explanation, and one open response question. Students received credit for completion of the assignment regardless of the accuracy of their answer.

B. Text Analysis

We use IBM SPSS Text for Surveys and IBM SPSS Modeler 14.2 Text Mining node to analyze constructed responses. These software identify *terms* from custom-built libraries, similar to dictionaries. Terms are classified into *categories* by predefined computer algorithms which are subsequently modified by the researcher. Each response can contain multiple terms, with each term belonging to one or more categories. The software also displays *web diagrams*, similar to those in Figure 2, illustrating the connections among categories within groups of responses. (For more details on the operation of the software see references 20 and 21).

C. Statistical Analysis

We conducted discriminant analysis to determine categories that predict correct and incorrect post-instruction responses for Question 1. The discriminant analysis used a stepwise-forward, Wilk's method with an F-in of 3.84 and F-out of 2.71 [19]. We used group sizes for prior classification probabilities and a leave-one-out cross validation. Discriminant analysis is similar to linear regression and results in a linear function that expresses the relationship between dependent and independent variables. However, in the case of discriminant analysis, the dependent variables are categorical instead of interval. For this analysis, we have a series of binary independent variables (presence or absence of a student's response in each lexical category) which are combined to predict categorical dependent variables (expert rating). In this analysis the dependent variable has two categories (correct and incorrect) which results in a single linear function. Discriminant analysis analyzes the covariance between independent variables, or whether the variables change together or not. Because of this, it is not the values of individual independent variables but the relationship among them that is critical in determining the discriminant functions.

For Question 2 and 3, we used cluster analysis [20], another classification approach, to determine how responses aggregate into distinct groups based on the combination of categories to which they are assigned. Cluster analysis differs from discriminant in that the identity of groups (clusters) is unknown prior to classification. Clusters are later examined for similar properties shared by responses in the cluster. We use *k*-means clustering which finds *k* clusters of cases (responses). Clusters are mutually exclusive. The responses are classified into the cluster that is closest to that cluster mean or centroid than to the centroid of any other cluster. *K*-means cluster analysis allows the recombination of cases and *k* user-defined cluster over repeated iterations. Recombinations are iterated until no further change occurs. The algorithm computes the F-statistic using

analysis of variance and specifies which lexical categories contribute most to differentiating among the clusters.

We use web diagrams to illustrate the frequency of and relationships among categories within a discriminant class or within a cluster.

III. RESULTS AND DISCUSSION

A. Question 1

The main objective of this part of our study was to investigate how students *describe* (Bloom's comprehension level) free energy change during an exergonic reaction using the graphic representation provided in Question 1 (Figure 1). We compared students' multiple choice and written explanations to Question 1. We analyzed 168 explanations from students who selected the correct multiple choice response. All responses were independently scored by two raters with expertise in biology and chemistry. Complete responses described the components of the system and the change in free energy (see below). The raters scored responses that had only correct ideas as 1. Responses with incorrect, incomplete or mixed (both right and wrong) ideas were scored 0 (this scoring group is hereafter referred to as "incorrect"). Raters demonstrated high scoring agreement (Cronbach's alpha = 0.88) and scoring disagreements were resolved by consensus.

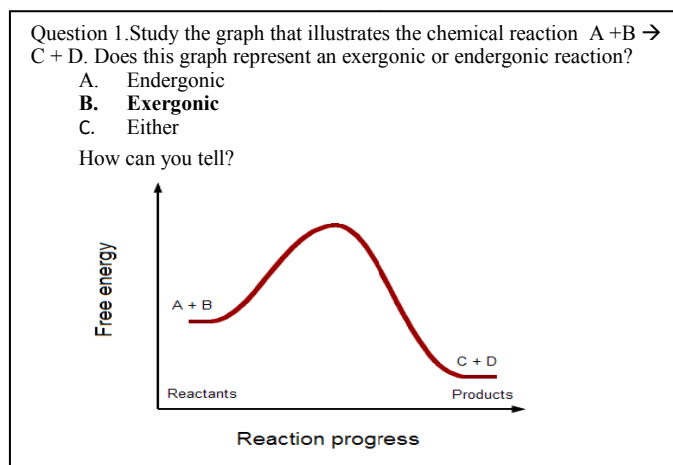


Figure 1. Question 1

The majority of students (84.9%) selected the correct multiple choice answer. However, 49% of these students had "incorrect" explanations for the type of reaction in the post test. Correct and complete responses compared the free energy of the reactants and products or referred to the net negative change in free energy for the reaction. The following are examples of correct responses:

Correct response 1: "energy is released as the reaction proceeds, with the products having less energy than the reactants"

Correct response 2 "The change in G is negative which implies the reaction is giving off energy"

Incorrect responses were either incomplete, completely wrong, or contained both wrong and correct ideas. The following are examples of responses scored as incorrect:

Incorrect Response 1 - Incomplete response: “releases energy” (This was the entire explanation submitted.)

Incorrect Response 2 - Only wrong ideas: “The energy is transferred from the reactants to the products”

Incorrect Response 3: Both correct and incorrect ideas, “You can tell because the reactants have more potential energy than the products. Also because there is a loss of free energy this reaction gives off heat.”

Text analysis successfully categorized all 168 responses into one or more categories. Categories (*in italics*) were first automatically generated by software and refined by researchers. For example, the category *products* was automatically created by the software to extract the word product and phrases containing the word product. This category was further modified by researchers to include the phrase “C+D”. This was important to capture, for in lieu of the word “products” several students mentioned C+D, the symbols representing products in the question diagram. The categories identified included

- components of the reaction (*reactants* and *products*),
- energy (*free energy* and *energy*),
- reaction types (*exergonic*, *endergonic*) and
- energy changes (*lower*, *release*, *higher*).

We used discriminant analysis to validate the categories from lexical analysis as the independent variables and expert scores (correct or incorrect) as the dependent variables. The use of a stepwise model allows only categories that are significant to the model to be included. We used a leave-one-out classification for cross-validation. The resulting discriminant function was significant (Wilk's Lambda = .629, Chi-square 47.111, df = 5, p <0.001). Discriminant analysis of post-instruction responses identified five categories that significantly predicted correct and incorrect responses. These categories and their standardized discriminant coefficients, which are similar to beta weights in regression, indicating relative weights among the variables, are reported in Table I. These categories were used to construct web diagrams illustrating the frequency of responses and connections among the categories (Figure 2).

TABLE I. STANDARDIZED DISCRIMINANT COEFFICIENTS FOR CATEGORIES PREDICTION OF HUMAN RATINGS

| Category | Standardized Discriminant Coefficient |
|--|---------------------------------------|
| Delta G | 0.525 |
| Energy of the products | 0.502 |
| Products | 0.492 |
| Lower | 0.469 |
| Reactants | 0.360 |
| Computer- Human Scoring Inter-rater reliability | Cronbach's Alpha = 0.75 |

Web diagrams illustrated distinct differences between correct and incorrect responses (Figure 2 a and b, respectively). Correct responses had considerably larger node sizes indicating the more correct responses contained these predictive ideas (i.e. *reactants*, *products*, *energy of products*, *lower* (energy). Correct responses also contained terms in the category *delta G* while incorrect responses did not.

We also observed more co-occurrences among categories in the correct responses than among categories in the incorrect responses web diagram. These co-occurrences are also more frequent as represented by the solid line between the nodes *reactants* and *lower* in the correct response web diagram.

These connections reflect the comparisons made by students giving correct responses, such as the response “...with the *products* having *less* energy than the *reactants*” which contained 3 ideas. In contrast, the fewer or weaker connections among incorrect responses were indicative of several incomplete responses such as “the *products* have *less* free energy”, in which students expressed fewer ideas.

Although most students could select the correct multiple-choice option post-instruction, only half of these provided complete and correct explanations for their choice. Problems understanding endothermic/exothermic process can be prevalent among students learning thermodynamics [10,13]. Our data show that this difficulty can extend to exergonic/endergonic processes as well. Additionally, the large number of students unable to describe the change in free energy in the system may have difficulty between the system and surroundings [1]. Our results demonstrate that this gap in student understanding could go undetected with only

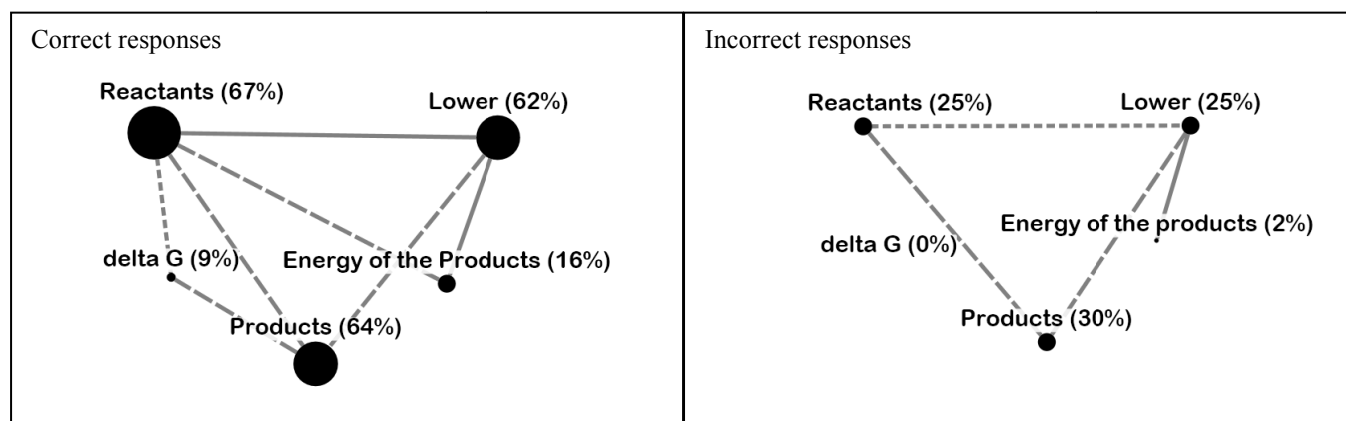


Figure 2. Web diagram of categories and links for a) Correct and b) Incorrect responses. Each category is represented by a node. The size of the node corresponds to the frequency of responses containing a category. Lines indicate the percentage of shared responses. Solid lines indicate that 75% shared responses; dashed lines 50-74%, dotted lines 25-49%. Nodes with fewer than 25% share responses were not linked.

multiple choice testing, but was revealed through written assessment, as has been observed in other fields [21,22].

B. Question 2

The main objective of Question 2 was to examine how students can use their knowledge of the definition of Gibbs free energy to *identify* (Bloom's comprehension level) conditions under which a reaction may become spontaneous.

Question 2. Can a non-spontaneous chemical reaction become spontaneous under different conditions? Explain your reasoning for your choice above.

Seventy five percent (n= 329) of students responded "Yes" to Question 2. We analyzed these 329 explanations using text and cluster analyses. Text analysis categorized the responses into 32 categories. Some of the most common categories were terms found in the question stem: *spontaneous* (70% of responses), *reaction* (45%) and *non-spontaneous* (36%). Other categories with high frequencies included *temperature* (48%), *change* (35%) and *conditions* (16%).

To identify groups among the responses, we used *k*-means cluster analysis. Values of *k* between 2 and 5 were examined. Categories from the question stem (listed in the previous paragraph) were removed from the cluster analysis as these ideas were not generated independently by students but may impact the results. With *k*= 2, the ANOVA indicated that the category *temperature* contributed the most to differentiating among the clusters. However, examination of the responses revealed a good deal of heterogeneity within the two clusters.

We decided to use three clusters, as trials with *k*=4 and *k*=5 showed little improvement in the distances among centroids and did not add much homogeneity to newly formed clusters. The *k*=3 cluster ANOVA identified the categories *change*, *energy*, *high*, *reactants* and *temperature* as contributing the most to differentiating among the models.

Cluster 1 identified 46 responses (14%) which demonstrated high quality explanations. These majority of the responses indicated that a non-spontaneous reaction could occur spontaneously at sufficiently high temperatures. This is observed in the web diagram (Figure 3a) showing that 58% of the responses in used the categories *temperature* and *high* (which in includes terms such as increased, greater and higher). These categories and the connection between them dominate the web diagram allowing a quick visualization of the main idea that is representative of Cluster 1.

A few students in Cluster 1 referenced the equation or definition for free energy, for example, "If temperature is increased in the $\Delta G = \Delta H - T \Delta S$ then the ΔG can go from positive to negative and become spontaneous."

However, some students also gave less detail, e.g. "Increasing the overall temperature of the reactants will cause a non-spontaneous reaction to become spontaneous."

Cluster 2 contained 112 responses (34%) in which students affirmed that under changed conditions, particularly temperature, a non-spontaneous reaction may become spontaneous. However, these students did not specify that a higher temperature was required and were less likely to refer to

the definition for Gibbs free energy. The strong association of *change* and *temperature* in Cluster 2 responses is shown in Figure 3b. We observe a change in the dominant variable and connection from *high* and *temperature* in Cluster 1 to *change* and *temperature* in Cluster 2. The following are representative of Cluster 2 responses

"Many times a non-spontaneous reaction can become spontaneous if the temperature is changed."

"You can change some reactions to become spontaneous by changing the temperature."

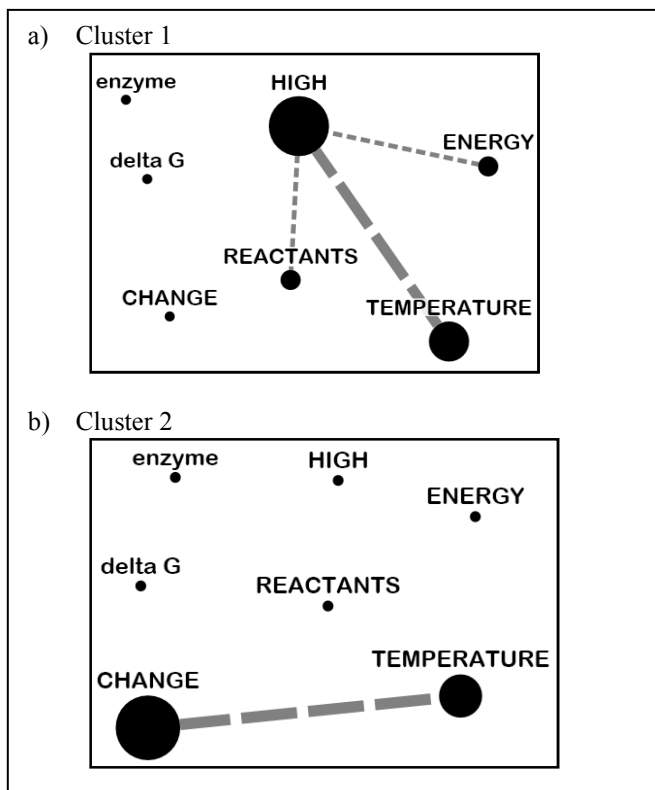


Figure 3. Web diagram of categories and links for a) Cluster 1 and b) Cluster 2 for Question 2: Spontaneous Reactions See Figure 2 caption for legend details.

Cluster 3 contained 171 responses (52%) that suggested reversing the reaction and selecting addition of an enzyme as a new condition. The use of *k*=4 analyses did not further divide these Cluster 3 into two distinct groups. Students who suggested reversing the reaction demonstrated knowledge of the free energy of the reaction but did not apply it correctly to the question. Responses suggesting the addition of an enzyme revealed a misconception held by students that enzymes alter the spontaneity of the reaction.

For example students stated that

"Added enzymes can make a non-spontaneous reaction spontaneous but not the other way around."

"catalysts lower the energy reaction pathway. An example of a catalysts [sic] is an enzyme. An enzyme reduces the transition energy pathway."

Keeping in mind that 75% of the students selected “Yes” - a change in reaction spontaneity is possible, we gain detailed information about student thinking from the use of the constructed responses. Coupling text analysis and cluster analysis, we were able to identify three groups of responses of varying content and quality. A subset of students in Cluster 1 presented a detailed explanation which included the definition or equation for free energy change. However, the majority of students did not reference this concept in their responses. Additionally, students hold misconceptions about the role of enzymes in reaction thermodynamics and kinetics.

C. Question 3

To observe how students *apply* (Bloom’s application level) thermodynamics concepts in biology contexts, we analyzed responses to question 3. Students were expected to use thermodynamic concepts to explain carbohydrate decomposition rate.

Question 3. A carbohydrate is composed of a string of covalently linked monosaccharides. Breaking those bonds between the monosaccharides is a chemically spontaneous reaction (ΔG for this reaction is -3.7 kcal/mol). However, this reaction occurs very slowly at room temperature. Why do you think this is so?

We analyzed 386 student responses. Text analysis generated 44 categories of terms. The most frequent categories containing terms not found in the stem were *temperature* (excluding room temperature) (34%), *energy* (25%), *high* (19%), *heat* (18%), *activation energy* (16%) and *catalyst* (13%).

For Question 3, we used *k*-means cluster analysis to identify groups, testing values of *k* between 2 and 5. We present the results for *k*= 3 which maximized the distance among clusters. The categories *enzyme* and *high* contributed most to differentiating among clusters.

Cluster 1 was the least well defined cluster. The 278 responses in this category were very heterogeneous. Some were vague, for example,

“This is because, the room temperature and the temperature of the reaction are very similar”

“Just because a reaction is spontaneous, does not mean it occurs fast.”

Other responses contained concepts such as phospholipids and descriptions of state changes of carbohydrates at room temperature that were unrelated to the topic.

Surprisingly, some correct explanations mentioning the high activation energy as a rate-limiting process were also included in this category. It is possible that the low number of responses (~10 %) using activation energy as the only or main idea made these cases difficult to classify. These did not form a separate cluster with *k* = 4 or 5.

The web diagram for cluster 1 is not shown as all connections observed shared fewer than 25% of responses for students connected few ideas.

Cluster 2 contained 71 responses (18%) expressing ideas about bond stability and the need for higher temperatures to

increase the rate of reaction (Figure 4). For example, students stated that:

“it is a more complex molecule with strong bonds. Though some bonds may break at room temperature, there simply isn’t enough energy to make it occur rapidly.”

“Since it is a spontaneous reaction it will happen without any added energy. A higher temperature might speed up the reaction because it would drive the reaction more than the lower temperature.”

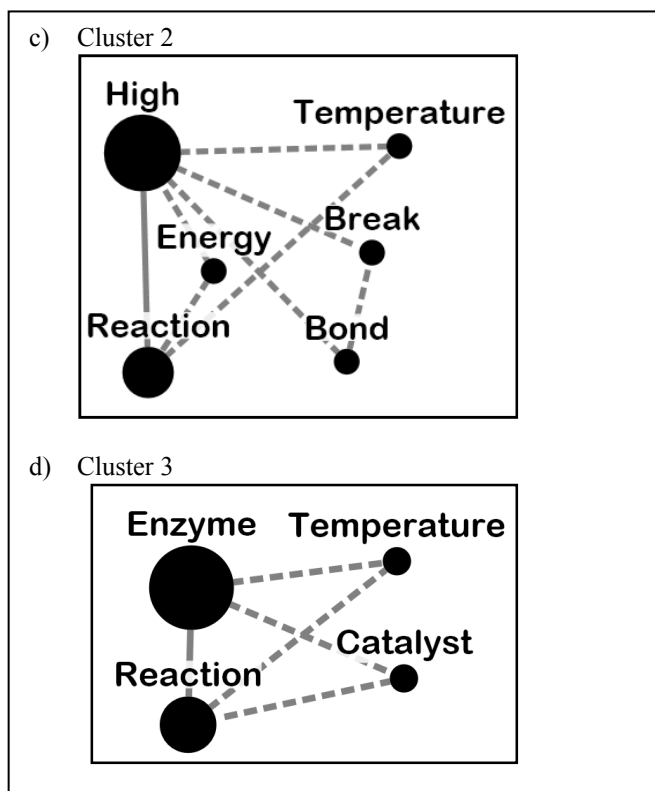


Figure 4. Web diagram of categories and links for a) Cluster 2 and b) Cluster 3 for Question 3: Reaction Rate. See Figure 2 caption for legend details.

Responses in Cluster 3 centered on the theme of enzymes and catalysts. About 10 percent of students described that a catalyst would help increase the rate. However, not all students detailed how the catalyst would change the thermodynamics or kinetics of the reaction. Some representative responses include

“because the room temperature is not high enough or it needs enzyme to speed up.”

“because in the body, where most starch is broken down, the temperature is greater than room temp, it has a different pH, and has enzymes that catalyze the reaction”

We observed in Question 3 that students give varied explanations of the scenario presented. Though instructors and/or researchers apply thermodynamics concepts to indicate why spontaneity does not determine reaction rate, students often gave vague or irrelevant surface-level responses. We also observed that some students drew only from their biology

knowledge and did not use thermodynamic concepts in answering this question. Students may require more explicit prompts to draw on knowledge from outside the domain of biology when answering problems within a biological context.

IV. CONCLUSIONS

Our analysis of students' written responses revealed that students held varied ideas that could not be observed from their multiple-choice responses. Though some students were able to articulate well thought-out responses incorporating thermodynamic concepts, others failed to identify, describe, and/or apply their knowledge of thermodynamics when asked to provide an explanation. Furthermore, when asked to apply thermodynamics concepts in a biological context, few students approached this question from an application level and most relied on surface-level descriptions, consistent with other research on conceptual change in novices [23].

Written assessment is an important component of thermodynamics and other STEM instruction [10, 21]. We have demonstrated that computerized lexical analysis, coupled with classification analyses, can be used to investigate large volumes of student writing. Lexical analysis allows patterns in student responses in the form of categories and their connections to be easily visualized. Statistical classification, with or without human scoring, can organize student ideas into related groups. One goal of the AACR group is to develop these assessment resources (questions, categories and scoring models) for STEM disciplines [15],[16]. As this body of work grows, it will be made available to instructors to facilitate rapid feedback and tailor their lessons to address student misunderstandings. Resources developed in this project are freely available at <http://aacr.crcsl.msu.edu/>.

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Work in Progress: Audio Reflections Provide Evidence of Metacognition during Students' Problem Solving Attempts

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Abstract— Creating instructional materials that facilitate students' metacognition (activities such as planning, monitoring, and evaluating) and critical thinking is challenging for instructors of first year engineering students. Students come into these programs at various levels of academic preparation, and students may experience cognitive overload when asked to simultaneously use mathematical skills and higher-order thinking skills. In order to demonstrate the effectiveness of new approaches to introducing complex, relevant contexts and skills, methods must be developed that can provide evidence of metacognition and critical thinking skills. These methods can also facilitate research into problem-solving strategies. The overall goal of this project is to design problems for first year students that introduce complex real world topics that are effective for building problem-solving skills for students at all levels of academic preparation. The study presented here is the preliminary qualitative analysis of students' audio commentary in which they reflect on their written problem solutions in a first year engineering course. These reflections were performed within 24 hours of completing written work. Our analysis provides evidence of metacognition retrospectively, as well as during the post-hoc think-aloud commentary. This research methodology effectively identifies student problem-solving strategies, including cognitive, metacognitive and procedural information, and provides evidence that think-aloud protocols are useful in eliciting metacognition and critical thinking.

Keywords: *first year engineering, problem solving, metacognition, think-aloud*

I. INTRODUCTION AND BACKGROUND LITERATURE

Problem solving is a critical skill in engineering, and identification of deficiencies is necessary to inform evidence-based educational reforms aimed at improving development of these skills. This project seeks to identify indicators of metacognition and critical thinking that occur with successful problem solving strategies for freshman engineering students. There is extensive literature available on engineering problem solving [1] but little on how students' academic preparation affects the development of their problem solving skills. The ultimate goal of this project is to design problems for first year students that introduce complex real world topics in a way that builds problem-solving skills for students at all levels of academic preparation.

"Think aloud" protocols, wherein students verbalize their strategies as they work through problems, have been applied in engineering education to track the progress of students' conceptual and procedural problem solving knowledge [2]. However, there is evidence that verbalizing one's thought process while working can alter the work produced [3]. Therefore, this study first collects written, temporal records of students' work, then records verbal audio commentary after the written work has been completed. This provides an authentic record of students' problem-solving processes (written work), with the additional benefit of the students' reflection on those processes (post-hoc "think aloud").

II. METHODS

The study was conducted as a phenomenography, an educational research method that categorizes subjects' descriptions of a "phenomenon" or event being studied [4]. In this study, the event is solving a problem. Students used custom-designed software on tablet computers to complete and submit selected assignments. They were then invited to review their work and add audio commentary reflecting on how they arrived at the solution, using an audio recording feature in the software. This feature allows audio recordings to be associated with specific strokes or erasures in students' written work. Written solutions were analyzed qualitatively by coding elements categorized as knowledge access, knowledge generation, self-management, errors, answers, and strategies [1]. Transcriptions of audio comments were analyzed by the research team while simultaneously replaying written work, including the codes associated with the work. Student audio comments that provided additional information or insight beyond what was evident in the written work were coded, using the coding scheme developed for the written work as a starting point. Codes related to problem solving strategies were added based on a set of non-domain-specific strategies [5]. Additional codes were added as needed by members of the research team while simultaneously analyzing three problems completed by three students randomly selected from a population of first year engineering students (n=28) who participated in this project. These mostly pertained to information in the audio commentary that did not appear in students' written work.

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III. RESULTS AND DISCUSSION

While much of the audio commentary reflected what was evident in the written work, preliminary results showed that the students' reflections provided insight into their comprehension, confidence, confusion, and use of strategies while completing the written work. For example, where a student's written work showed that she added units to numbers after performing a calculation, she acknowledged in her audio reflection that she recognized the importance of labeling parameters throughout her work. This is an indication that this skill (consistent use of units) may carry forward to other problems and applications, as she did not do it simply because she was instructed to. In some cases where students erased work frequently, which indicates confusion, their audio commentary revealed what aspects of the problem the student found confusing. For example:

"Um, I understood part B of this [assignment] but A and C confused me. I wasn't really sure what the directions were asking for.... I know now...a little bit better since I've reviewed more on it what it was asking for but at the time I was very unsure...."

Table 1 includes examples of student commentary that provide evidence of metacognitive thinking, namely planning, monitoring, and evaluating [6], while the students were completing written work.

Students also identified resources used that were not apparent in written work alone. Use of external resources is an important aspect of dynamic transfer [7], which is useful in assessing long-term learning. For example,

"I was stuck when I thought that you had to use all of the resistors and as you can see from my work I scratched out, but I was very confused and then I was told by one of my group mates that you didn't have to use all of them so that made it quite a bit easier."

TABLE I. AUDIO REFLECTIONS THAT INDICATE METACOGNITION [PLANNING, MONITORING AND EVALUATION] IN WRITTEN WORK

| Code | Student Comment |
|--|--|
| Acknowledge importance: identify equations / knowns [planning] | <i>When beginning a problem I like to write out all the formulas, any given information or formulas that I will like need to actually complete a problem. It kind of helps me get in like the mindset of the problem itself and what I have to do to solve it.</i> |
| Acknowledge importance: check accuracy [evaluation] | <i>With that correction that stood as a warning to me that I may need to review my previous equations to make sure that I had not left anything out from what I had learned. And after checking I hadn't.</i> |
| Acknowledge importance: labeling/renaming [monitoring] | <i>And going back, I did an ohms sign right after the 25.45 because I kind of figured that was important. So I forgot it, and went back and added it.</i> |
| Acknowledge importance: draw a picture [planning] | <i>So I made a picture of the circuit and this is what it looked like. It helped visualize the entire problem for what it was worth.</i> |

Other findings in our analysis of audio commentaries allow a deeper understanding of students' written work, and show evidence of strategies such as trial and error or means-ends

analysis. For example, a student whose work was quite efficient and included direct calculations within a circuit problem added the following comment, which indicted a "guess and check" strategy:

"Yeah, I just kind of picked out a voltage and a resistor that I thought that might work."

Without this added insight, it would not be apparent that he did not actually predict that the value he chose would work in his calculation, but rather took a (lucky) guess.

Some students recognized errors or inefficiencies in their work during their audio commentary, which they were not aware of while completing their written work. For example,

"Honestly after just sitting here I have realized that I did make a mistake in my calculation...that would... affect the rest of my calculation throughout."

This demonstrates the value from an instructional standpoint of having students reflect on their work after completing it. It is also possible that a concurrent think-aloud would provide this benefit as well, for the purpose of promoting metacognition.

IV. CONCLUSIONS

Our analysis of students' audio reflections on their problem solutions revealed aspects of metacognition during students' written problem-solving activities (acknowledging the importance of specific steps or aspects of their problem-solving strategies). They also identified the use of external resources, which is useful in studying dynamic transfer of knowledge. During post-hoc think-aloud sessions, students also recognized errors that they had not detected while completing written work, which demonstrates the value of think-aloud protocols in promoting metacognition. Other comments provided during audio reflections allow more accurate definition of strategies than is possible by analyzing written work alone. These results can help instructors identify patterns of inconsistent or ineffective problem solving strategies to inform development of more complex problems for first year engineering students.

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Work in Progress: Investigating Student Conceptual Understanding in Introductory Electrical Engineering Courses

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Abstract—We report on an ongoing investigation of student understanding of basic concepts in the context of various first-year undergraduate DC and AC circuits courses. Through analysis of student responses to mostly qualitative quiz and examination questions, we have identified characteristic difficulties with different topics. The results from this research are being used to guide the design of active-learning instructional materials that are aimed at strengthening conceptual understanding of circuit quantities and the relationships between them. Up to now, an initial set of 18 collaborative-group worksheets have been developed and implemented in two different instructional formats: large interactive lecture settings with an audience of more than 400 students and small course sections with about 20 to 25 students. Data from post-tests suggest that the materials can be used successfully in both formats. We are continuing to administer post-tests to strengthen our claims about the effectiveness of these materials. In addition, we are hoping to broaden our research base through interviews and further written tests, thereby laying the groundwork for a more thorough understanding of the nature of the student difficulties that we have identified.

Keywords: *Engineering education research, conceptual understanding, student difficulties, AC circuits, phase relationships, threshold concepts.*

I. INTRODUCTION

For the past three decades, a substantial amount of research has been carried out on student understanding of electric circuits at the secondary-school level [1]. There have also been some investigations in the context of introductory university courses, both for technical and non-technical careers [2], as well as some research with in-service high-school physics teachers [3]. Most of the work so far has concentrated on student ideas about simple DC circuits. Engineering students at the university level, however, are generally also required to study AC circuits, a topic that for many presents some additional mathematical and conceptual challenges. This situation has prompted us to extend our work in this field to genuine AC concepts such as phasor notation and phase relationships. Results of this project have been published previously [4, 5]; below, we review some results and suggest some new directions for this investigation.

Parts of this project were supported through a grant from NORDMETALL Stiftung.

II. CONTEXT AND METHODOLOGY

A. Context of Research

Our research is carried out in the context of different first-year electrical engineering courses at two different institutions in Hamburg, Germany. While these courses are intended for students of different majors (electrical and IT engineering, and mechanical and naval engineering, respectively) they all cover essentially the same curriculum, albeit at slightly different levels of depth and rigor. As it turns out, differences between the results from the various courses are relatively small for most of the questions we asked (after standard instruction).

B. Research to Investigate Student Understanding

Initial observations during informal contact had suggested some student difficulties in understanding *phase shifts* in AC circuits in that students tended to compare signals of the same type (i.e., two *currents* or two *voltages*) at different places in a circuit. We then proceeded to administer written questions mostly as short quizzes during lecture hours. The layout of the circuits used in these quizzes and the specific quantities that we asked the students to compare varied from earlier to later versions. While most of the quizzes included multiple-choice questions, students were always asked to explain their reasoning. The participation in the quizzes was voluntary and did not affect students' grades. However, virtually all students present in the lecture on the respective days participated in the quizzes and seemed to make a genuine effort in answering the questions. We therefore feel justified in assuming that the answers given by the students accurately represent their understanding of the material on the day of the quiz.

C. Development and Implementation of Materials

Worksheets were developed to address specific topics that our research had identified as conceptually difficult. In these worksheets, students are given mostly qualitative questions that guide them through the conceptual steps that appear to be necessary to develop a functional understanding of these topics. The worksheets are modeled after a similar set of materials for physics [6] that have been developed by the Physics Education

Group at the University of Washington in a decade-long iterative cycle of research and assessment. Both sets of materials follow an instructional strategy that can be summarized by the terms *elicit, confront, resolve*: Student ideas about a certain topic are first elicited; partly incorrect ideas are then confronted with contradictory evidence, either through observation or consistency arguments; finally, the cognitive conflict thus created is resolved as a valid model is constructed [7]. The instructional interventions took place in later semesters of some of the same courses used to investigate student understanding, but only at one of the two institutions.

D. Assessment of Materials as Input for Further Research

For the assessment of our materials, we used very similar questions as in the investigation phase of our study, referring to the same or to different circuits. However, we always satisfied the requirement that tasks used in post-testing (for assessing the effectiveness of instruction) were not used in pre-testing or teaching of the *same students*. A quantitative comparison of the number of correct answers to similar questions with and without instruction using our worksheets was used as an indication of the effectiveness of these materials. In addition, a qualitative analysis of student explanations served as a starting point for new questions that are currently posed to students in quizzes and examinations.

III. RESULTS

A. Student Understanding of Phases in AC Circuits

1) *Failure to recognize the implications of Kirchhoff's voltage law*: Several of our questions related to a circuit, in which a resistance and a capacitance are connected in parallel directly across an ideal sinusoidal AC voltage source. The students were asked to compare separately the phases of the voltages across (i) the resistance and the source (i.e., u_R and u_0), and (ii) the capacitance and the source (i.e., u_C and u_0). While the vast majority of the students in four courses (ranging from $N = 49$ to $N = 268$) correctly stated that u_R and u_0 were in phase, that fraction dropped substantially for the phase comparison of u_C and u_0 , ranging from about a third to one-half of the students. We interpret these results as an indication that many of these students do not have a functional understanding of Kirchhoff's voltage law in the context of AC circuits.

2) *Failure to recognize the implication of Kirchhoff's current law*: Questions about phases of currents in series connections resulted in similar difficulties, although to a slightly lesser degree.

3) *Incorrect interpretation of phase behavior*: Students giving incorrect *answers* to the questions associated with the circuit described above frequently explained their reasoning by interpreting the "characteristic phase relationship" of resistive or reactive circuit elements not as a statement about current relative to voltage for the same element but instead as a statement about either quantity relative to some other current or voltage in the circuit. As this incorrect idea can lead to a correct answer for question (i) about the voltages across the resistance and the source, we are reminded that the students' incorrect responses are far from arbitrary.

B. Effectiveness of Tutorial Worksheets

In order to assess the effectiveness of the modified instruction using our tutorial worksheets, we administered a task about the phase relationships between different currents and voltages in a circuit consisting of series and parallel connections. In a course that used the worksheets in an interactive lecture section with more than 400 participants, the post-test was given as part of the final examination. In a course in which the worksheets were implemented in small sections of about 20 participants, the same post-test questions were given as an unannounced lecture quiz about one week after the respective section meetings took place. Questions that after traditional instruction were answered correctly by about 50% of the students or less now yielded a success rate of about three quarters. We interpreted these results as an indication that the use of our worksheets was beneficial to the students. As the results after traditional instruction were largely independent of the time spent on the topic considered (due to the fact that different courses yielded very similar results) we ascribe the effects of the worksheets to the instructional strategies used rather than the (possibly) slightly larger investment of time.

IV. FURTHER RESEARCH AND THEORETICAL FRAMEWORKS

While the development of instructional materials to teach a specific topic in an electrical engineering course has been somewhat successful, it seems likely that further progress can be made only after a deeper understanding of the prevalent student difficulties is achieved. At TUHH, we are therefore considering possible theoretical frameworks to explain student learning of these topics. A promising idea seems to be the theory of threshold concepts as proposed by Meyer and Land [8], suggesting that some concepts may act as a "threshold" to the understanding of subsequent course material.

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Implementation of a Multidisciplinary Introduction to Microfabrication at Binghamton University

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Abstract— Microfabrication is a critical area to many branches of science and engineering. Beginning in 2009, we undertook a broad multidisciplinary approach to bring microfabrication into all aspects of the science and engineering curriculum. This program was coupled with a comprehensive assessment activity to evaluate the program's effectiveness and continuously improve it year to year. In this paper, we report on the details of our implementation process, the techniques we have found to bring a hands-on experience to large classes and the lessons learned from our attempts to make this topic a mainstream part of engineering and science education.

Keywords- *microfabrication, nanofabrication, engineering education*

I. INTRODUCTION

Microfabrication is inherently multidisciplinary. The processes for fabricating miniature structures of micrometer sizes and smaller are based on many disciplines including chemistry, physics, and optics. The devices they make also span the spectrum from completely electrical devices (like microprocessors), to completely mechanical devices (such as microfluidic channels) or mixed devices (such as accelerometers) which combine mechanical elements with electrical components. As such, the most appropriate way to introduce it is in a multidisciplinary way.

The science programs in Binghamton University's Harpur College of Arts and Sciences and the engineering programs in the Watson School of Engineering are very highly regarded. To maintain and enhance this reputation, and to continue to provide high-quality education, it is essential for classroom pedagogy to reflect the state of the art in science and engineering. In this paper, we report on a project to introduce microfabrication to the curricula of the physics, chemistry, mechanical engineering, and electrical engineering departments. In this new program, microfabrication is introduced in a fundamentally multidisciplinary way.

Unlike engineering-as-practiced, engineering education is frequently single-discipline and often lecture- and classroom-based. This cohesive set of activities that we introduce here is both multidisciplinary and project-oriented, which addresses those two common complaints about engineering education[1,2].

II. OVERVIEW

This topic was introduced in a cohesive comprehensive way in many the scientific and technical courses taken by science and engineering majors. Our general approach consists of an introduction to microfabrication in the freshmen year, pipeline modules in core courses in the sophomore and junior year, and an opportunity to take a capstone microfabrication class in the senior year [3,4,5].

The objective is to present microfabrication as part of science and technology by using it as a relevant example of a standard course topic; for example, diffraction can be taught using the example of resolution limits in microfabrication. The idea is to get students to think that making microprocessors and MEMS devices is a legitimate engineering and science endeavor, as much as physical chemistry or circuit design.

The pipeline modules consist of a small experiment or activity that is microfabrication-focused and is integrated into the course. This 'capstone' course attempts to tie together the miscellaneous acquire fabrication knowledge in a cohesive whole involving both theory and practice. It is designed as a lab-and-theory microfabrication course with a multidisciplinary emphasis. It is cross-listed in the Physics and Electrical Engineering Departments, and has attracted students from Mechanical Engineering as well.

III. CAPSTONE COURSE

In this section we will describe the implementation of the capstone course, and the demographics of the students who registered. Throughout we will try to illustrate plans for improvement.

In the spring of 2011, the capstone course entitled "Introduction to Microfabrication" was offered for the first time. The syllabus description of the course is given in Figure 1.

Essentially, this course is a microfabrication course which *makes a particular effort to span multiple disciplines*. The projects it encompasses involve microfluidics, electronic devices, and optoelectronic devices. In addition to covering most major clean room tools and theory, it also introduces experimental techniques through device characterization, and

an exposure to the utility of microfabrication in a variety of different disciplines.

EECE578

Intro to Microfabrication

EECE431

PHYS 483A

PHYS 583A

Catalog Data:

(Various) Multidisciplinary Introduction to Microfabrication: Introduction to clean room tools, procedures, and theory through the fabrication and characterization of various devices from the fields of electrical engineering, mechanical engineering, physics and chemistry. Fabrication of the devices will cover most clean room tools and techniques, including lithography based patterning methodologies; chemical vapor deposition; sputtering; thermal and e-beam evaporation; thermal oxidation; reactive ion etching; ion implantation; and wet chemical processing. The accompanying lecture will cover the theory of the tools used. 4 credits, one lab hour and 3 lecture hours/week

FIGURE 1

BRIEF SYLLABUS DESCRIPTION OF THE CAPSTONE MICROFABRICATION COURSE

The course included three laboratory modules; fabrication of transistors, OLEDs, and microfluidic devices. A fourth laboratory module on fabrication of optical gratings was developed this summer. In addition, it included a major project using the simulation capabilities of the Nanohub (<http://www.nanohub.org>), an excellent facility supported by the National Science Foundation.

IV. COURSE DEMOGRAPHICS

This initial runs of the course had the following demographic of students, broken down by major, gender, and academic year (and final grade awarded).

TABLE 1: DEMOGRAPHICS OF CAPSTONE COURSE ‘INTRODUCTION TO MICROFABRICATION’, 2011 AND 2012

| 2011: 17 students total | Breakdown |
|--------------------------------------|---|
| | 6% Junior, 18% Senior, 88% graduate student |
| By Year in School | |
| By Major | 52% EE, 35% ME, 12%PHYS |
| By Gender | 12% Female, 88% Male |
| By Awarded grade | 47% A, 18% A-, 18% B+, 12% B, 6% B- |
| 2012: 10 students total (2 auditing) | Breakdown |
| By Year in School | 20% Senior, 80% graduate student |
| By Major | 30% EE, 20% ME, 50%PHYS |
| By Gender | 20% Female, 80% Male |
| By Awarded grade | 25% A, 63% A-, 14% B+ |

The capstone course is limited by lab capacity to no more than 18, and the first year it was offered, it was filled to capacity (a single student dropped the course, which is why the course had only 17 students graded).

One concern, illustrated by the demographics in both years, is finding a way to attract more undergraduate students.

There is a similar course in physics which does attract some of the ‘market’ in physics students. We attribute this largely to this being the first two years that this elective was offered. It is not yet a required course in any minor or category, and is not well known in among the undergraduates.

The course is popular among graduate students. It is one of the first attempts to formalize the education that many of them need to complete their research in clean room techniques.

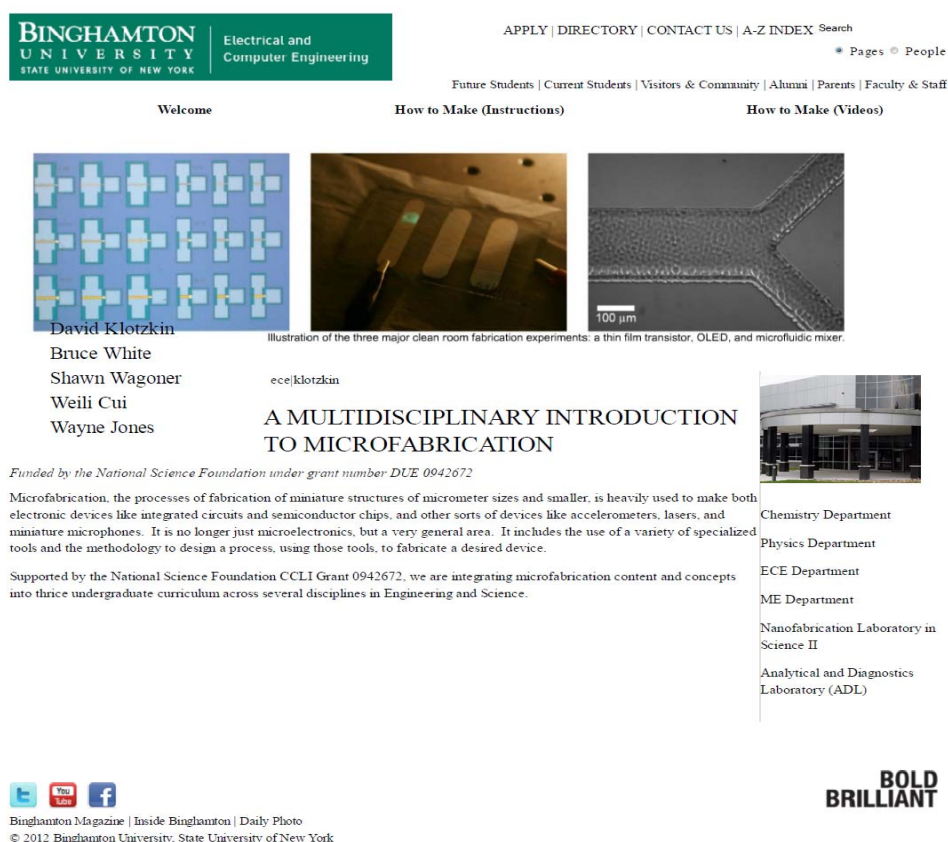
One of our goals is to increase the fraction of undergraduates in the class, as well as attract more majors from outside electrical and mechanical engineering. On the positive side, the students in this course were quite committed, and motivated. The grading was not inflated – most of the students in the course were invested in the material and learned it very effectively.

V. REACTION TO THE CAPSTONE COURSE

Reaction to the course has been quite positive. Positive comments mentioned the relevance of the course to engineering, and that it piqued the students’ interest in the subject.

For balance, most of the suggestions for improvement requested an even-more hands-on fabrication lab experience. All of the students reported medium or high interest in the subject matter after the class, and 80% reported that the labs were useful.

possible, a level above a demonstration, but at the same time



Last Updated: 1/6/12

FIGURE 2

MULTIDISCIPLINARY INTRODUCTION TO MICROFABRICATION WEB PAGE (AT [HTTP://WWW2.BINGHAMTON.EDU/ECE/KLOTZKIN/](http://www2.binghamton.edu/ece/klotzkin/))

VI. WEBPAGE

Many of the activities and results from this pedagogical development activity were collected into a 'Microfabrication' web page, shown in Figure 2. This is intended to be an online resource at Binghamton University or elsewhere for students and faculty in educational aspects of microfabrication. The webpage contains links to videos describing the fabrication process, as well as detailed instructions for the fabrication of each of the various modules.

VII. MICROFABRICATION PIPELINE MODULES

One of the most important aspects of this project was the development of pipeline modules, which are experimental activities that are introduced in lower level classes to expose students to microfabrication [7]. The pipeline modules are designed to attract students from each department into the capstone microfabrication class. These modules fulfill the dual role of complementing the class they are associated with while exposing undergraduates to microfabrication technology. The ambition is to make them as 'hands-on' as

taking into account the time constraint of the existing course and the reality that the students are not qualified to safely do much in the clean room.

The original idea of the project was to make the pipeline modules the characterization part of the microfabrication lab, but that proved largely impractical due to class sizes and lab capacities. In this first year of the project, development of pipeline modules took the form of developing several videos which portrayed device fabrication and characterization. Scenes from a typical video are shown in Figure 3 and links to these videos are also on the microfabrication web page. Two videos have been completed so far, one on fabrication of

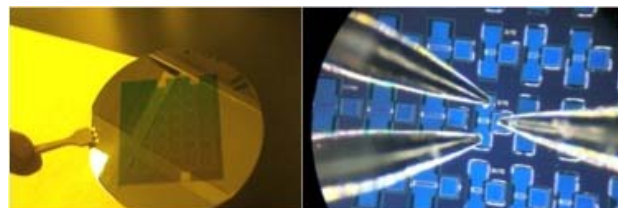


FIGURE 3

FRAMES FROM THIN FILM TRANSISTOR PROCESS DEVELOPMENT VIDEO

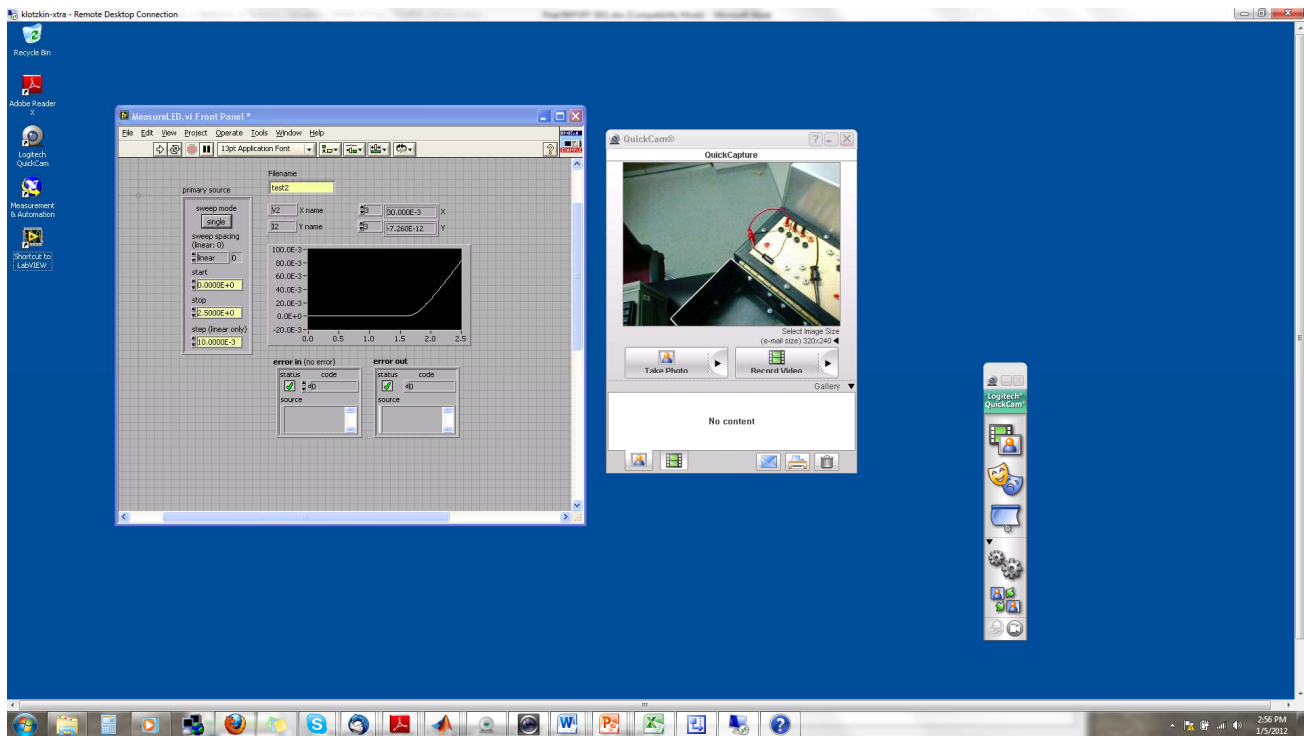


FIGURE 4

WINDOW FOR REMOTE LED EXPERIMENT IN WHICH THE STUDENTS CAN DO EVERYTHING BUT TOUCH THE SETUP: THEY CAN GATHER DATA, RUN THE INSTRUMENTS, AND SEE THE DEVICE BEING TESTED. WHILE OF COURSE THIS IS NOT AS GOOD AS FULL LABORATORY EXPERIENCE, IT IS MUCH BETTER THAN EXPERIENCING ELECTRONIC DEVICES JUST AS DESCRIPTIONS AND GRAPHS IN TEXTBOOKS, AND PRACTICAL FOR LARGE CLASSES. IN THIS EXPERIMENT, THE STUDENTS CAN ADJUST THE START AND STOP VOLTAGE APPLIED TO THE LED AND GET AND SAVE L-I-V CURVE, WHILE WATCHING FOR THE OPTICAL TURN ON.

organic light emitting devices and one on fabrication of thin film transistors. Another video, on fabrication of a microfluidic device, has had the footage shot and is in the midst of the editing process. These videos are used in relevant classes to expose students to the fabrication processes of the devices.

Another idea which we applied particularly for large classes was the remote experiment [8,9]. Instructional lab work typically involves a great deal of hands-on setup and manipulation followed by a brief experimental phase (taking the data) and an analysis phase. What we have done is implemented the first phase for the student for some simple experiments. This gives a very important opportunity for students to relate to a physical device. To illustrate it by example in Figure 4, a remote experiment on light emitting diode characterization was set up using a camera, Labview software and Remote Desktop. This combination allows the student to ‘log on’ to the lab from anywhere and run the experiment. In the experiment, the students were requested to remotely connect to the host computer, collect data, and analyze it. Other hands-on pipeline module activities are under development. We hope the remote experiments described here will be some of the many that we can gradually incorporate into classes such as semiconductor electronics, or solar cells.

The modules developed were incorporated into a variety of courses, as listed in Table 2. The goal was to give students an appreciation for the role of microfabrication, apart from the

various materials used. Each activity was generally accompanied by an assessment to aid us in refining the activity and to measure how well the desired learning outcomes were being achieved.

TABLE 2: COURSES IN WHICH PIPELINE MODULES HAVE BEEN APPLIED

| Course | Pipeline Module Used | Assessment Results |
|--------------------------------------|---|--|
| WTSN 111 Introduction to Engineering | Slide overview of microfabrication process | Clicker-based questionnaire on microfabrication topics |
| EECE332 Semiconductor Devices | Remote LED experiment; transistor fabrication video | Before and after microfabrication survey |
| PHYS227 | Fabrication of diffraction grating | Microfabrication survey |
| Chem 445 | Fabrication of OLED module | Microfabrication survey |

VIII. ASSESSMENT

To continuously guide and improve the program, baseline measures of nanotechnology content mastery were implemented across several courses and departments. A 23-question survey on general microfabrication knowledge, the Microfabrication Knowledge Inventory, was developed and administered to many classes. In addition, a more specific 'Microfabrication Concept Inventory' was developed for use with the capstone course, to evaluate its effectiveness. Some of the flavor of the assessments is contained in the typical questions shown in Figure 5. The Concept Inventory is much more specific, designed to be used with classes specifically in Microfabrication; the Knowledge Inventory is general knowledge of micro- and nano-fabrication and is intended to gauge how much the students absorb of microfabrication knowledge through their undergraduate curriculum. These assessment instruments were developed by the PIs based on what students could reasonably be expected to know about microfabrication from a conventional suite of engineering, chemistry and physics classes.

A full analysis of this data is ongoing, but typical results are shown in Figure 6. A class in semiconductor devices (EECE 332) did a subset (constrained by the time allowed) of the Microfabrication Knowledge Inventory test before and after participating in a pipeline module consisting of the 'Making of a Transistor' video, and the online experiment. Below summarizes the results; the nanotechnology activity seems to have enhanced their knowledge of microfabrication. We note that this is the result of all the questions asked of the students; some showed no statistical change, but in the main, the

CONCEPT INVENTORY QUESTION

14. At pressures typical of e-beam evaporation, the mean free path of the evaporating material
- is very small relative to the size of the deposition chamber
 - is typically similar to the size the deposition chamber (56% of responses on the pre-test were correct; 64% of responses on post-test were correct).**
 - has a size similar to the smallest feature size on a substrate
 - none of the above, the mean free path is not well defined for evaporating material

KNOWLEDGE INVENTORY QUESTION (WITH % CORRECT ANSWERS FROM INTO TO ENGINEERING, 2011)

Rank these in order of size, from largest to smallest:

- 1) Diameter of a human hair
- 2) Influenza virus
- 3) State of the art memory transistor
- 4) Width of a strand of DNA

- A) 1, 2, 3, 4 46%
 B) 4, 3, 2, 1 10%
 C) 2, 3, 1, 4 8%
 D) 3, 1, 2, 4 35%

FIGURE 5

TYPICAL QUESTIONS FROM CONCEPT INVENTORY AND KNOWLEDGE INVENTORY

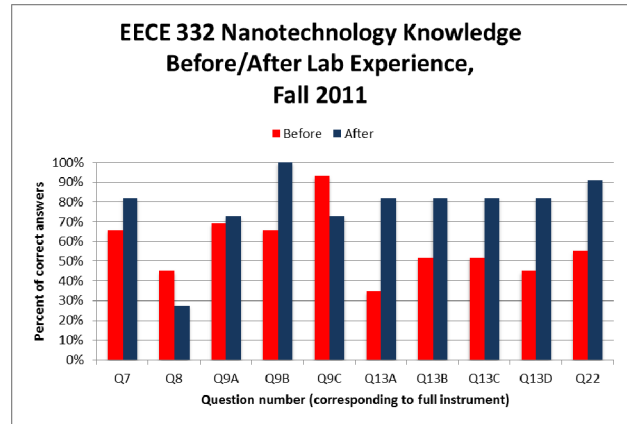


FIGURE 6

MICROFABRICATION KNOWLEDGE ASSESSMENT RESULTS IN EECE 332 BEFORE AND AFTER PARTICIPATION IN A PIPELINE MODULE.

module seemed effective.

A secondary goal of this project is to track the students' acquisition of microfabrication knowledge throughout the program, including both those exposed and not exposed to these pipeline modules and capstone course. A comprehensive list of all the assessments done is given in Table 3. We are also working towards refining the assessment instrument.

TABLE 3: ASSESSMENT ACTIVITIES

| Course | Assessment Used | # |
|--|---|------------------|
| WTSN 111 Introduction to Engineering Fall 2009 | Microfabrication Knowledge Inventory - subset | ~100 |
| WTSN 111 Introduction to Engineering Fall 2010 | Microfabrication Knowledge Inventory - subset | ~100 |
| EECE578, EECE431 PHYS 483A PHYS 583A Intro to Microfabrication Spring 2011 | Nanotechnology Concept Inventory | (9 pre/ 13 post) |
| Physics 132 Fall 2010 | Full Microfabrication Knowledge Inventory | 255 |
| ME362 | Full Microfabrication Knowledge Inventory | 121 |
| ME 480-590 | Full Microfabrication Knowledge Inventory | 18 |
| EECE260 Spring 2011 | Full Microfabrication Knowledge Assessment | ~80 |
| Physics 131 Spring 2011 | | |

Preliminary assessment results suggest that the pipeline modules, and capstone course, do effectively convey the desired information. The final piece of information we hope to obtain for this program is a short-term 'longitudinal study' indicating how many students who participated in this program up to the capstone course continued on to careers in microfabrication. This longitudinal survey will be done in the fall, but anecdotally, at least two students (out the 24 so far) who took the capstone course also took jobs directly involving microfabrication.

IX. SUMMARY

A plan for a comprehensive approach for integration of microfabrication activities into engineering and science curriculum is outlined. Assessments are used to continuously monitor the effectiveness and improve the approach. It is our hope that this multidisciplinary activity will not only expose students to the art of microfabrication, but will also enhance their appreciation for the need of interdisciplinary research early in their engineering and scientific career

ACKNOWLEDGMENT

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Work in Progress: Weekly Innovation Challenge

Changing the Mindset One Step at a Time Every Week

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Abstract—While the value of the entrepreneurial mindset in engineering is now well recognized, faculty members are still struggling to find curricular and extracurricular activities to instill this mindset. This paper presents weekly innovation challenges as a relatively easy to implement set of activities that can be incorporated into:

- *Existing courses* as impromptu competitions and icebreakers that require no major curricular overhaul,
- *Extracurricular activities* to effectively engage students and faculty, and
- *Outreach activities* to promote STEM and entrepreneurship through summer camps, engineers week competitions, K-12 outreach, and open-house events.

The goal of the weekly innovation challenges is to instill the entrepreneurial mindset and foster interdisciplinary team to address a need under tight time constraints. In the long-term, the challenges have the potential to change the eco-system of the entire school. This paper provides insights into the organization of such challenges and logistics in conducting them.

Keywords—component; innovation; entrepreneurial mindset; multidisciplinary teamwork; challenges

I. INTRODUCTION

The Weekly Innovation Challenge (WIC) is an integral part of entrepreneurial education at Saint Louis University. It puts students in a real life situation involving collaborative and investigative learning, community exploration, and innovation. Participants exercise a frugal, flexible, and feisty approach to problem solving like MacGyver. Such an approach is a key to successful start-ups and innovation [1].

Companies are increasingly valuing creative, innovative, entrepreneurial employees. The experiential activities like the WIC help students hone these sought after skills. Experiential learning activities connect theory with practice and allow the participants to apply concepts and integrate experience with education [2]. Activities such as design challenges require students go beyond planning to prototyping and testing and serve to foster critical design skills such as problem solving, creative thinking, teamwork, and communication skills in an exciting, relevant way [3, 4]. Hence many programs are incorporating activity-based learning in the classroom and

curriculum. Some examples of activity-based learning that incorporate innovation are MIT's D-Lab, Harvard's public service classes, and "flipped classrooms" where the lectures are watched online as homework and the class time is for activities in an effort to create a more engaging learning experience [2,5,6].

Institutions often leverage competitions to motivate their students to exercise creativity and experience entrepreneurial skills. While business plan/pitch competitions are common, several competitions are focused more on engineering innovation. Lawrence Tech's Innovation Encounter, ASME IShow, the National Collegiate Innovators and Inventors Alliance OPENMinds competition, I2P (Idea to Product) competition, and Georgia Tech's Inventure Prize are examples of competitions focused on engineering innovation [7, 8, 9, 10, 11]. While these competitions foster innovation in a similar way to the WIC, they require a significant effort for a short time. Participants often move on after the competition. On the other hand, WIC requires consistent effort for a specified duration regularly. It can easily be incorporated into the participant's weekly routine.

At Saint Louis University, the WIC is hosted every week of the school year for continuous engagement to all students and faculty. While other competitions encourage interdisciplinary teams and restrict the number of teams, the WIC mandates interdisciplinary teams and puts no cap on the number of participants. Further, participants can just show-up at the start time to compete in the challenge.

Currently, Gonzaga University and Kettering University have embraced this idea. While Kettering University conducts similar challenges as a part of the speaker series, Gonzaga University conducts them on a monthly basis.

II. STRUCTURE OF WEEKLY INNOVATION CHALLENGES

A. Goal

The goal of the WIC program is to promote the entrepreneurial mindset through multiple exposures to innovation challenges in a competitive, multidisciplinary, team-based, creative environment where the students take on one challenge and one team is chosen as the winner. Just as people are encouraged to exercise everyday to keep the body fit, the WIC is designed to keep the mind fit. It's a mind

workout. The impact of the WIC is that participants entering the challenge are able to exercise their creative side, work in interdisciplinary teams, and experience the team dynamics. They tackle a novel situation under intense competitive time pressure, while networking with other students outside their disciplines, and most importantly, fine-tuning their entrepreneurial skills.

Each WIC is aimed at nurturing creativity, innovation or entrepreneurial mindset. For the purpose of WICs, creativity is defined as the ability to transcend traditional thought patterns and break through hidden assumptions. Theodore Levitt's quote "Creativity is thinking up new things. Innovation is doing new things." best summarizes our view of innovation. In the WIC, innovation is bringing the idea to life [12]. Entrepreneurial mindset takes innovation to the next step by adding value perspective. It is bringing a product or service with a unique value proposition that can provide a sustaining value to all stakeholders. In the WICs, the three concepts are distinguished using the judging criteria shown in Fig. 1.

Creativity = Ideas

Judged by novelty

Innovation = Ideas + Action

Judged by both novelty and usefulness

Entrepreneurial mindset = Ideas + Action + Value

Judged by novelty, usefulness, and value proposition

Fig. 1. Three concepts - Creativity, innovation and entrepreneurial mindset

B. Team Formation

The WIC is open to all students of Saint Louis University. The teams are restricted to exactly three members. To encourage multidisciplinary collaboration, the team members must be from different majors. At least one participant should be an engineering major.

Some participants form their teams ahead of the challenge time and come to the challenges. Several participants come to the challenge without forming their teams. The organizers help them to form teams. The team members get to know each other briefly before the challenge.

Due to significant interest from faculty and staff and requests from students, the challenge rules were modified to allow a maximum of one faculty or staff member per team. The multi-disciplinary requirement is enforced even for these teams. Normally, students select the faculty or staff member that they want to work with.

C. Time, Location, and Incentives

The challenge is held each week (except during the mid-term and finals week) on Tuesdays in the Engineering School Rotunda (shown in Fig. 1) from Noon to 1:00 pm. As it is held at the same location and time, the challenge can easily be integrated into the student's weekly routine.

The features of an ideal location are:

- *Central Space* which can attract a number of participants and readily accessible.
- *Open Space* that can accommodate the participants. Anticipate growth in the numbers as the challenges become popular.
- *Public Space* where a number of people will pass through. As people pass through the challenge location (while leaving or entering the building during lunchtime), it attracts attention. Passers-by may participate in future challenges.

The teams work on the challenge for about 50 minutes. The judges announce the winner at the end of the challenge. The winning team takes the entire prize money (\$225). Within 24 hours of the completion of the challenge, participants or viewers can submit written reflections on their learning. The best reflection wins \$75.



Fig. 2. The challenge space

III. OVERVIEW OF WEEKLY INNOVATION CHALLENGES

22 challenges were conducted during academic year 2011-12. Table I summarizes these challenges. The headings for columns 4, 5, and 6 in Table 1, C, I, and E denote creativity, innovation, and entrepreneurial mindset (refer Fig. 1). Detailed information on running the individual challenges and the learning outcomes is provided in the free iBook [12]. A brief description of each challenge is given below:




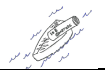








A. The Marshmallow Challenge

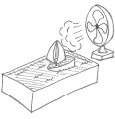









Participants were asked to build the tallest freestanding structure with a marshmallow on top. The best of two trials determined the winner. The time limit for each trial is 18 minutes [13].

B. The Toaster Challenge

Participants were informed that the design department created five unique toasters. Teams selected a toaster that they perceived as most sustainable and designed the packaging for that toaster to make it visually appealing to a "green" shopper.

TABLE I. INNOVATION CHALLENGES CONDUCTED

| Challenge | Description | C | I | E |
|---|--|---|---|---|
| Marshmallow Challenge  | Build the tallest freestanding structure that can support a marshmallow. | | X | |
| Toaster Challenge  | Design an appealing packaging for a toaster to a "green" shopper. | | | X |
| Puzzle Challenge  | Complete a given set of puzzles – the fastest team wins. | X | | |
| Foil Challenge  | Create a boat to float most quarters. | | X | |
| Scavenger Hunt Challenge  | Hunt the locations of close-up pictures. | X | | |
| Elevator Pitch Challenge  | Pitch an idea to add a healthy breakfast on campuses. | | | X |
| Newspaper Table Challenge  | Build the tallest table using newspaper to support a ream of paper. | | X | |
| Rubberband Car Challenge  | Build a car powered by a rubberband to travel the farthest distance. | | X | |
| Gmail Challenge  | Pitch improvements to Gmail. | | | X |
| Balloon Plane Launch Challenge  | Launch a paper plane using a helium balloon and the longest hovering plane wins. | | X | |
| Aesthetic Bridge Challenge  | Build an aesthetic bridge to support a certain weight and span a given gap. | | | X |
| Game Theory Challenge  | Play a series of game theory games and earn points. | X | | |

| Challenge | Description | C | I | E |
|--|---|---|---|---|
| Raft Challenge  | Build the cheapest raft to float a certain weight and travel a given distance using wind power. | | | X |
| Queen Bee Challenge  | Build the tallest tower – worker bees who are blindfolded build while queen bees can only instruct. | | X | |
| Electric Outlet Marketing Challenge  | Create the product presentation for a surge protector. | | | X |
| Reuse Bird Feeder Challenge  | Build an aesthetic bird feeder from trash materials. | | X | |
| Think Globally - Act Locally Challenge  | Bring a global best sustainability practice to a local level. | | | X |
| Outsourcing – Planner/Builder Challenge  | Recreate a Lego creation – planners create assembly instructions and a builder assembles. | | X | |
| Supply Drop Challenge  | Protect two glass candle holders from a two-story drop. | | | X |
| Space Launcher Challenge  | Build a device to launch ping-pong balls through a suspended ring. | | X | |
| Student desk challenge  | Prototype a student desk for a dorm room | | | X |
| Code Transmission Challenge  | Develop a code that can securely relay a message across a 20 ft. gap. | X | | |

C. The Puzzle Challenge

Participants solved a series of 10 puzzles and were timed. The first team to complete all 10 puzzles was the winner. Puzzles ranged in difficulty from relatively simple (laying dominos on a modified chessboard) to complex (balancing 10 nails on top of one nail fixed in place) [14].

D. The Foil Challenge

Teams created a boat capable of floating the most quarters possible using a 3×3 inch piece of aluminum foil. They had 30 minutes to prototype the boat. Teams could test the boat in the water during prototyping. The winner is determined on one final run.

E. The Scavenger Hunt Challenge

This challenge helps participants to be aware of their surroundings. Teams were given close-up pictures of sixteen locations around campus. They identified the items using only their knowledge of the campus and problem solving skills. The second part of the challenge included four tasks such as obtaining a signature from the director of the Intellectual Property Office. The first team to come back with the most correct responses won.

F. The Elevator Pitch Challenge

Participants were challenged to promote a healthy campus by adding a healthy breakfast to the students' diets. They were to create a plan and sell that idea to the community. They had 40 minutes to work on their ideas and then, pitch for 90 seconds to a rotating set of judges.

G. The Newspaper Table Challenge

This challenge was modified from the PBS Design Squad challenge [15]. Participants were given the following challenge: Design and build a table out of newspaper to support a paper ream. Participants could not open or damage the paper ream. The winner was determined based on the height from the base of the table.

H. The Rubberband Car Challenge

Participants were challenged to build a car that travels the farthest distance. Rubber bands can be the only power source.

I. The Gmail Challenge

Much of our communication heavily relies on email. Participants conceived and developed their concepts to improve Gmail in 40 minutes and then, presented them to judges.

J. The Balloon Plane Launch Challenge

The challenge is to use the helium balloon to launch a paper airplane. The airplane that stays in the air (launch to landing) the longest time wins.

K. The Aesthetic Bridge Challenge

The challenge is to design and build a bridge that supports 1 lb. and spans a two-foot gap. The most aesthetically pleasing (or best looking) bridge won.

L. The Game Theory Challenge

The challenge pitted teams against each other in a series of game theory games where the outcome of the games

determined the number of points a team had. The team with the most points won.

M. The Raft Challenge

The challenge is to build a raft that can float the Billiken and travel 2.5 feet on water using wind power. The participants used fake money to pay for materials, the lowest costing raft that performed the functions won.

N. The Queen Bee Challenge

The challenge is to build the tallest tower with several cups of different sizes. A maximum of two team members can be the worker bees and can touch or move the cups. The worker bees are blindfolded. The other member(s) act as the queen bee(s) and can provide only oral instructions.

O. The Electric Outlet Marketing Challenge

The challenge is to create a prototype model of the product presentation. Several innovative electrical outlet designs are provided to the participants. Participants can choose to create just the package or the product and package.

P. The Reuse Bird Feeder Challenge

The challenge is build an aesthetic bird feeder from trash. The teams have to upcycle material such as soda cans, plastic bottles, paper, and foam.

Q. Think Globally – Act Locally Challenge

The challenge is come-up with a concept from the global best practices. The team should bring the best practice to a local grass-root level innovation (product/service/campaign/...). The presentation is judged based on the innovation, potential impact, and feasibility.

R. Outsourcing – Planner/Builder Challenge

The challenge is to effectively communicate between planners and builder without face-to-face, verbal interaction. The planners reverse engineer a Lego Friends creation and write assembly instructions to aid the builder recreate the creation accurately.

S. Supply Drop Challenge

Participants created the inside packing for container that can keep two glass candleholders safe from a two-story drop. They purchased supplies using fake money. The cheapest design that kept the candleholders intact won.

T. Space Launcher Challenge

Participants built a device that could launch Ping-Pong balls into a suspended ring from a certain distance away. The team that got the most ping pong balls through the ring won.

U. Student Desk Challenge

Participants were asked to design and create a prototype of a student desk for a dorm room. The participants could not pitch or demonstrate the prototype to the judges.

V. Code Transmission Challenge

Participants developed an encryption code to transmit a secure message across a twenty-foot gap. The first team that transmitted the message securely and correctly won.



Fig. 3. A collage of the challenge pictures

IV. INNOVATIONS IN THE WIC

The first WIC was the marshmallow challenge where the teams must build a freestanding tower to support a marshmallow. As the challenges progressed during the academic year, several changes were introduced to make the challenges more open, better the learning experience, and be more unique. These innovations include:

- *Open-endedness*: The supplies in the later challenges are more open-ended where the teams select or buy their supplies. The criteria for winning were expanded beyond pure technical merit. For instance, the aesthetic bridge challenge is judged based on the ability to carry the predetermined weight (a technical criteria) and aesthetics (a qualitative non-technical criteria).
- *Learning Experience*: Initially, after the experiential activity of the challenge, all participants were given a debrief statement to help them to consolidate their learning experience. However, their learning experience could be quite different and can never be completely formulated before the challenge. Therefore, the format is changed to incorporate individual participant reflections. The reflections are posted in the reflection blog [12].
- *Uniqueness*: The challenges were altered to place a significantly higher emphasis on the teamwork. Both the queen bee and outsourcing – planner and builder challenges force the teams to collaborative and

communicate at a much higher level. The uniqueness of these challenges lies in the technical, business, and societal aspects to solve customer needs. Think globally – act locally challenge helps the participants to come-up with implementable green design solutions which will be embraced by an average customer.

V. ASSESSMENTS

The purpose of this paper is to discuss how to emulate these challenges and use them as good tools for teaching the entrepreneurial mindset. Currently, we are using reflections from participants, surveys, and focus groups to assess their learning. During the spring semester, an external moderator was used to conduct a focus group study. 12 student participants were randomly selected to provide feedback. The goal of the focus study is to determine the impact of the challenge and characteristics of winning teams. Preliminary results indicate a positive learning experience. The discussion of the results of assessment is beyond the scope of this paper.

Participant's written reflection on what their learning and/or their unique perspective on the challenge. Reflections are incentivized with cash prizes for the best reflection. Here is a sample reflection for the electrical outlet marketing challenge:

Most of our focus is usually on inventing and designing a product, it was difficult to switch gears and think about what would get the product sold in a store. By thinking about the products we personally like to buy, we decided that packaging must be simple and efficient but also appealing to the eye. We realized that the name and directions should clearly explain the product's purpose. Through working in this challenge, we discovered that our own experiences as consumers can be a great resource when trying to figure out what the public is looking for in products [12].

The participants believe that the WIC is changing their mindset. The WIC best summarized in participants' own words:

The WICs are changing the mindset one step at a time every week.

Innovation Challenge is the best opportunity to realize your full potential as a human being as well as an engineering student.

I enjoy participating in the innovation challenges because they provide problems that are different than those that I face in the classroom and require me to work with a group of students from diverse backgrounds to come up with unique and creative solutions.

The participants and winners come from a variety of backgrounds and is summarized in Table II.

TABLE II. LIST OF PARTICIPANTS MAJORS AND TIMES WON

| Majors | Total | Times Won |
|---|----------|-----------|
| Mechanical Engineering | 42 | 8 |
| Aerospace Engineering | 35 | 14 |
| General Engineering | 29 | 0 |
| Business | 24 | 2 |
| Biomedical Engineering | 18 | 2 |
| Electrical Engineering | 13 | 7 |
| Civil Engineering | 12 | 4 |
| Undecided | 12 | 0 |
| Aviation Science | 6 | 2 |
| Biology | 6 | 1 |
| Faculty/Staff | 5 | 1 |
| Computer Engineering | 4 | 1 |
| Physics | 4 | 1 |
| Computer Engineering, Entrepreneurship | 4 (each) | 0 |
| Computer Science | 3 | 3 |
| Political Science | 3 | 2 |
| Mathematics | 2 | 3 |
| Accounting, Biochemistry, Education, Engineering Physics, Finance, Leadership, Philosophy, | 2 (each) | 0 |
| Investigative Medicine | 1 | 2 |
| Music | 1 | 2 |
| Public Health | 1 | 1 |
| Bioelectric Engineering, Chemistry, Communication Science, Dietetics, Economics, French, Geology, Graphic Design, Health Mgmt., Information Tech Mgmt., Marketing, Neuroscience, Nursing, Physical Therapy, Psychology, English | 1 (each) | 0 |

VI. CONCLUSIONS

A recent article states “To encourage more play on the job, colleges and universities could emulate nonacademic institutions like Google, Bell Labs, and IDEO by establishing playrooms and allocating time specifically for the purpose of fostering creativity. Another idea is to create an innovation hothouse, like Stanford University's Hasso Plattner Institute of Design, where the goals are teaching imagination, choosing risky, out-of-the-box solutions, and working through repeated failures as part of the creative process” [16].

The WIC is designed to both foster the playful creative mindset and set a specific time every week for exercising the mind. The nature of each challenge is playful and is further accentuated with the materials used in the challenges. Challenges use water, colorful balloons, popsicle sticks, Legos, crayons, markers, tape, glue, construction paper and many more things that naturally bring out the “kid” in everyone.

While all engineers face challenging situations similar to the WICs where they have to come-up with creative ideas under tight time constraints, what differentiates leaders is how they deal with them. Eugene “Gene” Kranz, NASA Flight Director for the Apollo 13 mission, is known for the quote “Failure is not an option” [17]. During Apollo 13 mission, he successfully led NASA mission control to bring back the crew.

They solved a series of challenges such as jury-rigging a life saving carbon-dioxide filter from available materials. The NASA team demonstrated the critical improvisation skill, which is also a hallmark of the WICs.

The WIC cultivates an action-oriented culture in participants. A lack of action is a major obstacle to most entrepreneurs; they get caught up in the planning and the data gathering and focus less on the execution [18]. Entrepreneurs who take small, yet concrete action consistently, bring their ideas alive faster and better understand the business potential [18]. The WIC stresses continuous quick action - prototyping and refining. Thus, the WIC transforms participants into action-oriented, entrepreneurial-minded engineers.

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Constructing a Collegiate Motorsports Engineering Program

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Abstract—A handful of universities around the country have capitalized on the increased visibility of the sport of auto racing, the financial growth in the motorsports industry, and the increased need for technically trained individuals to work in that industry. The motorsports industry has some unique challenges based on the extreme conditions in which products must operate, the rapid pace at which changes must be designed and implemented, and the necessity for engineers to operate in hands-on mode with the vehicles they oversee which requires a strong applied aspect to engineering education. This paper will examine the creation of the first four year Bachelor of Science degree in Motorsports Engineering offered in the United States. This paper will include a discussion of how new classes were selected and developed in conjunction with the program's industry advisory board. The design of applicable student projects will be examined, including how these various projects were utilized in the design and construction of actual vehicles used both in competition and as teaching tools. Developing any new program requires attention to not only curriculum construction but to student and program assessment as well. The efforts to develop unique assessment tools for this unusual program will be discussed as will the ongoing commitment of the program to work closely with industry advisors to produce graduates with the correct skills needed for the motorsports industry. The lessons learned from creation of this new program can prove useful to those involved in the creation of other unique engineering and technology programs.

Keywords—Motorsports, Program Development, Innovative Practice

I. INTRODUCTION

In 2006, the dean of the Indiana University Purdue University Indianapolis (IUPUI) School of Engineering and Technology (E&T), Dr. Oner Yurtseven, suggested that with the school located in the self-proclaimed "World Capital of Auto Racing" it would be appropriate for IUPUI to develop a motorsports program. [1] With that objective, the faculty members who had motorsports experience discussed what classes might be pertinent to add to the program in order to offer students some technical elective courses with a motorsports flavor. It was decided to create a new Introduction to Motorsports course and a Vehicle Dynamics course and offer them out of the Engineering Technology Department, which oversaw the more application based programs within the school. Additionally, a dormant course on Internal Combustion

Engines was resurrected and reinvigorated, adding a performance slant consistent with the motorsports theme.

Additionally, a motorsports project was initiated to take a donated production sports car and turn it into a competition race car. This car was to be used as a teaching tool in the new classes and also was advertised as a student project which volunteers from within the school could work on. All three of the classes filled in their first offering and were considered a great success by both faculty and students. This success soon led to the idea of creating a Motorsports Certificate Program which could be offered independently, or similar to a minor, as an accompaniment to a BS degree. In the end, an additional new class was created, in Motorsports Data Acquisition, and two versions of the certificate were offered, one with a mechanical slant and one with an electrical slant. These certificates required a minimum of three of the motorsports specific classes along with several existing classes from the School of E&T's curriculum. Additionally, it was required that the student participate in one of the projects being offered on the school's racecar design and construction. In two years of offering these options, the classes continued to fill and the race car (Figure 1) was successfully completed and began to compete in the Sports Car Club of America's (SCCA) autocross and club racing divisions, winning championships in both. Students graduating with the Motorsports Certificate have been successful in gain internships with both race teams and the sanctioning body for IndyCar racing.

In 2008 Dean Yurtseven instructed the Motorsports Program Director to draft a proposal for creation of a new BS degree in Motorsports Engineering, which would be similar to degrees existing in Europe, but would be the first of its kind in the United States. This program was approved in May of 2009, [2] accepted students for the fall semester of 2009, and had its first graduates in May of 2012. The model used to create this program and ensure its success is worthy of study, not just for those interested in motorsports, but by anyone considering developing a new university engineering or technology program.

II. DESIGN OF THE NEW PROGRAM

The proposal which was created capitalized upon the fact that Indiana's governor had recently made a point of acknowledging motorsports as one of the key economic drivers

for the state. The objective of the program, as stated by the proposal was as follows:

The Motorsports Industry offers a thriving and expanding career field requiring employees with specific engineering skills. This degree program would train engineering graduates for these industries which have recently become recognized by the State of Indiana as a major contributor to the state's continued economic growth.



Figure 1. The IUPUI Motorsports Director and the school's first race car project. (IUPUI Media Gallery)

Recognition of the economic impact of a new program, and how it fits with the state's economic and growth goals should be a key element in the decision process to create any new university program.

Using his own experience from motorsports, the program director created a list of twelve new classes that would have a specific motorsports angle. [3] These were then melded with existing classes from the Mechanical Engineering (ME), Electrical Engineering (ECE), Math and Science departments. By doing this, it was not necessary to create as many new classes. The math and science courses were chosen to be the same as they would be for a typical ME program. Additionally, fundamental classes which apply to multiple programs of study, such as Materials, Thermodynamics, Electrical Circuits, etc. were shared with the existing ME and ECE programs. The draft plan of study included the following courses:

Engineering

ENGR 195 (Intro to Engineering)
MSTE 272 (Intro to Motorsports)
ENGR 197 (Programming)
ME 200 (Thermodynamics)
MSTE 210 (Statics & Dynamics)
ECE 204 (Electrical Circuits)

ME 272 (Mechanics of Materials)
MSTE 320 (Motorsports Design)
MSTE 330 (Motorsports Data Acquisition I)
MSTE 340 (Dynamic Signals & Systems)
MSTE 350 (Computer Aided Engineering)
ME 310 (Fluid Mechanics)
MSTE 331 (Motorsports Data Acquisition II)
ME 344 (Materials)
MSTE 472 (Vehicle Dynamics)
MSTE 426 (Internal Combustion Engines)
MSTE 360 (Control Sys. Anal. & Design)
ME 401 (Engineering Ethics)
MSTE 414 (Motorsports Capstone)
MSTE 420 (Automotive Controls)
Technical Electives

Humanities/Social Science

ENGL W131 (Writing)
COMM R110 (Speech)
TCM 360 (Technical Writing)
IET 350 (Economics)
General Electives

Math and Science

MATH 165 (Calculus I)
CHEM C105 (Chemistry)
MATH 166 (Calculus II)
PHYS 152 (Physics I)
MATH 171 (Multi-Dimensional Math)
PHYS 251 (Physics II)
MATH 26 (Multivariate Math)
MATH 266 (Differential Equations)
IET 150 (Statistics)

As can be seen, this list maximized what the faculty believed were the necessary and pertinent supporting and foundational courses already being offered in other departments, as well as adding new motorsports related courses to the curriculum (all new courses are designated MSTE for Motorsports Engineering)

This list of courses was then sent out for review by a list of industry reviewers. The Executive Director of the Indiana Motorsports Association was asked to assist in the selection of the reviewers to ensure a broad cross section of representation. Three IndyCar race teams, three stock car race teams, three drag racing teams, and six businesses that support the motorsports industry were selected. After review by this group, the following classes were added to the list:

MSTE 297 (Motorsports Modeling)
MSTE 410 (Motorsports Internship)
MSTE 310 (Business of Motorsports I)
MSTE 311 (Business of Motorsports II)

The internship course was suggested by the reviewers because they wanted to ensure that hands-on experiential learning was a

required part of the curriculum since it plays such a large role in motorsports success. Additionally, they urged that experiential opportunities be included in as many of the design and analysis classes as possible. The modeling class was recommended because it would include the skills most likely to be used by students in internships. The business of motorsports classes were added because every member of a motorsports team is likely to be involved in decisions relating to the marketing and management of the team, and because more race teams fail due to poor management than due to poor race cars.

These activities demonstrate how review by, and feedback from, members of industry were used to develop the plan of study. This is pertinent because these are the businesses that will serve as internship homes for students, employers for program graduates, and potential collaborators for both faculty and student projects.

This program has served as a model for collaborations within the School of E&T. The decision was made to locate the new engineering program in the engineering technology side of the school so that it could make use of the more applied nature of that side of the school, as well as its hands-on laboratory facilities. This was consistent with the industry recommendation to keep the program tied to real world applications and experiential learning opportunities which are a strong point of the IUPUI technology programs. So while the program uses engineering classes as its foundation, and develops its own specialized engineering classes on motorsports topics, it maintains a strong tie to the hands-on nature of the technology side of the school. Additionally, the certificates are now offered as technology certificates to accommodate a motorsports option for all students in the School of E&T, regardless of program. This is an example of how programs with differing backgrounds and aspects can work together to create successful new programs.

Motorsports Engineering has proven to be the fastest growing program on the IUPUI campus, and a successful one in other ways, too. IUPUI's racing karts, both gas and electric, have proven the dominant entries in both the Purdue Grand Prix and the Electric Vehicle Grand Prix with the winning team shown in Figure 2. The school's initial entry into the Society of Automotive Engineers (SAE) annual Formula SAE competition, shown in Figure 3, proved to be the highest placed rookie team. All of the vehicles within the program were designed and built as projects associated with classes in the program, thus turning every one of these competition vehicles into a teaching tool. Additionally, a collaborative research project with a major drag racing team resulted in a new chassis design which set a new world record. [3,4]

III. ASSESSMENT OF PROGRAM

This curriculum was then compared against the guidelines set by the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET). The desired outcomes of the program were then established by the motorsports engineering faculty at IUPUI are:

- a. Demonstrate and apply knowledge of mathematics, science, and engineering with:
 - a1. Knowledge in chemistry and calculus-based physics in depth
 - a2. Mathematics through multivariate calculus, differential equations, and linear algebra
 - a3. Probability and statistics
 - a4. Mechanical engineering sciences: solid mechanics, fluid-thermal science, material science



Figure 2 IUPUI's winning kart team at the Electric Vehicle Grand Prix. (IUPUI Media Gallery photo)



Figure 3 IUPUI's entry in the Formula SAE competition (Andrew Borme photo)

- b. Design and conduct experiments methodically, analyze and interpret data
- c. Design a system, component, or process,

meet desired needs with applications to:

- c1.** Mechanical systems
- c2.** Thermal systems
- d.** Function in teams to carry out multidisciplinary projects
- e.** Identify, formulate, and solve engineering problems
- f.** Understand professional and ethical responsibilities
- g.** Communicate effectively, in writing and orally
- h.** Understand the impact of engineering solutions in a global and societal context through broad education
- i.** Recognize the need to engage in lifelong learning
- j.** Demonstrate knowledge of contemporary issues
- k.** Use the techniques, skills, and modern tools of engineering effectively and correctly in engineering practice with:
 - k1.** Engineering analysis tools
 - k2.** Engineering design and manufacturing tools
 - k3.** Internet and library resources
 - k4.** Mathematical computing and analysis tools

Additionally, the program was assessed against the schools Principles of Undergraduate Learning (PULs) which are given here:

- 1(a) - Express ideas and facts effectively in written formats
- 1(b) - Comprehend, interpret, and analyze texts
- 1(c) - Communicate orally in one-on-one and group settings
- 1(d) - Solve problems that are quantitative in nature
- 1(e) - Make efficient use of information resources and technology for personal and professional needs
- 2(a) - Analyze complex issues and make informed decisions
- 2(b) - Synthesize information in order to arrive at reasoned conclusions
- 2(c) - Evaluate the logic, validity, and relevance of data
- 2(d) - Solve challenging problems
- 2(e) - Use knowledge and understanding to generate and explore new questions
- 3(a) - Apply knowledge to enhance personal lives
- 3(b) - Apply knowledge to meet professional standards and competencies
- 3(c) - Apply knowledge to further the goals of society
- 4(a) - Display substantial knowledge and understanding of at least one field of study

- 4(b) - Compare and contrast approaches to knowledge in different disciplines
- 4(c) - Modify their approach to an issue or problem based on contexts and requirements of particular situations
- 5(a) - Compare and contrast the range of diversity and universality in human history, societies, and ways of life
- 5(b) - Analyze and understand the interconnectedness of global and local concerns
- 5(c) - Operate with civility in a complex social world
- 6(a) - Make informed and principled choices regarding conflicting situations in their personal and public lives and to foresee the consequences these choices
- 6(b) - Recognize the importance of aesthetics in their personal lives and to society

Table I gives the outcomes for the MSTE degree, how they map to Bloom's taxonomy of learning, the IUPUI PULs, and ABET criteria a-k. This shows how a proposed program should be compared against relevant criteria prior to implementation, to ensure that all pertinent goals, objectives and projected outcomes are aligned.

IV. COLABORATIVE RELATIONS

The Motorsports Engineering program at IUPUI has grown, and the Industry Advisory Board (IAB) has continued to be a strong part of program development, meeting twice per year with the faculty and administrators to discuss possible improvements to the program. The BS program has reached its fourth year, with all classes having been taught at least once, and the first graduates nearing their walk across the stage at commencement. At this stage in the program, the program director was sent for a sabbatical in the field to spend time with over fifty race teams, sanctioning bodies, and motorsports manufacturing firms. The objective was to once more examine the needs of the industry and to audit whether or not the program was accomplishing the desired goals and creating the graduates that the industry needed.

One of the questions asked of those organizations visited was, "what course or courses are the most important for a graduate to have in order to have maximum potential in your organization?" The results are shown in Table II.

This is indicative of the fact that it is necessary to continually align the program to the needs of industry to produce the best graduate for the market. In this case, there were obvious additions needed to the program, as items 8-15 were not part of the original plan of study, yet clearly scored well on the list of priorities. An Aerodynamics and Computational Fluid Dynamics course and a Motorsports Project Management class have subsequently been created. Courses from the IUPUI Energy Engineering program and Mechanical Engineering Technology program will be made available to meet the needs relative to the green engineering and machining topics.

Table I Program Outcome Mapping

| Upon completion of the BS degree, students will be able to: | Bloom's Taxonomy | ABET a-k criteria | IUPUI PULs |
|---|------------------------------------|-------------------|----------------------------|
| 1. Demonstrate knowledge and skills in the use of the design and analysis of mechanical systems. Demonstrate a working vocabulary and knowledge of industry requirements and regulations. | Knowledge & Comprehension | a | 1d,1e, 3b,4a |
| 2. Use current knowledge of mathematics, science and emerging tools to solve problems and demonstrate solutions. | Application | b | 2a,2b, 2d,3c, 4a,4c |
| 3. Identify, analyze and integrate technical requirements with the needs of the industry as required in the degree program's courses. | Analysis | f | 1b,1d, 2a,2b, 2c,2d, 4a,4c |
| 4. Apply and design solutions for issues identified in industry. | Synthesis | d | 2b,2d, 3c,4a, 4c,6b |
| 5. Conduct, analyze and interpret experiments, gather data, and assess results. | Application, Analysis & Evaluation | c | 1b,2a, 2c,2e |
| 6. Function as a member of a team to complete a task in a timely manner. Demonstrate ability to organize work done by team members. | | e | 1c, 5c |
| 7. Write technical reports; present data and results coherently in varying formats. | | g | 1a,1c, 3a,5c |
| 8. Demonstrate skills for life-long learning by locating, evaluating and applying relevant information using external resources. | | h | 3a, 5c |
| 9. Demonstrate ethical conduct. Demonstrate knowledge of professional code of ethics. | | i | 2a,3b, 5b,6a |
| 10. Demonstrate a respect for diversity. Recognize contemporary professional, societal and global issues. | | j | 2e,3b, 3c,4b, 5a,5b, 5c,6a |
| 11. Demonstrate quality, timeliness and ability to complete increasingly complex projects. | | k | 1e,2e, 4c,6a |
















V. CONCLUSIONS

The IUPUI Motorsports Engineering program serves as an example of how new university programs can be developed, and demonstrates some aspects of program design and development that can aid in success, such as the following:

1. Ensure that the new program aligns with industry needs and has economic merit for the graduates and the university

2. The program plan of study should maximize synergy with existing programs and courses on the campus so as to minimize the new work required to create the program.
3. Use industry feedback to ensure that the plan of study is designed to produce a graduate with the skills needed for a career in the industry.
4. Use new programs to diminish barriers between programs and departments by fostering collaboration and cross disciplinary cooperation.
5. Build and maintain a strong ongoing relationship with the industry to ensure that the program stays abreast of new technologies and new issues.

Table II Top Industry Priorities for Motorsports Graduates

| Subject | Number of Times This Subject Was Listed as a Top Priority |
|--|---|
| 1. Vehicle Dynamics |  |
| 2. Data Acquisition |  |
| 3. Design |  |
| 4. Engines |  |
| 5. Field Experience & Hands-On Studies |  |
| 6. Modeling/Analysis |  |
| 7. Business & Marketing |  |
| 8. Aerodynamics & Computational Fluid Dynamics |  |
| 9. Green/Electric Technologies |  |
| 10. Process Engineering |  |
| 11. Machining & Numerical Control |  |
| 12. Project Management |  |
| 13. Advanced Materials |  |
| 14. Simulation |  |
| 15. Failure/Quality |  |

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Designing Technology for Resource-Constrained Environments:

Three Approaches to a Multidisciplinary Capstone Sequence

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Abstract—In this paper we describe three different offerings of a multi-quarter multidisciplinary capstone experience where students engaged in designing and building technology to address problems faced by populations in local and remote resource-constrained environments. We define resource-constrained environments broadly (e.g., low-income communities, low bandwidth environments). These environments provide unique constraints (e.g., cultures where people are unfamiliar with or afraid of technology, environments where power and network connectivity are scarce and expensive). Students are partnered with organizations interested in piloting a solution they devise. The course brings together multidisciplinary teams of students to conduct fieldwork with potential user populations, design a technology to solve a problem inspired by a community-based organization, implement a solution, and evaluate that solution. Students work on projects with real-world impact and gain valuable experience with multidisciplinary design and multidisciplinary team work. In this paper we describe the three class formats we have attempted, sample student projects, and course outcomes based on student projects and survey responses. We also address the various ways projects have continued past the course, and we analyze the structural course and project elements that have contributed to student and research successes.

Keywords - capstone, multidisciplinary, resource-constrained environments, ICTD

I. INTRODUCTION

Highlighting the ways engineering contributes to the larger social good is increasingly seen as a way to attract students to the field – and retain them through the duration of their degree program [1]. At the same time, ABET guidelines specifically ask that we provide students with “the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.” [2] As we have discussed elsewhere [3, 4], we have spent the last several years building on an approach that exposes students to ways technology has an impact in low-income regions as one mechanism for making engineering relevant and showing its power to impact the world positively. For three years we have conducted a multi-quarter multidisciplinary capstone experience where students engage in designing and building technology to address problems faced by populations in local

and remote low resource environments. While this class did not emerge specifically in response to ABET guidelines, the overlap is certainly beneficial.

ABET, for example, asks that we provide students with “an ability to function on multidisciplinary teams” [2]. The multidisciplinary approach discussed in this paper grew out of a capstone experience that was originally grounded in one discipline and sought to provide additional disciplinary perspectives through guest speakers. We shifted that approach over time to more deeply explore how a multidisciplinary approach would enhance the educational experience. One of the strengths of that new approach, which is described in this paper, is the deep collaboration required by student teams. Throughout this multi-quarter course, students from different departments enroll for different credit levels which creates a layer of complexity within the class, but they also have to acknowledge varying disciplinary contributions and distribute workload effectively, in addition to performing traditional project management tasks such as managing expectations and ensuring that deadlines are met. The projects also provide students with the opportunity to experience project lifecycles: the class begins with open-ended ideation, includes engaging real world populations, and ends with implementation and evaluation. This deep experience with multidisciplinary teams is unique in the curriculum in our departments.

In the pages that follow, we describe this multi-term cross-departmental course on designing technology for resource-constrained environments. We define resource-constrained environments to refer to a range of conditions, including material issues such as limited electricity as well as societal conditions such low literacy rates. Resource-constrained environments provide unique infrastructure, technical, and social constraints that demand innovative design approaches. In this course, student teams implement a variety of projects that make them consider design challenges not encountered in their previous engineering courses; the course sequence also forces them to work in teams that challenge their conception of expertise and relevant skill sets. The strength of our approach is that students work on projects that (1) contribute to the social good (2) explore local and global impacts of technology, (3) give them experience working on multidisciplinary teams, (4)

interact with eventual users of their design, and (5) work under unique design constraints [4].

We have offered this course sequence three times since 2009. Each offering has differed slightly in structure and instructional staff. In all three instances, students were organized into project teams organized around student interests and drawing on local and international partnerships. Each team was multidisciplinary, consisting of students from Human Centered Design and Engineering (HCDE), Computer Science and Engineering (CSE), and at times also from departments of Psychology, Public Policy and Informatics. All three offerings have followed a somewhat similar pattern across quarters. This course is based on an earlier CSE capstone course on Information and Communication Technologies for Development (ICTD) [3].

In one quarter, HCDE students were responsible for doing needs analysis through fieldwork, literature searches, and social impact analyses to lay project groundwork. They conducted fieldwork through interviews, observations, web surveys, and user testing. CSE students generated initial prototypes and discussed technical specifications with the team. In the next quarter, CSE students (enrolled in a CSE capstone course) were partnered with HCDE students and the team built prototype implementations of the designs that had been developed in the prior quarter; HCDE students led the evaluation of the prototypes.

In the remainder of the paper we describe the three course offerings in detail, including sample projects, and discuss the trade-offs of various course structure and project elements. Our primary goal in the paper is to discuss how we iterated the course, seeking to improve the educational experience. However, since instructional staff changed slightly for each offering, what we learned from the evaluations was implemented within the constraints of how different instructors approach a classroom setting. While from a pure research perspective this introduces confounding variables, it is also a realistic presentation of how curricular innovations evolve and take root.

II. RELATED WORK

Service learning has long provided a way to incorporate engineering projects that have a positive impact on society [5-8]. Benefits of a service learning approach include building stronger relationships between the university and the community and attracting students to the field through the context of the projects. While we do not employ all aspects of the service learning approach in our course, we saw students engaged by the potential to use their design and implementation skills for social benefit. Other projects have motivated students by the incorporation of open-source humanitarian projects [9] and assistive technologies [10] into capstone courses or as independent study projects. Colorado School of Mines offers a Humanitarian Engineering minor [11]. Socially relevant projects are seen as a good fit for the altruistic leanings of this generation of students [12], and some studies have found that female students in particular are more likely to select humanitarian engineering capstone projects [13].

Our course is based on earlier offerings of a CSE capstone course on ICTD [3]. ICTD is an area of research that studies the opportunities and impacts of applying information and communication technologies in developing economies [14, 15]. ICTD projects are currently being pursued in many engineering departments and emphasize the importance of collaboration with fields such as public health, education, agriculture, and business. Examples of projects in this area include tracking adherence to HIV/AIDS regimens, making crop prices available to farmers, and collecting records of microfinance transactions. A few universities integrate ICTD into their undergraduate curricula [16, 17]. Having students work on ICTD-related projects forces them to consider design challenges not encountered in other computer science courses, such as creating low-cost technology solutions suitable for environments with intermittent power and low Internet connectivity, and designing interfaces appropriate for users who are illiterate or lack deep experience with technology. We differ from these approaches in that we define resource-constrained environments more generally than ICTD, encompassing geographic areas in both the developed and the developing world. Expanding our scope allows us to more easily connect students with accessible user populations and clients.

Much work has been done on multidisciplinary engineering projects in undergraduate education [18-21]. Our work differs in that it focuses on collaborations composed of students from two disciplines – human centered design and engineering (HCDE) and computer science and engineering (CSE) – one focused on understanding and designing around the human aspect of the problem, the other focused on the technical implementation of those human-centered designs. Students in the HCDE department learn to research, design, and engineer interactions between humans and technology. Although the HCDE department is unique to our university, students from human-computer interaction, design or psychology programs could play a similar role.

III. DESCRIPTION OF COURSE SEQUENCE

Since 2009, we have had three offerings of a variable-credit, multi-quarter course coordinated by the CSE and HCDE departments at the University of Washington (UW). Each offering has differed slightly in structure; the overall structure of the course across all offerings is shown below in Table I.

TABLE I. COURSE STRUCTURE

| | Autumn Quarter | Winter Quarter | Spring Quarter |
|-----------|--------------------------|--|---|
| 2009-2010 | 1 credit reading seminar | 2 credits for CSE 5 credits for HCDE (HCI Course) | 5 credits for CSE (capstone course) 2 credits for HCDE |
| 2010-2011 | | 2 credits for CSE 5 credits for HCDE (HCI Course) | 5 credits for CSE (capstone course) 2 credits for HCDE |
| 2011-2012 | | 2 credits for CSE 2 credits for HCDE | 5 credits for CSE (capstone course) 2 credits for HCDE |

A. Autumn 2009- Spring 2010

During the 2009-2010 academic year (consisting of three ten-week quarters), we offered a variable-credit, three-quarter

course. The sequence was co-taught by two instructors, one from HCDE and one from CSE. In autumn 2009, 17 students enrolled in a one-credit seminar to read and discuss research papers about projects in developing countries and resource-constrained communities within developed countries (i.e., low-income communities, homeless populations, low bandwidth environments). The purpose of this seminar was to familiarize students with some of the unique constraints encountered when designing for resource constrained environments (e.g. How do you design for cultures where people are unfamiliar with or afraid of technology, or for environments where power and network connectivity are scarce and expensive?). The course met one hour a week, and a different application area or design constraint was discussed at each meeting. Sample topics include education, transportation, non-literate user interfaces, designing technology for homeless populations, healthcare, and agriculture (full reading list on the course web page [22]).

Winter 2010 was a project design studio. 22 students enrolled in a five credit HCI course offered by HCDE partnered with 13 CSE students registered for two credits. Students were divided into project teams and each team consisted of both CSE and HCDE students¹. On Tuesdays, all students met together (CSE and HCDE students), and topics relevant to the project were discussed (reading related to resource-constrained communities, selection of project topics, team work skills), and project presentations were given to the class. On Thursdays, only the HCDE students met; during these sessions they discussed fieldwork and HCI topics. In addition, the instructors met regularly with each project team for a half hour to discuss progress and issues specific to that team.

There were seven project teams with about two CSE students and four HCDE students per team. Within the project teams, HCDE students were responsible for doing needs analysis through fieldwork, literature reviews, and social impact analyses to lay project groundwork. HCDE students did fieldwork in a variety of domains and scenarios including: interviews with doctors and medical students at local medical clinics, observations of food bank operations and elementary school classrooms, web surveys of potential carpoolers, and email surveys of Ugandan midwives. CSE students were responsible for coming up with initial prototypes for the technology and discussing technical specifications with the team. Throughout the course, teams gave presentations to the class, and at the end of the quarter a poster fair and demo session was held for the general public.

In spring quarter, 12 CSE students enrolled in a five credit capstone course were partnered with 10 HCDE students signed up for two credits of directed research. CSE students built prototype implementations of the designs developed in winter, and HCDE students helped evaluate the prototype through user testing. Throughout the quarter, teams presented their ideas to the class and to panels of experts in formal presentations, poster sessions, and written reports. There were a limited number of full class meetings; instead the instructors met with

each team for a half hour each week to discuss progress and issues specific to that team. The class as a whole met three times during the ten week quarter to select project teams and to give presentations.

Each team was assigned about four CSE students. Three of the projects from winter quarter were selected to continue into spring; they were chosen based on student interest and progress made in winter. Some teams had most members carry over from winter; others had several new members join the project at the beginning of spring quarter. All project teams were comprised of students from multiple departments.

B. Winter 2011- Spring 2011

During the 2010-2011 academic year, the course sequence was shortened to remove the autumn reading seminar. However, there is a multidisciplinary weekly discussion group focused on this subject area [23], and students from that discussion are now recruited into the class; for many of the students that weekly discussion serves as a substitute for the background introduction gained previously through the reading seminar. We also added some of the more critical readings to winter quarter. The 2010-2011 sequence was co-taught by two instructors, one from each department. An additional CSE instructor joined for spring quarter. Winter 2011 followed a format similar to the previous year. 27 students enrolled in a five credit HCI course were partnered with 15 CSE students registered for a two credit design studio. A similar structure of course and team meetings was used. There were eight project teams with approximately two CSE students and two to six HCDE students per team. Spring 2011 was also similar to the previous year in format. 15 CSE students enrolled in a five credit capstone course were partnered with 7 HCDE students signed up for two credits of directed research. The class as a whole met six times during the ten week quarter to select project teams, discuss challenges and evaluation strategies, and to give presentations. As in the previous year, instructors met with teams each week for half an hour to discuss progress. Six teams continued from winter and consisted of two to three CSE students and one to three HCDE students. Due to student interest and the nature of their particular projects, two teams consisted only of CSE students.

C. Winter 2012- Spring 2012

During 2011-2012, the pairing with the HCI course was dropped due to scheduling issues. Instead, in winter quarter 8 HCDE students registered for two credits of research, and 10 CSE students registered for a two credit design studio. The course sequence was co-taught by three instructors, two from CSE and one from HCDE. In winter 2012, without the pairing with the HCI course, all students registered for the two credits and attended the same number of meetings. The course met once a week for two hours. Approximately six of the meetings were used for organization, class discussion of readings, and presentations. On the remaining days the class met together for a few announcements before breaking up into teams the instructors then visited to discuss progress and give feedback. Instructors held a few other meetings with teams. There were six teams with one to three CSE students and one to two HCDE students per team. Spring 2012 was similar to the previous two

¹ Students enrolled in the HCI course were predominantly HCDE undergraduates but also included students from a variety of majors (Informatics, Psychology, Art, CSE). For simplicity we refer to all non-CSE students as HCDE students.

years in format. 16 CSE students enrolled in a five credit capstone course were partnered with 9 HCDE students signed up for two credits of directed research. All of the HCDE students who signed up for spring quarter were Masters-level students. The class as a whole met three times during the ten week quarter to select project teams and give presentations. All six teams continued from winter and most consisted of one to four CSE students and one to two HCDE students. One team consisted only of CSE students and one consisted of only HCDE students.

IV. COURSE PROJECTS

Over the three course offerings students have tackled a variety of projects ranging from relatively cleanly-scoped local projects (design intake and inventory software for a local food bank) to open-ended international collaborations (help an existing medical school program train midwives in Uganda to use ultrasound more effectively). Examples of projects include:

- Tailor a system that allows sharing of a single computer by multiple students to local schools
- Coordinate translation services for immigrant populations
- Diabetes screening application for a local health organization
- Device to measure the time water carrying cans move each day to determine the time cost of water gathering
- Smart phone application for converting paper forms to digital format using the camera on the phone
- Smart phone application for registering vaccinations
- Text-messaging system for encouraging pregnant mothers
- Visual modeling tool for vaccine cold chain management

Below we discuss two projects in more detail to give the reader a better sense of these student collaborations.

A. Midwives' Ultrasound

The Midwives' Ultrasound project was a collaboration with a Radiology professor who was working on a project to train midwives in Uganda to use ultrasound technology. They were having some issues with commercial portable ultrasounds (cost, difficulty of user interface, etc.), and so the problem posed to the students was: how can you make ultrasound more usable by midwives with limited training? And can you make it cheaper? In winter 2010 there were two CSE students and three HCDE students on the team. Students surveyed local area midwives, created surveys to send to Ugandan midwives, investigated other developing world based maternal ultrasound projects, conducted a literature review for maternal ultrasound, met with local radiologists and ultrasound technicians to learn about ultrasound technology, and contacted ultrasound manufacturers to find a less expensive technology that would be viable for the purposes of the project. The students took significant initiative in contacting both NGOs conducting ultrasound-related work, and ultrasound manufacturers, eventually finding an ultrasound probe on campus they could use for their project. In addition, the students applied for and won a capstone award from the College of Engineering.

In spring 2010, two more CSE students and one HCDE student were added to the team. The team obtained an ultrasound probe and sample control software, and

implemented a prototype interface designed for use by Ugandan midwives. They continued to design a help system and did user evaluations with local ultrasound technicians and radiologists. This team was characterized by a highly motivating problem, great team dynamics, an unfamiliar and remote user population, and an interesting technical challenge. There have been multiple positive outcomes moving forward from this project. Four of the original students continued their work on the project outside of the course. In March and July 2011, three of these students went to Uganda to do a preliminary evaluation of the project with midwives. Several other students and doctors joined the team, they published multiple academic papers (all with student authors, e.g. [24]), and in October 2010 was awarded a Bill and Melinda Gates Foundation Grand Challenges Exploration grant.

B. Milk Bank

The Milk Bank project was a collaboration with a non-governmental organization (NGO) working in South Africa and a faculty member and graduate student in the CSE department. In sub-Saharan Africa approximately 40% of HIV positive children are infected with HIV through their mother's breast milk. One approach to addressing the problem is to provide pasteurized breast milk from milk banks. Since pasteurization techniques used in the developed world are expensive, a low cost method of flash heating has been proposed, although the process is non-trivial to implement. The students were given the task of designing the user interface for a low cost breast milk flash-heating system that provides feedback for each step of the process and sends the temperature curve of the process to quality assurance (QA) personnel. The QA person then evaluates the curve, determining if the milk is safe for consumption by infants, and sends a response to the user.

In winter 2011 there was one CSE student and four HCDE students on the team. The students worked with the CSE graduate student and interviewed staff at the local and South African offices of the NGO to determine the background and training of potential users and details about the environment where the device would be used. The students created a survey to investigate what combinations of lights, sounds, and text would work best as feedback to users. They used hot plates, gas and electric stoves, to explore the range of temperature curves users might obtain. Finally they tested their own prototype and a higher fidelity prototype provided by the graduate student.

In spring 2011, the team consisted of two CSE and three HCDE students. Using the framework provided by the graduate student, students implemented a handheld device to provide feedback to a user heating milk. The device uses SMS to send temperature curves to a server that forwards them to quality assurance personnel. The students also created a smart phone application that allows viewing and approval/disapproval of temperature curves. Students tested the prototype and created user instructions based on a persona they created. One of the original HCDE students has continued work on the project, testing the system as it prepared for a pilot deployment in South Africa in May 2012 sponsored by the NGO. There has been a publication with five student authors from the class [25] and recently the project was awarded a Bill and Melinda Gates Foundation Grand Challenges Exploration grant.

V. LESSONS LEARNED

In this section we discuss structural aspects of the three course offerings and their impact on overall course outcomes. Across all three offerings, in addition to official end of course evaluations, we administered an end of course (and often mid-quarter) anonymous web survey (full results not presented here, some described elsewhere [4]). While not all lessons learned have been fully implemented, we have iterated on the course structure based on the constraints of a public university, especially as this course is an unfunded initiative. It has been especially informative to see what kinds of instructional changes are viable with instructor change-over and variations in scheduling. We are particularly interested in sharing these findings with the community because we believe this is a realistic attempt at curricular reform that responds to institutional limitations.

A. One-credit Reading Seminar in Autumn 2009

One problem with the three-quarter structure used in 2009-10 is that few students enrolled in the entire sequence. Of the 17 students enrolled in the autumn 2009 reading seminar, only 3 continued with the winter 2010 course. Attrition was due to a variety of factors including that we did not advertise it as a required pre-requisite for the remainder of the course sequence. Scheduling constraints also played a role. To accommodate the other 32 students enrolled in winter 2010, at the start of the winter quarter we repeated a few of the autumn readings.

With the availability of a separate multidisciplinary seminar on ICTD [23], and because of the low numbers of students continuing previously from autumn to winter, we have not offered the reading seminar since autumn 2009. Instead we start the winter quarter course with several key readings. While in our context we have found this approach to work well, other universities without as strong of an ICTD research presence would likely find the reading seminar valuable. We would also encourage other schools to consider offering this one credit reading seminar as a multidisciplinary introduction to designing technology for resource-constrained environments even without offering the full project course sequence.

B. Pairing with an HCI Course in Winter 2010 and 2011

The major difference between the 2011 and 2012 offerings of the course was that in 2012 there was no pairing with an HCI course in winter quarter. Some differences due to this change were:

- *Equal number of credits and “buy-in” for both cohorts in winter 2012.* In both of our previous winter end of course surveys we observed some complaints and confusion about the amount of work each cohort was responsible for. Some students enrolled in the 5 credit HCI course felt that if the CSE students on their team were not fully dedicated to the project it was easier for them to slack off since they were only signed up for 2 ungraded credits. Some CSE students observed that some non-CSE students on their team only cared about course deadlines and not the overall project.

- *Equal number of meetings for both cohorts in winter 2012.* In previous surveys some students expressed concern about the difference in number of meetings. Although CSE

students were welcome to attend both days of the HCI course, few did. Some CSE students felt that they were missing out on things that went on in the other meetings of the HCI course.

- *More graduate HCDE students in winter 2012.* In the 2010 and 2011 offerings, students in the HCI course were putting skills they learned in the course to use in their team projects. Without the pairing with an HCI course, in winter 2012 it was necessary to recruit more experienced HCDE students who already had those skills. This led to the majority of the HCDE students in winter 2012 being graduate students.

C. Course Deliverables

All three courses had similar deliverables for spring quarter: a final paper, a poster, and team presentations. In 2010 and 2011 the winter deliverables were similar, while in winter 2012 a briefer implementation plan was required instead of a paper. We feel these deliverables have worked well, but future offerings may collect these artifacts on a web site. When the winter course was tied to the HCI course we needed to specify which parts of the final paper the CSE students could help with. Similarly for all offerings of the spring course we have had to specify which parts of the final paper HCDE students should help with. We found that having students give presentations to audiences outside of class drives home the importance and relevance of their projects.

D. Course and Team Meetings

In both winter and spring quarters the courses were composed of a mix of entire class meetings and team meetings with instructors. Over the three course offerings we have experimented with different numbers of these meetings. In all of our course surveys, students have never expressed a desire for less individual team meeting time with the instructors. Many have cited these meetings as a crucial part of their learning, and some have expressed a desire for more meeting time. Students seem to have more mixed opinions about the number of times the class should meet as a whole. Some felt that the time could be better spent meeting with their team members, while some expressed a desire to at least see the entire class more often. We came up with somewhat of a compromise in winter 2012. Even on days the instructors met with teams individually, we first convened the entire class together for a few announcements before breaking up into teams. The instructors then moved around among the teams checking in with their progress and offering feedback. In this way, students had at least one 2-hour slot each week when they knew everyone in their team could meet together. It also allowed students to see their entire class at least briefly to provide some feeling of a unified cohort.

Scheduling team meetings so that all members can attend is difficult. This can be a challenge in any team project course, but scheduling meetings with students from multiple majors only throws more diverse course schedules into the mix. It is additionally challenging to accommodate schedules of a diverse set of students from one quarter to the next. In some quarters we were able to solicit student input on meeting times for the subsequent quarter. In other cases, we had to pick times knowing that it would not work for all students. The challenges of scheduling team meeting time outside of class and a lack of

team member continuity from quarter to quarter were both factors that detracted from true multidisciplinary collaboration and in some cases overall project success.

E. The Importance of Project Selection

Picking appropriate projects for students is probably the single most important step in course planning. Excitement about their particular project and dedication to their fellow team members were the two most common factors students cited for continuing from winter to spring. For our multidisciplinary course we have found it was important to select projects that provided challenges and rewards for both the CSE and HCDE cohorts. Selecting projects with accessible end user populations (or a reasonable surrogate) was critical for allowing the HCDE students to do fieldwork. In addition, we have found it useful to identify projects falling within a technological “sweet spot” – where the technical challenges are significant enough to be interesting yet not paralyzing.

We have found it to be incredibly motivating for students to have projects connected to organizations on the ground that are looking to pilot their solution. In their evaluations, students often mention their excitement about the opportunity to serve a real need as opposed to “doing the same project over again” as a design exercise. These interactions provide realism often lacking in courses where students devise their own projects and gives them valuable experience with “customer relations” and satisfying real needs. Finding a client or outside expert who was responsive was critical for all cohorts in terms of keeping them motivated and providing details about functionality.

F. Projects Continuing Beyond the Course

Of the nine student projects from the first two offerings of the course, six have lived on beyond the course in significant ways. Many of these have turned into long-term research projects and pilot deployments, involving students from the original course. Five have produced publications with student authors and three have received significant research funding. We have found that pairing teams with a graduate student mentor has helped students make progress during the course and has facilitated continuing the project beyond the course.

VI. CONCLUSIONS

Overall, all three offerings of the course have resulted in successful student project experiences. Our particular multidisciplinary approach is somewhat unique in combining two student populations that may be more likely to not understand the depth of each other’s skill sets, coming from disciplines that tend to attract different types of students with differing methodologies. We have found that the domain of resource-constrained environments is well suited to this kind of experimental multidisciplinary learning experience. The design challenges are complex, and the human-centered challenges are as complicated and rich as the computing-centered challenges. When we can unite both of these types of challenges with a motivating real-world problem, we can create opportunities that allow diverse teams of students to pull it all together and create great things. Students gain a multitude of skills, as well as unique preparation for the workplace where they will often

have to interact with people from varying backgrounds and with skill sets far from their own.

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Using Domain General Learning Models to Guide Engineering Education Research

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Abstract - The goal of this session is to help attendees understand the difference between domain general and domain specific theories of learning, and how to apply domain general models of learning to engineering classroom research. The participants will work with the presenter to develop new ways of thinking about their own research through the use of examples and group work.

Index Terms - AboEngineering Education Research, Learning, Modeling

DESCRIPTION OF TOPIC

The study of learning and cognitive processing generally falls into two camps: domain general vs. domain specific. The domain general approach argues for broad principles applied to any context. The domain specific approach argues for narrow principles unique to context. For example, information processing models are domain general whereas models of expertise are domain specific. However, rather than a dichotomy, researchers argue for understanding domain general and domain specific processes as complementary during learning and strategy use [1]-[3].

A domain general model of learning should be broad enough to cover a wide range of learning tasks. Hirschfield and Gelman [4] define it as a body of knowledge that organizes a set of phenomena with shared characteristics, essentially offering a simplified framework for understanding a large amount of complicated information [5]. A domain general learning model should include a streamlined set of components that can explain learning across a broad range of contexts.

The components of domain general models also provide causal mechanisms, generally grounded in information processing theory [6], for understanding learning and cognitive processing [3]. Aspects of information processing related to working memory, including knowledge activation, executive functioning, and novel problem solving are most often considered domain general and common across all learning tasks [2][5][7].

Providing engineering education researchers with background knowledge of domain general theories, and how they can be applied to specified to engineering education contexts, can help them to organize future classroom studies around casual learning mechanisms central to any learning task. This can improve the external validity of future research projects and provide insight into how to choose

variables for classroom research and specify learning models based on theory and data.

SESSION AGENDA

FullIn this session, participants will be encouraged to work along with the presenter to learn about domain general models in education research. The participants will engage in activities designed to help them meaningfully interact with the new information and examples, with the goal of applying the learning objectives of the session to their own research interests.

The session will be organized around short activities that are followed by the presentation of new information and examples. The short activities are designed to help participants activate relevant prior knowledge and experiences, and share these experiences in informal groups. Below is a brief outline of these activities and approximate times for pacing instruction.

- **Introductory Activity:** Participants will write about and discuss example learning tasks from their classrooms and research studies that may be interesting for research. Participants will share their responses. (10 min)
- **Domain General vs. Domain Specific Theories:** Instructor will present on the differences between domain general and domain specific learning theories. The instructor will present a common domain general model of learning based on information processing theory. (20 min)
- **Collaborative Activity:** Participants will attempt to fit one of the learning tasks they described in writing at the beginning of the session into a domain general model. Participants will work together in informal groups to develop a simulated research topic (15 min). This activity will be guided by a handout that will guide basic steps of the process.
- **Application and Specification of Domain General Models:** Instructor will present on how to apply common learning variables to domain general approaches to research. Instructor will present on common methods for specifying the relationships among variables chosen for the model using both theoretical and empirical approaches. (20 min)
- **Collaborative Activity:** Participants will chose pertinent variables for the model they developed in the previous activity, discuss potential measurement

instruments, and brain storm methodological techniques for researching and specifying their models. Participants will share their responses (20 min). This activity will be guided by a second handout which will require answering specific open ended questions about research methods than can be applied to the simulated research topic.

- **Example Study:** Instructor will present an example study from his own work in engineering education research that demonstrates each step of the process: choosing a model, applying the model, specifying the model. Results will be discussed with the audience at a high level to emphasize conceptual guidance.

ANTICIPATED AUDIENCE

Because of the domain general nature of the learning theory that will be discussed, and the broad range of applicability, the participants can be any conference attendee interested in classroom engineering education research.

EXPECTED OUTCOMES

The session is designed to help participants rethink classroom research in the context of domain general and domain specific cognitive processes. The session is intended to help them design learning models for engineering education contexts, and to apply and specify theses models according to their research questions and data.

This session is important to me because it is part of a larger methodological interest of mine related to how to study the interaction of domain general processes with domain specific variables. Insights into how to apply and specify domain general learning mechanisms to specific learning tasks can help researchers to understand the nature of the complex network of relationships at play during learning in engineering classrooms.

JUSTIFICATION

This session should be considered because it has broad applicability to engineering education (i.e. it is generalizable across classroom research), it is grounded in contemporary cognitive psychology central to knowledge construction, and it will provide researchers the informal opportunity to design models which explain learning in engineering classrooms.

Presumably, these benefits, along with the example provided in the presentation, will help participants learn to organize research questions around domain general learning mechanisms.

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Panel: Ethics in Engineering Case Study

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Abstract— This panel session is designed to guide faculty members as they work to create a dialogue introducing students in Engineering, Computer Science, and Technology to ethical dilemmas faced by engineers in the fast-paced, budget-constrained, competitive workplace where on time, on budget performance is required. Industry panelists will explore engineering decision-making protocols that can be utilized to help students gain real-life perspective and make better decisions under pressure. The moderator/leader will introduce a set of questions/criteria engineers can routinely employ as a means of ensuring the highest ethical standards of decision-making.

Keywords- ethics, engineering education, computing education.

I. DESCRIPTION OF THE PANEL

Panelists representing multiple perspectives of aviation design and manufacturing will give specific examples. Audiences will leave the sessions with knowledge of specific industry examples of ethical dilemmas facing engineers/business

people and new perspectives on making decisions under pressure.

The introductory presentation will cover: personal accountability, character development, culture of accountability in business, ethical pitfalls in everyday life, ethics and integrity as the foundation of the future, framework of ethical decision-making, understanding and conveying one's values, defining boundaries, personal responsibility, working through ethical dilemmas and tough decisions, following values under pressure, and core questions to guide ethical decision making. Following the introduction, panelists will give examples of dilemmas faced by engineers in industry and demonstrate patterns of decision-making that follow a prescribed set of pre-determined questions to be employed time and time again to guide ethical problem solving.

The goal of the session is to increase awareness and provide educators with a detailed, ethics-based, decision-making strategy to impart to students. Attendees will learn about a step-by-step decision-making process model and multiple examples of industry-related case studies.

Panel: Engineering and Development: Facilitating Successful Project Work in Diverse Global Contexts

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Abstract—Over the last decade, a growing number of initiatives have emerged to provide engineering students, faculty, and professionals with opportunities to work on service-oriented projects in developing contexts. And while these courses and programs provide needed resources and services to communities in far-flung locations, they also pose unique challenges and difficulties. For example, projects of this type often require knowledge, skills, and attitudes that are not typically covered in traditional engineering courses nor possessed by many faculty. Additionally, there is growing recognition regarding the need to predict and evaluate the full range of impacts that student projects have on partner communities – both positive and negative. This panel engages these kinds of challenges by bringing together a group of individuals with extensive experience preparing engineering students for project work in developing contexts. In addition to representing programs at four institutions (Colorado School of Mines, Michigan Technological University, Purdue University, and Worcester Polytechnic Institute), the presenters are involved with a host of related national and international initiatives. Each panelist will give an overview of their efforts, with particular emphasis on observed successes and failures, conceptual hurdles faced by students and professionals, pedagogical approaches employed, and most useful resources. The primary audience for this panel includes faculty, staff, and students who lead, support, and/or study global service learning. To enable a more engaging, interactive, and productive session, ample time will be provided to allow attendees to describe their own experiences, share resources, and pose questions. The primary intent of the panel is to help university students, faculty, and staff be more effective when undertaking engineering work in developing contexts, including by promoting scholarly community and collaboration, sharing resources, and seeding new research initiatives.

Keywords—community development; engineering education; global engineering; PBL; project-based learning; service learning

I. INTRODUCTION

Engineers have for centuries served as key agents of nation building. Early on, countless engineers assumed roles serving national development needs “at home,” while others fanned out to support colonial empires. During the 20th century, and

especially during and after WWII, many engineers from the West became involved in a new wave of development-oriented projects and initiatives abroad, often under the aegis of government or corporate interests [1]. Even more recently, globalization trends, the rising prominence of global “grand challenges,” and intensified calls for engineering education reform have led to an expanded array of curricular and extracurricular initiatives that provide engineering students, faculty, and professionals with opportunities to work on service-oriented projects in developing global contexts [2].

While these courses and programs often provide sorely needed resources and services to communities in far-flung locales – while at the same time building competence among participants – they can pose unique challenges and difficulties, [3]. For example, there is growing need to more systematically evaluate and predict the full range of impacts that projects have on partner communities – including positive and negative outcomes. At the forefront of this movement are organizations like Engineers Without Borders (EWB) Canada, which has published its annual *Failure Report* since 2008 and developed an accompanying web site and database [4].

This panel poses a series of provocative questions for participants and attendees. Are we brave enough to look at our programs and initiatives in the mirror? To boldly and critically evaluate their true impacts – both good and bad? To strive for continuous improvement in how we prepare students and faculty for service work abroad? As summarized below, our panelists respond with brief descriptions of their own efforts, placing particular emphasis on strategies that help enable positive outcomes for all participating stakeholders.

II. LEARNING FROM ENGINEERING AND DEVELOPMENT

A. Faculty-led Interdisciplinary Research Projects in the Developing World (Vaz)

Increasingly, engineering students are being exposed to challenges in the developing world, both through classroom activities and experiential work. When designed well, these interactions can benefit communities, while helping students

understand sustainability, grapple with appropriate technology, and reflect on their future roles as practitioners. Worcester Polytechnic Institute's approach involves faculty-led project work in Costa Rica, Namibia, South Africa, and Thailand. Since 1989, about 1,200 WPI students have completed over 300 interdisciplinary research projects in the developing world, focusing on topics such as energy sustainability, water resource management, community development, and sustainable agriculture. The overriding educational goal of these projects is for students to understand the social and cultural contexts in which technology comes to bear. WPI's experience is that these projects can benefit both local communities and students, but only if considerable attention is paid to program design and delivery. Five lessons that have emerged will be discussed and illustrated: (1) it is beneficial to develop strong, long-term relationships with local community organizations; (2) problems should be locally defined, and solutions locally endorsed; (3) students benefit from intensive preparation, including culture, history, and language, but also focusing on previous research and methods; (4) participatory methods and action research approaches often result in more lasting impacts, particularly when local partners can team with the students; and (5) capacity building and increased mutual understanding, rather than physical infrastructure or process improvement, are the most important long-term goals of student programs in the developing world.

B. Engineering Global Engagement: Strategies and Outcomes at Michigan Tech (Paterson)

A small group of visionary faculty started a grassroots effort for global community engagement at Michigan Tech beginning in 1995. Since then, nearly 20 distinct programs have been crafted, offering opportunities for students in most disciplines and levels. This presentation will focus on three of these programs, especially targeting engineering students: (1) a graduate level program, Peace Corps Master's International in Civil and Environmental Engineering, (2) an international senior design program, *idesign*, and (3) a graduate level course, *Discover Design Delight*. Objectives, design, activities, resources, and outcomes of each program will be summarized. Despite their unique features, recent efforts have focused on providing program integration through the creation of the D80 Center for Global Good. Among other developments, a baseline assessment program and an annual conference are key assets to this campus culture; both will be shared in brief.

C. Bridging Sustainable Community Development and Social Justice (Lucena)

This presentation briefly traces the history of engineers' involvement in international development to community development, and highlights when and how "sustainability" and "humanitarianism" became important dimensions of engineering work and education. Yet throughout this trajectory, a number of engineering mindsets have come to shape how engineers engage communities and contributed to making social justice invisible to most engineers, especially their ability to contribute to a fair distribution of rights, opportunities, and resources when working in community development and humanitarian endeavors. This presentation outlines these mindsets, and proposes a number of possibilities to overcome them so engineers can meaningfully and

effectively address social justice within their practices and projects in community development.

D. Integration of Global and Local Service-Learning Design Experiences (Oakes and Huff)

Engineering Projects in Community Service (EPICS), a vertically-integrated, engineering-centered service-learning design program, currently distributes over 350 students per semester from over 70 majors across 30 divisions with more than 80 active community-based design projects. Since its inception in 1995, the program has collaborated with local community partners. In recent years it has also expanded to include international partnerships with service organizations working in Haiti, Columbia, and Ghana. The majority of partnerships intentionally remain local, but the international partnerships have added an exciting dimension to the program. Some of these global partnerships began as new partnerships while others have grown out of local partnerships. The methods of interacting with community partners have evolved to better accommodate collaboration with trans-national communities. Some student have been able to travel to some of the partners with others having only remote access. In this presentation, we discuss the strengths and limitations of this approach and discuss EPICS as a model for immersive service-learning experiences that span local and global engineering designs. We also discuss how students develop cross-cultural competency and how partnerships are intentionally framed to ethically and appropriately benefit students and communities.

E. Building Global Design Teams (Dare and Jesiek)

Purdue University's Global Engineering Program (GEP) launched the Global Design Team (GDT) service-learning program in 2008. GDTs are designed to provide high-impact, multi-disciplinary, collaborative experiences that allow students to participate in real-world, full-cycle design projects, while raising global awareness amongst team members, faculty, and partners. The program strives for positive, sustainable interactions with partner communities through application of technical, global, and professional competencies to identify and address specific local needs. The goal is mutual benefits for all stakeholders, including through exchanges of knowledge and solutions that positively impact enrolled students, collaborating communities, NGOs, and partner universities. In this presentation we review the GDT curricular model, assessment results of design experiences since 2009, and content and outcomes from our inaugural Global Engineering Design Symposium (GEDS) held in early 2012.

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A Sophomore Capstone Solid Modeling Experience: Virtual Dissection and Reassembly of Legacy Drawings

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Abstract—A sophomore computer aided design course is investigated with respect to its ability to prepare students for an authentic team-based design experience surrounding solid modeling of a set of legacy drawings by a master draftsman from an earlier age. Work products include an electronic archive stored on a shared drive, part and subassembly renderings, a shop-ready drawing package, accurate animation of part assembly as well as normal operation, and reflective writing about the project. Preparation for the final project includes just-in-time use of locally authored videos supplied via the course website, deployment of peer mentors within the computer lab, and scaffolding provided by four different mini-projects. Intermediate milestones given on the course website, impromptu instructor/team/mentor meetings next to computer monitors as well as an overhead projector screen, and exemplary portfolios of student work are considered essential for guiding team-based work on the final project. Significant personal growth in engineering graphics skills leading up to the final project and throughout the final project has been observed in an end-of-course surveys that explore many attributes of pre-cad sketching, part modeling, assembly modeling, and creation of engineering drawing packages. Some refinements to the survey are needed to capture more of the wisdom embedded in many legacy drawings and the wisdom typically gained through the final project.

Keywords—solid modeling, virtual dissection, legacy drawings, drawing package formulation, rendering, animation

I. INTRODUCTION

A recent article in the Chronicle of Higher Education listed three practices to improve retention: 1) improve student's spatial-visualization, 2) use everyday examples to engage the students, and 3) improve faculty student interactions [1]. Educational researchers and professional task forces underscore the importance of these same steps in learning engineering [2,3,4,5]. Many engineering programs assume linear dependence between these three steps and tackle them sequentially over several years of study. Engineering graphics is part of the pre-engineering experience where students often learn model building and simple design analysis techniques through a tutorial-driven approach [6,7]. Theory in mid-program engineering science courses is connected generic examples that are anchored in disciplinary examples as part of junior-level courses within the major. Spatial visualization and engagement between students and faculty is often most intense surrounding senior design projects and electives at the end of the program [3,5]. This approach puts a large burden on

students to connect and internalize experiences in separate environments at different times in their academic career. Energetic and creative faculty often try to shoulder some of this burden by infusing compelling examples in introductory math, science, and engineering courses that involves some attention to spatial visualization. However, without an active learning design that promotes knowledge construction, socialization, and self-assessment, this approach is not guaranteed to yield significantly better results [8]. A more robust relationship between the three practices would be simultaneous immersion in which students and faculty alike take the plunge together in tackling spatial design problems in an engineering context that is new to both parties. All would face unknowns that require personal and collective inquiry as well as humility to overcome. This article describes how the University of Idaho uses the virtual dissection of legacy drawings of a rediscovered historical engine each semester to engage students, staff, and faculty in a meaningful learning experience at the end of an introductory solid modeling course.

II. COURSE DESIGN

Our introductory CAD course introduces sophomores to concepts and tools for producing solid models and engineering drawing packages that can be efficiently manufactured in an engineering shop. The knowledge, skills, and perspectives that students develop are intended to enhance upper-level design experiences and to be highly marketable in the engineering workplace, including summer internships. The first two-thirds of the course entails structured and interactive lab exercises surrounding a number of physical prototypes that have been previously produced in the University of Idaho mechanical engineering shop. Undergraduate mentors are used to assist faculty in coaching daily exercises at the keyboard. Prior to class, students view 4-6 minute videos created by previous undergraduate mentors on specialized topics in CAD sketching, part modeling, assembly modeling, and generative drawing. Each day, these are reinforced with short quizzes and large group show & tell sessions before the start of individualized lab exercises. Four different mini-projects are used to synthesize sketching skills, part modeling skills, engineering drawing skills, and assembly modeling skills. The final one-third of the course engages teams of 5-8 in a large-scale, team-based reverse engineering project involving legacy drawings that are 50 to 100 years old. Teams create extensive, shop-ready drawing packages along with renderings and animations of

their completed assembly. Examples of course materials and finished products from past projects can be seen on the course website [9].

The course supports the following learning outcomes that are typical of many first courses in engineering graphics with solid modeling [6,7].

- Describe drawing intent based on details shown in an existing engineering drawing and interpretations based on drawing standards/conventions.
- Use hand sketching to communicate design intent and reference geometry that is a value-added starting point for a CAD model.
- Accurately model parts using fully defined sketch entities, reference geometry, extrusions, lofts, sweeps, revolved features, and patterns.
- Accurately combine parts into assemblies that are constrained to display correct kinematic behavior.
- Make comprehensive part and assembly drawings that follow standard practices for dimensions, through holes, threaded connections, radii, and bill of materials. These drawings should provide all information necessary to manufacture and assemble the components.
- Identify key tolerances associated with part assembly and explain how to inspect parts to determine the degree to which parts match their corresponding drawings.
- Create and thoughtfully maintain an electronic drawing package with assembly, sub-assembly, and part drawings following a departmental template.
- Explode, animate, and render assemblies to illustrate part assembly as well as normal operation.

The course also supports the following design synthesis and professional growth outcomes desired by industry [4]. These build on the traditional outcomes listed above and ensure readiness for upper division design and manufacturing work.

- Document solid modeling work and resulting design products in a manner that others can use to identify underlying assumptions and replicate design intent, including the ability to edit specific features of the model.
- Make meaningful self-, peer-, and instructor-recognized contributions to an engineering design team tasked with creating a shop ready drawing package from a set of hand drawn prints for a mechanical system from a former technological age.

Quizzes, mini-projects, and the final project each account for approximately 1/3 of the course grade. Items that are scored are done so on the four point scale shown in Table 1. Work that meets performance expectations outlined in various

assignment check sheets is awarded a 3.0. Instructors often keep copies of work that is awarded a 4.0 as exemplars for future students. Students must earn an average of at least 3.2 to receive an ‘A’ in the course. The cutoff for a ‘B’ is 2.7 and the cutoff for a ‘C’ is 2.2. This system inspires students to invest time striving for excellence rather than just meeting the grade.

Table 1. Scoring scale used in course assignments.

| Score | Attributes |
|-------|--|
| 4 | Exemplary, insightful, worthy of sharing with entire class |
| 3 | Complete, correct, long-term reference value to self |
| 2 | Largely complete, numerous errors, limited reference value to self |
| 1 | Incomplete, major errors, no supporting documentation |
| 0 | Submitted late, missing major components |

III. ROLE OF MINI-PROJECTS

Four individualized mini-projects help students cultivate engineering graphics skills associated with the competency outcomes. Each of these mini-projects is scored separately in three different dimensions: (1) pre-CAD planning, (2) documentation of the modeling process, including lessons learned, and (3) finished products. Four to five key attributes unique to each mini-project and mapped to each of the three dimensions are given in a check sheet that students use to guide their work and self-assess their submissions. The first mini-project challenges students to sketch their initials with Solidworks using minimum dimensions and maximum relations. They are encouraged to implement ‘powerful’ sketches that are fully defined. Next they are challenged to investigate new and personally interesting feature tools, making their initials ‘cool and 3D’. An assortment of font styles, basic shapes, creative orientations, and surface textures result. The effectiveness of this assignment in capturing student’s imagination while underscoring proper sketch definition can be seen in the example of student work shown in Figure 1.

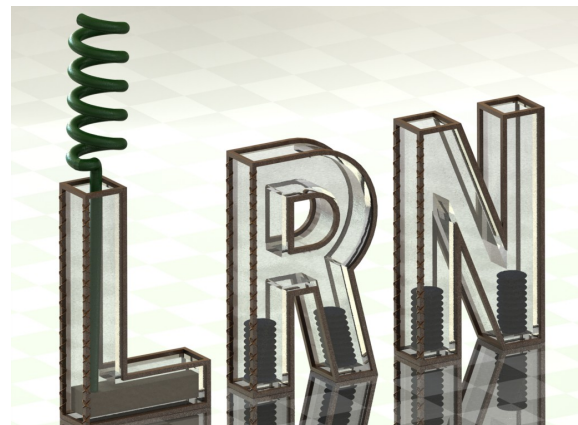


Figure 1. Exemplary submission associated with initials mini-project.

The second mini-project asks students to recreate a complex, patterned object created in our machine shop from a fully-dimensioned, fully-annotated engineering drawing. This requires students to combine and properly sequence many of the CAD tools they learned in various tutorials within a single object. Parts and accompanying drawings associated with previous capstone design projects have been a popular focus of this mini-project.

The third mini-project asks students to generate a solid model and shop ready part drawing from a parameterized part with complex geometry, usually derived from one of several mechanical drawing books published over a half century ago. Unique parts are selected each semester and these come from a rich array of valves, brackets, bearing mounts, and frames. Thoughtful origin selection, calculation of dimensions, use of reference geometry, and implementation of primary versus secondary features is necessary for a tractable model and sensible engineering drawing that uses the University of Idaho sheet format. One of the aims of this mini-project is to familiarize students with the look and feel of drawings from a past era. Extensive use of design tree annotations along with a design journal that describes part realization is expected with the finished product. Figure 2 illustrates a legacy drawing used for a recent part mini-project along with an exemplary render of the resulting part model.

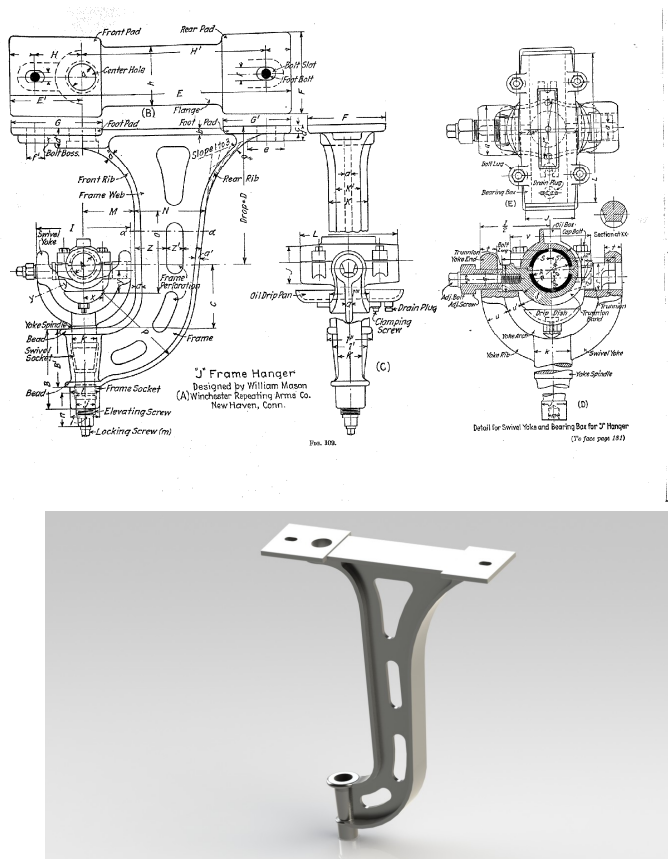


Figure 2. Legacy drawing of hanger for pre-electrification power take-off shaft (above) and example of rendered part submission (below).

The fourth mini-project presents students with a set of ready-made parts for a simple assembly. They are expected to organize these into sub-assemblies, assign part numbers and part property data, and combine the sub-assemblies into a working main assembly which is both rendered and animated. Sub-assembly level and assembly level drawings should use the University of Idaho drawing template that applies a standard sheet format for the title block and that is populated with part property data. Figure 3 illustrates typical work products from this mini-project.

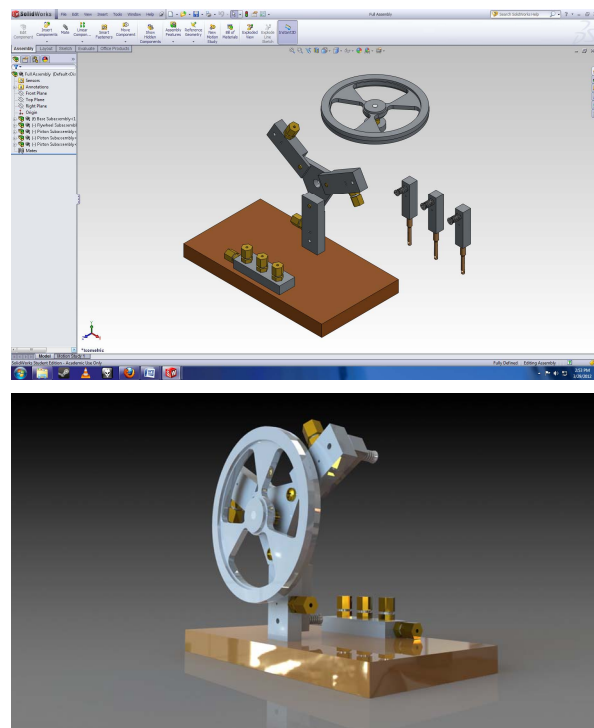


Figure 3. Air motor sub-assemblies before positioning and mating (above) and rendering image after assembly (below).

IV. FINAL PROJECT

The final project begins with a set of drawings taken from a similar source to that used in the third mini-project, avoiding copyright issues. Final projects and the problems that they raise are authentic to all involved—students, mentors, faculty, and machine shop staff. Projects are intentionally not repeated but are shared liberally to communicate and elevate project expectations. The project is team-based (5-10 person teams selected by the instructors, depending on the complexity of the design) and the goal is to recreate an accurate 3-D solid model of all the components, sub-assemblies, and assemblies. Deliverables include an electronic file management system on a shared drive at the University of Idaho, a complete set of engineering drawings that could be fabricated in our machine shop, animations showing assembly steps and operating principles of the engines, and reflections on lessons learned about the design, about the CAD tool, and about engineering teamwork.

Teams decide who is assigned to each component, part numbering protocols, and sub-assembly content. A team recorder is identified who keeps track of project completion using a spreadsheet template perfected by a former team. Complex prints are often enlarged to full size to facilitate visualization and validation of assumptions surrounding part placement and dimensions. Often there is some background information available on the internet, but this invariably is for similar but not identical machines that are defined by the legacy drawings. Figure 4 shows students interpreting a full-sized drawing for a 3 ½ x 5 vertical steam engine [10]. This is a vertical steam engine which has a characteristic ‘bottle’ shape typical of small single cylinder engines at the turn of the 20th Century, a Stephenson valve train, and a reversing linkage.



Figure 4. Students deciphering features and dimensions shown in fullsize assembly drawing for a 3 ½ x 5 Marine Engine.

Project outcomes include student, faculty, and staff respect for craftsmanship from another era, insights about intriguing mechanisms that have a place in the history of technology, and error discovery/correction opportunities not possible with modern 3D design materials. We have also found that these projects create a class wide identity tied with a particular semester project and heightened awareness of pre-course and post-course engineering graphics skills as well as software tool limitations. Figures 5 and 6 show fully-functional sub-assembly and assembly models associated with the Marine Engine.



Figure 5. Rendered Marine Engine Crankshaft.



Figure 6. Rendered Marine Engine Full Assembly.

Project portfolios are a source of pride amongst nearly all design teams. We select some of the best ones each term as a tool for orienting future students about our engineering graphics course and expectations associated with the final project. The portfolios include attractive renders and complete shop-ready drawing packages that have removed some apparent errors in the original legacy drawing. All involved in the project are surprised how few errors students actually find.

V. EDUCATIONAL IMPACT

A. Feedback from Students

Prior to the start of the final project, and again at the end of the final project, students are surveyed about their perceived efficacy in traditional engineering graphics skills [6]. These skills are divided into four areas (a) pre-CAD sketching, (b) part modeling, (c) assembly modeling, and (d) engineering drawing. In the first survey, students provide data on where they believe they were at the start of the semester as well as at the start of the final project. In the second survey, students update data on where they believe they were at the start of the final project as well as where they believe they are at the end of this project. The five point scoring scale below was used to query past and current states of development.

- 0 = not familiar with this skill
- 1 = awareness of what this skill means
- 2 = could perform this skill with coaching
- 3 = could perform this skill using the help system
- 4 = could perform this skill without other resources
- 5 = could effectively and efficiently teach this skill to others

At each stage of development, averages and standard deviations for each skill are computed across the class. Figures 7-10 present longitudinal findings for forty students

pre-CAD sketching attribute

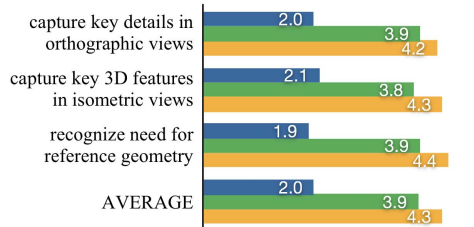


Figure 7. Student self-assessment of pre-CAD sketching efficacy

part modeling attribute

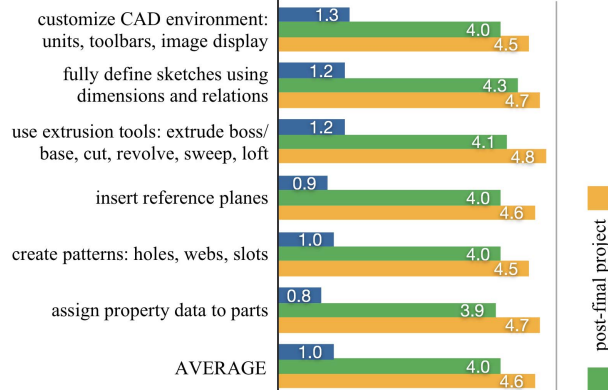


Figure 8. Student self-assessment of part modeling efficacy

assembly modeling attribute

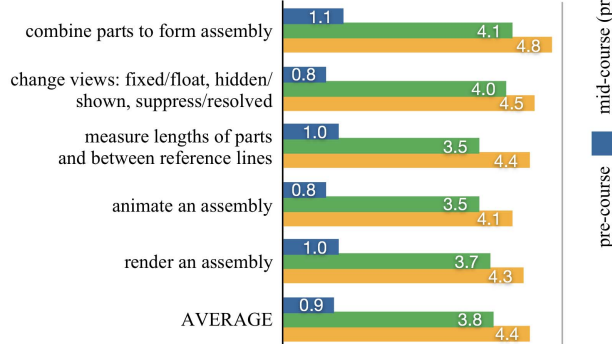


Figure 9. Student self-assessment of assembly modeling efficacy

engineering drawing attribute

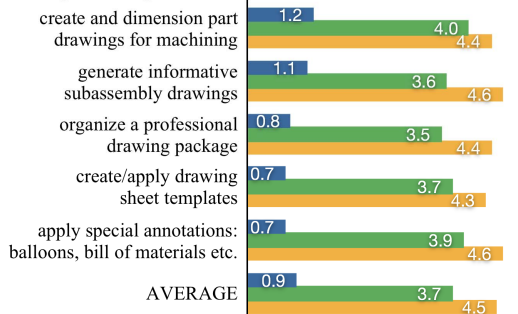


Figure 10. Student self-assessment of engineering drawing efficacy

enrolled in two different sections of the Spring 2012 course. The blue bars indicate perceived skill levels upon course entry. The green bars indicate perceived skill levels after the air motor mini-project but prior to the final project. The orange bars indicate perceived skill levels during the last week of the final project.

Figures 7-10 show the same general trend and improvement for all engineering graphics skills from the beginning of the course, through the mini-projects, and concluding with the final project. Students self-assessed that their familiarity with hand sketching generally exceeds their familiarity with solid modeling. There is wide variation in pre-course scores because this is the first engineering graphics course in our program. At this point, standard deviations in specific skills are as high as 1.5. By the start of the final project, the typical students report growth in perceived ability by nearly two levels. Class wide standard deviation in reported scores is now roughly half that reported for the beginning of the course. Additional growth in engineering graphics skills by one-half to one full level typically occurs throughout the final project.

Design teams write 2-4 pages of lessons learned through the final project. Overall, these comments demonstrate a level of maturity that would be appreciated by employers who hire mid-program students as interns. The wisdom contained in many of these exceeds the skill set queried by the engineering graphics survey. For many teams, the importance of pre-CAD sketching was expanded to include pre-CAD planning that accounted for features on adjacent parts as well as pre-thinking about the organization/naming of files and folders. In the area of part modeling, some teams shared best practices such as documenting assumptions in the comment fields associated with the part properties menu, labeling elements in the design tree to facilitate part debugging, and outlining how to obtain high quality renders. In the area of assembly modeling, thoughtful part numbering schemes, intra-team communication protocols, and spreadsheet designs for tracking project progress were frequently cited. In the area of engineering drawings there was heightened awareness about the use of drawing templates, error elimination through use of part property fields in the sheet format, and recommendations for improving drawing readability.

All design teams were aware of opportunities for additional growth in engineering graphics skills in future design projects. This is evident in representative comments such as:

We should have anticipated some of the adverse consequences of changing names of our directories after assembly began.

It was difficult to dimension sweeps and lofts and we wish we had avoided these more.

It would have been more efficient and effective if we had a clearer story line mapped out before we started our animation.

We assigned someone to lead each sub-assembly, but we underestimated the level of team communication required to make a fully-functioning main assembly.

Some of our drawings would have been improved by using additional sheets to capture multiple layers of detail.

B. Feedback from Instructional Staff

Based on input from the faculty, technical staff, and graduate student mentors who work with capstone design students on drawing package realization, class-wide performance in each of the skills areas queried in the engineering graphics survey should be at a post-course proficiency level of 3-4. This means that students have sufficient CAD efficacy to teach themselves what they have forgotten or don't know about part modeling, assembly modeling, and engineering drawing creation. At the end of each semester, a focus group consisting of CAD course instructors, undergraduate mentors, and senior design staff reviews the entire set of design portfolios that are created. It is their conclusion that actual student proficiency in the areas explored in the student survey exceeds the targeted proficiency.

When faculty started using legacy drawings, they provided novel mechanisms, components and assemblies that both students and faculty had not encountered before. In the end, students, machine shop staff, and faculty had to have a rich conversation that included hand gestures and simple sketches. To be successful, both students and faculty needed to have deep engagement in the project, adding to its value as an authentic engineering learning experience.

As we went deeper into these legacy drawings and the sources they came from, a tremendous respect for former engineers and their era developed. We also found that instructors in the past had pedagogical concerns similar to own. For example, design faculty today worry about students mindlessly clicking through the steps of excellent tutorials that come with the software. Faculty know first-hand how well-written tutorials leave users with the impression that they know the software as well as how to use it in subsequent design work. Faculty also know how easy it is for this impression to unravel in detailed design work surrounding original designs in subsequent projects. A hundred years ago, students learning the trade would make tracings of previous drawings. The following quote from Henry Spooner sums up the worries of that time (1908), *but only very exceptional workers could survive a long course of tracing, for it tends to blunt the perceptions and stifle the powers which are required to make good draftsmen and clever designers. Indeed, tracing has been defined as 'a diabolical invention for destroying draftsmen during their process of incubation [11].*

It is also human nature to worry about what we might not be doing that was part of routine practice in a bygone era. This is also found in the writings of Henry Spooner, *for in ordinary practice mechanical draftsmen are no longer called upon to*

produce drawings with delicate, beautifully joined lines, soft and rich shadows true to geometry, when describing a drawing created in the 1860's [11]. The economy imposed by the cost of vellum and the drawing effort to required maintain these has given way to the ease with which engineering drawings can be electronically propagated from part and assembly models. However, there is no reason that the finished products can't be as insightful and aesthetically pleasing. Outstanding designs still require a special eye and no less critical thinking than the original author. Between semesters, faculty and student mentors invest time updating quick references and video resources to better capture how drafting know-how of old is best translated into solid modeling practice with modern CAD software.

VI. CONCLUSION

Almost all of us have a fond memory of that one class period or that one project where there was special learning happening. It was challenging, engaging and time seemed to stand still. Mihaly Csikszentmihaly wrote about this phenomenon in his book about flow experiences [12]. Once you have had such an experience, you want to experience it again. For the past four years, the virtual dissection and electronic re-assembly of legacy drawings has predictably recreated one of these learning experiences. This is as true for faculty and staff involved in the project as it is for students. In the future, we plan to elaborate on some of the skill descriptions in the current engineering graphics survey in a way that captures more of the special wisdom gained through the use of legacy drawings in the final project.

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Physical Modeling in Design Projects: Development and Testing of a New Design Method

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Abstract— Physical models are widely used as idea generation tools by industrial designers, engineers, engineering educators and government agencies. Many schools promote the use of physical models in their engineering curricula. Despite the apparent popularity of physical models, little is known about their cognitive impacts and when they should be implemented in the design process. A few studies have explored physical models and their use as idea generation tools; however the guidelines from them are conflicting. Based upon these conflicting guidelines, a series of controlled and qualitative studies are conducted by the authors to understand the cognitive impacts of physical models in engineering idea generation. In addition to the insights from these studies, data are collected from a project-based graduate design course. The reports from design teams prototyping their ideas as a part of a class project are studied. These reports provide insights about the conceptual errors that student designers make as they build and test physical models of their designs. To reduce the two most critical errors, a design method (Model Error Reduction Method) is formulated. This design method forces the designers to think about two potential conceptual errors in their designs and provides guidance to rectify the issues. The two conceptual errors that the method addresses are: failure to account for critical loads and failure to design connections. This paper presents a controlled experiment evaluating the effectiveness of the method. The preliminary results show that novice designers find the design method extremely useful; moreover, the method seems to help eliminate, to a large extent, said conceptual errors. These findings suggest that the method might augment existing engineering design curricula.

Keywords— *Physical Models; Design Method; Prototyping Guidelines; Design Cognition*

I. INTRODUCTION

Physical modeling plays an essential part in the design curricula of the world's top engineering schools [1]. Using Lidwell's, et al.'s definition, this paper defines a physical model as a prototype of any scale created as a part of the design task [2]. Physical models vary greatly in their complexity level, from very simple mock-ups to fully functional models [3]. They help designers identify flaws in their designs before the production stage of a project [4]. Consequently, physical models help reduce the risk associated with innovation [5]. Since physical models reduce risk, industry tends to encourage their use [4, 6].

Though existing literature fails to provide clear guidelines regarding physical model creation, many design teams, including student design teams, build physical models during their projects [7-9]. By building prototypes, designers aim to communicate their design to third parties, prove the feasibility of their design (proof-of-concept models) and estimate dimensions otherwise indeterminable. Still, recent research demonstrates that, if designers spend more time, money or effort building a physical model of an idea, they fixate to that idea [10]. Fixation can negatively influence the functionality of the overall system if the fixated idea happens to possess undesirable attributes [11, 12]. In the end, the disparate prototyping effects necessitate the formulation of clear guidelines and methods to increase the efficiency of the physical modeling process.

The study presented in this paper applies content analysis [13] to design reports from graduate design teams to identify conceptual errors in physical modeling. Based upon the results from this analysis, the authors develop a set of guidelines to make physical modeling more effective. Additionally, the formulation and testing of a Model Error Reduction Method solving two critical prototyping issues occurs. Subsequent sections include results from the testing of the method along with details regarding the development of both the design method and the guidelines.

II. BACKGROUND

A little empirical work exists about the role physical models in engineering design. The following subsections summarize the few important works in the literature and the authors' prior studies leading to the present work.

A. Physical Models in Engineering Design

Many researchers advocate using physical models as a part of design projects. Kelley, of the famous product design firm IDEO, describes physical modeling as the short hand of innovation [6]. Building physical models at early design stages can help designers visualize and solve problems in complex systems [14]. A verbal protocol study shows that physical models help students tackle ambiguities while solving ill-structured problems [15]. Physical models help students comprehend the difference between the behavior of actual and ideal systems. Building physical models early in the design process stimulates concrete discussion between designers, improving the quality of the final product [16]. Prototypes help designers detect and fix flaws in their designs before significant

effort is put into production [8, 17, 18]. Models also facilitate the communication of ideas across various disciplines [19].

Some researchers warn about the use of physical models in engineering design. Baxter [20] cautions about the resources involved in building a physical model. In order to optimize resource utilization, Burr and Andreasen [21] suggest building of physical models with optimum numbers of features. Kiriya and Yamamoto's observational study shows that building physical models lead graduate design teams to fixate [8]. Fixation involves blindly adhering to presented examples or initial ideas [11]. Similarly, the observational study by Christensen and Schunn [7] finds that physical models suppress distant domain analogies in professional engineers. Still, a study by Youmans [22] fails to detect fixation effects from the use of a physical model.

B. Insights from prior Studies on Physical Models

In light of the conflicting recommendations described previously, the authors conducted a series of controlled and qualitative studies to explore the role of physical models in design [10, 17, 23, 24]. These studies investigate the cognitive effects of building physical models during engineering idea generation. The results from these studies show that physical models help designers identify the flaws in their own internal representations, leading them to higher quality ideas [10, 17]. Physical models also help designers identify the drawbacks of certain undesirable example features present in their ideas, providing avenues to learn through their own mistakes [25]. In the end, physical modeling needs to be promoted as an essential part of engineering design process.

These studies also show that design fixation is not an inherent aspect of physical modeling; instead, it results from the Sunk Cost Effect [10]. The Sunk Cost Effect refers to a person's tendency to adhere to a selected course of action after investing significantly in that path [26, 27]. According to the Sunk Cost Effect, if a particular physical model costs significantly more to construct (where cost can be money, time or effort), designers might hesitate to consider alternate design solutions. Therefore, when building a physical model, one must reduce the associated cost. This reduction mitigates potential design fixation and maximizes the positive uses of the physical model.

Building upon the prior studies, the current work explores the conceptual errors by graduate design teams in building physical models as part of their coursework. Out of these errors, the authors formulate a set of guidelines. Furthermore, to solve two of the most critical issues, the authors test and create a novel design method. The guidelines and the method attempt to reduce the cost associated with the building process, potentially improving the benefits of utilizing physical models.

III. UNDERSTANDING CONCEPTUAL ERRORS IN BUILDING PHYSICAL MODELS

In order to understand the conceptual errors by designers during physical modeling, the data collected from graduate design teams were qualitatively analyzed. Next, content analysis technique was used to categorize the various errors. Based upon the identified categories, guidelines were formulated to facilitate the mitigation of these errors. Since a

majority of the errors led designers to an increased building time, it was essential to eliminate these conceptual errors to maximize the benefits of future physical modeling.

A. Design Teams and Data

The data were collected during two different semesters of a graduate design course taught by one of the authors. In this one semester course, the students completed a team project by applying engineering design theory based on Otto and Wood [3]. In this course, the teams went from gathering customer needs to proof of concept models with more focus on idea generation. The teams typically consisted of 3 or 4 students, but one student chose to work alone. Project topics ranged from industry-sponsored issues to projects solving design problems from developing countries. By the end of the course, each group had built a working proof-of-concept model and had presented it to the instructor. They were allowed to create either physical or virtual proof-of-concept models. There were five teams in the first semester and seven teams in the second semester. Two teams from each semester utilized only virtual models as proof-of-concepts; hence, their data were not included in the analysis.

To collect the data from the design teams, the authors utilized each team's final report and two specialized templates designed to study the cognitive impacts of physical modeling on graduate design teams [24]. The templates captured changes made to the ideas during the physical modeling stage of the project. Additionally, the template asked the teams to report the motivation for the change. Considering the data, the authors observed that design teams identified many difficulties with their ideas during construction; moreover, as reported in the templates, these problems led to changes in the original design. Consequently, one might conclude that the templates provided rich and relevant information regarding the difficulties faced by designers during physical modeling. More details concerning the templates and the primary results obtained from them are available in [24].

B. Procedure

A content analysis [13] was performed on the data obtained from the reports and the templates. During content analysis, the authors concatenated the textual information relevant to physical models or physical modeling. Next, the texts were divided into stand-alone sentences that convey a concept. Based upon the judgment of one of the authors, these sentences were sorted into groups. One of the groups contained information pertaining to the conceptual errors committed by the teams during the physical model construction process (For more information about the other categories from content analysis, refer [28]). In the next step, the textual information from this group was further categorized to identify similar conceptual errors. Following categorization, the categories were reanalyzed and combined to eliminate dependencies and increase categorical differences. The final set of categories represented the conceptual errors by the designers during the building of their physical models. The major errors identified are given below:

- Failure to consider one or more critical load, leading to the failure of the part/parts of the system

- Failure to design junctions of two or more parts (connections) leading to the failure of the assembly
- Improper planning of available time or budget, leading to inefficient utilization of resources
- Hesitancy to significantly modify parts after failure (Fixation to existing parts)
- Use of a complicated measurement system when a simpler one is available
- Building new parts when standardized parts are available for purchase at a lower cost
- Building physical models that provide no novel details
- Failing to properly scale loads when the parts are scaled
- Selection of materials (especially to reduce material cost) that require costly machining which leads to a higher overall cost

C. Formulation of Guidelines for Physical Modeling

Based upon the conceptual errors discussed in the previous section and various observations concerning the effective practices utilized by the design teams, the authors formulated a set of guidelines. TABLE I. lists the guidelines. These guidelines aimed to reduce the observed conceptual errors and decrease the total cost associated with the building process.

TABLE I. GUIDELINES FOR BUILDING PHYSICAL MODELS FORMULATED FROM THE ANALYSIS

| | |
|----|--|
| 1 | Support building with analytical calculations - use basic strength equations for calculations |
| 2 | Design the connections (interfaces of parts) before commencing construction |
| 3 | Plan the building process – in terms of time and budget |
| 4 | Combine superior features from multiple solutions |
| 5 | While scaling the model, scale loads accordingly |
| 6 | Be aware of unexpected phenomena during building |
| 7 | Wherever possible, use commonly available parts |
| 8 | Wherever possible, avoid complicated machining |
| 9 | Wherever possible, select materials that can be easily machined, |
| 10 | If standardized parts are available, use them instead of building new ones |
| 11 | When using parts of standardized length (e.g. Legos), make sure that other dimensions change accordingly |
| 12 | Use visual measurements if complicated measurement techniques are not necessary |

IV. DEVELOPMENT AND TESTING OF THE MODEL ERROR REDUCTION METHOD

From the list of conceptual errors mentioned in the previous section, the two critical ones are: failure to include critical forces in design and failure to design connections of parts. If present in the design, these two conceptual errors can lead to the failure of part(s) in the system or the failure of the entire design. Since the rectification of these two conceptual errors might involve redesigning the system, these issues typically involve comparatively higher costs (in terms of money, time and effort).

To develop a design method which rectifies the two most critical issues, the authors assume that, if designers are forced to think about each force and connection in their design, the quantity of complete designs will increase. Consequently, the method involves two templates as shown in Figure 1. and Figure 2. These templates are to be filled out by the designers once the design is complete but before the beginning of the building process. Template 1 forces designers to draw complete free body diagrams of each part and list the forces drawn on the free body diagrams in a table. Also, designers note down whether they considered the forces in their designs before using the template. Template 2 attempts to encourage the design of the connections involved in the system. It asks the participants to draw the free body diagram of each connection, marking the

forces on the parts. Later, participants are asked to note down the forces in the table below. Following this, participants are asked whether they considered the contact forces in their design before using the template. Both templates instruct designers to go back and incorporate any missing forces in their design.

The following subsections detail the controlled experiment and involve a discussion of the results.

A. Experiment Method

The controlled experiment testing the effectiveness of the Model Error Reduction Method templates follows a within-subject design. In the experiment, novice designers design a familiar mechanical system without the help of the templates. Later, they are instructed to fill out the templates and make the necessary changes in their designs. The scope of the changes made to the designs as participants complete the templates is studied to infer the effectiveness of the method. A more detailed description of the experiment follows.

Participants

The participants in this experiment were senior undergraduate students in the Mechanical Engineering Department of Texas A&M University. They were recruited through class announcements. Twelve students volunteered for the experiment. Three of them were female. The participants

were screened before the experiment to ensure that they had completed their courses on mechanical design of machine elements. This ascertained that each participant possessed the same level of expertise in mechanical design. None of the participants possessed more than 6 months of industrial experience. For participating, each person received either monetary compensation or extra credit in one of their classes.

Part name/number:
Free body diagram: (You may annotate your forces and use these annotations in the table below)

List the forces that you drew on the free body diagram in the following table:

| Force acting on the part | Type of force (tension, compression, bending, shear etc.) | I considered this force in my original design (Y/N) |
|--------------------------|---|---|
| | | |
| | | |

Figure 1. Template 1 of the Model Error Reduction Method (motivates designers to think about missing forces)

In order to ensure the effectiveness of these templates, a controlled experiment is designed and conducted. The controlled experiment tests the following hypothesis:

The use of the two templates motivates designers to rethink about their design calculations, helping them identify forces missing from said calculations.

Part name/number:
Part name/number:
Free body diagram: (of the two parts showing the forces between them - You may annotate your forces and use these annotations in the table below)

List the forces that you drew on the free body diagram in the following table:

| Force acting on interface | Type of force (tension, compression, bending, shear etc.) | Part on which the force acts | I considered this force in my original design (Y/N) |
|---------------------------|---|------------------------------|---|
| | | | |
| | | | |

Figure 2. Template 2 of the Model Error Reduction Method (for missing connection designs)

Design Problem

Each participant was asked to develop a detailed mechanical design for a bicycle. They were given a concept

sketch for a bicycle design (Figure 3.). The problem instructed them to develop a detailed design for the system as a whole and the components involved. Participants were allowed to make any necessary assumptions. No specific constraints were provided to them, but they were asked to list the steps they followed with the help of diagrams and descriptions. They were also instructed to state their assumptions and list the equations they utilized. They were told not to consider the seat, spokes and wheels in their design. They were also instructed to treat each member of the frame as a separate part. Since the final numerical values were not of interest in this experiment (the interest was on the design procedure), estimates of the dimensions of each part were available to the participants.

The bicycle design problem was selected for this experiment due to its sufficient complexity and the likelihood of participant experience with the device itself. If the design problem was too simple or contained too few parts, measuring the effect of the templates would be difficult. The bicycle problem was difficult to finish within the allotted time of the experiment, but participants were asked to only fill the templates out for the parts finished. Such a tactic avoided any bias due to an incomplete design.

Experiment Materials

The experiment involved three different activities, and in each activity the participants received a different set of materials. In the first activity, the participants were provided with the problem statement, instructions and a few blank sheets of paper. The participants were allowed to use as many sheets as they desired and were instructed to number the sheets in the order of their use. In this activity, the participants also received a copy of “Shigley’s Mechanical Engineering Design” textbook [29] and a calculator. In the second activity, the participants received copies of Template 1 and a different color pen to write with. The different color pen enabled easy tracking of any changes they made to their original design from the first activity. In the last activity, they were provided with copies of Template 2 and a pen with a third color. The problem statement and the original design were available to the participants throughout the experiment, and they were encouraged to make changes to the original design.

Procedure

As the participants entered the experiment room, they were guided to their seats. Up to two participants underwent the experiment at the same time, but their seats were separated by curtains. As the experiment began, participants received the design problem and the instructions. They were given 90 minutes to work on the design. Since completely designing the bicycle in 90 minutes was nearly impossible, they were instructed to complete as much of the design as possible in the time provided. They were given 5 minute breaks 50 minutes into the design and at the end of the design. After the second break, the participants were given copies of Template 1. They were instructed to fill the templates out for each part completed during the first activity. They were also told to mention whether they had considered all the forces in their free body diagram during the original design stage. If they did not, and if they thought that force was important, they were allowed to go back and make changes to the original design. This activity

lasted for 30 minutes. In the third activity, participants filled out Template 2. They were required to complete template 2 for each connection in their design. Also in this activity too, they were allowed to go back and make changes to their original design. This activity too lasted for 30 minutes. Participants were allowed to move on if they finished any activity before the time limit was reached. At the end of the experiment, they were asked about any previous industry experience.

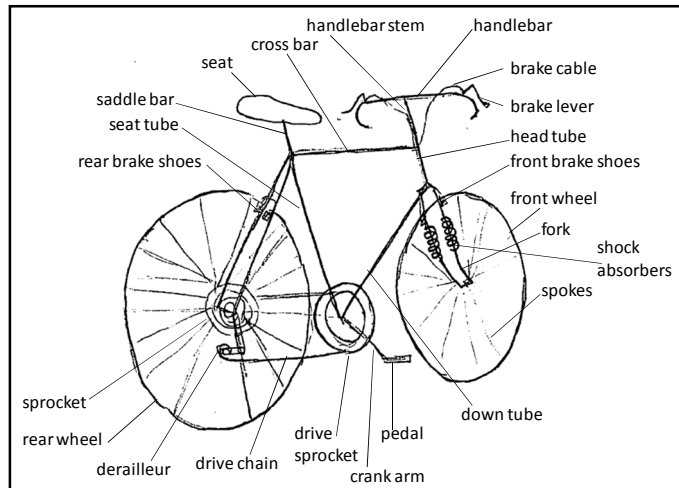


Figure 3. Bicycle concept provided to the participants in the experiment

Metrics for Evaluation

Two different metrics are employed to evaluate the effectiveness of the design templates: Number of extraneous template forces and number of design modifications. The method templates help designers in identification of forces not considered in their original design and prompt them to modify their designs including those extraneous forces. Number of extraneous template forces is defined as the number of forces listed by the participants in their design templates minus the ones already considered in their original design. This metric is calculated separately for the two templates. Number of design modifications measures the number of changes that the participants make to their original design as they use the templates. This metric also measures how many of the extraneous forces identified by the templates are perceived to be important by the participants. These forces are likely to be missed by the participants during their original design. These two metrics together provide valuable insights about the usefulness of the design method developed.

B. Experiment Results and Discussion

The results obtained for the metrics show that the newly developed design templates provide effective means in design calculations. A more detailed description of the results for each individual metrics is provided in the following sections.

Number of Extraneous Template Forces

It is observed that as participants use the method templates, they list many forces that they have not considered in their original design. For example, some participants considered only the forces from hands of the operator in the design of the handle bar. In reality, in addition to the forces from hands, the

handlebar takes the loads from handle bar stem also. Figure 4. shows the mean number of extraneous forces identified by the participants from each template. It is observed that majority of the participants fail to produce complete free body diagrams of the parts or connections they design, which leads them to missing forces in the calculations. As the design templates force them to draw a free body diagram for each part, they identify those missing forces.

A paired-sample t-test [30] is conducted to analyze the data statistically. This test confirms if the number of extraneous forces identified is statistically different from zero. The results show statistical significance for both the templates (for Template 1: $t = 2.98$, $p = 0.01$; for Template 2: $t = 3.91$, $p < 0.01$). This result confirms that in significant number of cases, the templates help designers in detecting extraneous forces in their designs. It also confirms that the templates satisfy their intended purpose of helping designers in identification of missing critical loads in their designs.

Number of Design Modifications

From the data, it is observed that the participants make many changes to their original design based on the extra information gained from the method templates. Though the templates provide them the extraneous forces, the participants do not include all those forces in their design. They include only those forces they perceive to be important for their design. Figure 4. shows the number of modification resulted from the individual templates and from the whole method. Only the changes that contribute significantly to the design are counted (for example: addition or deletion of the forces, modification of points of action of forces etc.).

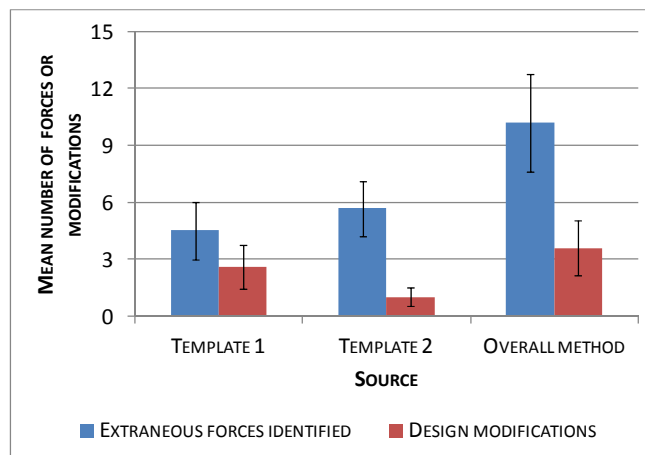


Figure 4. Mean number of design modifications due to the method

A paired-sample t-test is used for the statistical analysis of these data too. The results show that the number of design modifications is statistically significant (From Template 1: $t = 2.27$, $p = 0.04$; From Template 2: $t = 2.09$, $p = 0.06$; Overall: $t = 2.51$, $p = 0.03$). This shows that the method templates prompt designers to make significant number of changes in their design. This result provides strong support for the presented hypothesis and shows that the new method is effective in helping designers with their calculations for building physical models.

It is observed that though the participants identify more extraneous forces from Template 2 compared to Template 1, majority of the design modifications result from Template 1. This shows that the participants perceive the contact forces to be less critical compared to the forces on the parts. This may not be true in all design calculations. Forcing the participants to calculate the values of these forces and make the decisions based on the values may eliminate this difference.

V. LIMITATION OF THE DESIGN METHOD

The Model Error Reduction Method introduced here is shown to be very effective by the experiment results; however it possesses a limitation. This method is useful only for structural calculations as it mainly deals with forces on the parts and systems. However, in many cases design of systems include calculations from other disciplines like thermodynamics, fluid mechanics, chemical and material science etc. The current method cannot deal with such calculations; however, it can be easily modified to include these too. This needs to be completed in future work.

VI. CONCLUSIONS

Physical modeling is considered to be an efficient tool in engineering design as it helps to reveal the flaws in the ideas. This paper discusses the conceptual errors that novice designers face as they build physical models of their design concepts. These conceptual errors lead them to a higher building time and thus affect the effectiveness of physical modeling. To rectify this, a set of guidelines for physical modeling is proposed. A Model Error Reduction Method solving two critical errors (failure to consider critical loads in their design and failure to design connections) that novice designers make is formulated and tested. The test results show that the newly formulated design method is effective in rectifying the said two conceptual errors. However, the method needs to be expanded to include more problem domains.

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Work in Progress: Using Rigorous Design Reviews to Teach and Assess Students' Design Capabilities

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Abstract— This paper presents a template for conducting rigorous reviews in design projects that set high standards for design excellence, thereby teaching and assessing students' design capabilities in the context of authentic design experiences. In engineering professional practice, the design performances of practitioners are tested in design reviews conducted at critical milestones of each project. For projects requiring approval by the US Food and Drug Administration (FDA) or other high stakes projects, design reviews evaluate the rigor and documentation of design processes as well as the quality of products delivered. The proposed design review structure draws from these rigorous design reviews to provide context, questions, and scoring rubrics that guide and probe design team achievements, documentation, and understanding.

Keywords: design assessment; design reviews

I. INTRODUCTION

Engineering is vital for advancing the economic well-being of the nation and for solving great engineering challenges [1, 2]. Although ability to design is a required student outcome of every ABET accredited engineering program, students' design competencies will vary greatly, depending on the authenticity of their design project experiences and the instructor's instructional methods and performance expectations [3].

In the world of engineering professional practice, the design performances of practitioners are tested in design reviews conducted at critical milestones of each project. For projects requiring approval by the US Food and Drug Administration (FDA) or other high stakes projects, design reviews evaluate the rigor and documentation of design processes as well as the quality of products delivered [4]. Engineering education programs should similarly utilize formal design reviews to (a) prepare graduates for professional work expectations, (b) ensure the quality of students' design solutions, and (c) examine and document the rigor of design activities supporting a solution.

II. DESIGN REVIEWS

The proposed design review structure draws from the rigorous practitioner design reviews to provide context, questions, and scoring rubrics for guiding and probing design

team achievements, documentation, and understanding of design. Design reviews are supported by high quality, organized design records:

- *Design History File:* Records of design activities
 - Answer questions of “why” design decisions were made (e.g., why a concept was chosen, why a need was ignored, why a solution was thought adequate).
 - Typically include meeting minutes, sketches of ideas, calculations, Pugh charts, interview notes, data, research summaries, etc.
- *Design Master File:* Archive of design solution stages
 - Define the “what” of the design at a distinct stage
 - Show a time-stamped problem definition (including specifications) and solution (including descriptions, explanations, drawings, etc.)

Design reviews are used to identify weaknesses in design processes and to guide design development toward better and more defensible design solutions. A design review will typically address the following categories of questions:

- How adequate is the **process** used to conduct this stage of development?
- How adequate are the **criteria** defined for acceptability of design products for this stage of development?
- How adequately did the **evaluation process** judge the design product's acceptability?
- How well do **records** defend the design process and outcomes?
- What are **plans** for advancing the design to the next stage?

Three design reviews are proposed for student projects – one at each of three decision points in solution development:

- 1) *Preliminary **Problem Scoping Review*** – problem definition, solution specifications and constraints

- 2) *Interim Concept Selection Review* – concept generation and selection, and defense of chosen concept
- 3) *Critical Solution Realization Review* – detailed design and evidence of its satisfying user needs

A. Problem Scoping

The first design review examines the design team's definition of the design problem and the set of requirements a solution must satisfy. The review probes the team's processes and achievements to understand stakeholder needs and to translate these needs into specifications (specs) for the functionality, technical feasibility, financial contributions, and social impacts of the solution.

B. Concept Selection

The second design review focuses on the design team's selection of a solution concept that best meets the solution specifications. This review probes the team's sources of concepts and their processes for selecting and evaluating plausible concepts, as well as their documentation of processes and solution concepts.

C. Solution Realization

The third design review focuses on the final solution presented by the team and its justification. This review probes (1) processes used in component design, component integration, prototype development, and solution evaluation, (2) value of final solution to stakeholders, and (3) quality of documentation of design processes and stages of the solution.

III. EXAMPLE DESIGN REVIEW

Design reviews should be conducted with all important stakeholders present to ensure that the review is thorough. Let's use the problem scoping review as an example. For this review, schedule approximately an hour and invite key individuals who may use, manufacture, maintain, dispose, or market the product. You also may invite any community or special interest groups concerned about the product. Request from the design team an organized set of design documentation for the project.

Alert the design team and invited audience members to the types of questions that need to be answered in a successful review. For a problem scoping review, these include:

- A. *How adequate is the problem scoping process?*
 - 1) What stakeholder groups were included? Adequate?
 - 2) How were "needs" converted into specifications?
- B. *How adequate are criteria for "good" specifications?*
 - 1) How well do criteria address clarity, measurability?
 - 2) How do criteria enable creativity? Revision needed?
- C. *How well do problem definitions meet "good" criteria?*
 - 1) How does project scope fit time and resource limits?

- 2) Which specs meet criteria for "good"? Need revising?
- D. *How well are processes and results documented?*
 - 1) How well are decisions explained? Revision needed?
 - 2) How well are stages of development documented?
- E. *How well are next steps defined?*
 - 1) How well do steps support solution excellence?
 - 2) What resources are required to be successful?

IV. DESIGN REVIEW FEEDBACK

The design review should produce feedback on the quality of the design process and products, as well as specific items that need attention. A suggested format for design review feedback is illustrated below.

PROBLEM SCOPING DESIGN REVIEW FEEDBACK

1. *Problem Scoping Process*
 - a. Adequacy: 5 4 3 2 1
 - b. Comments/required actions:
2. *Criteria for Specifications*
 - a. Adequacy: 5 4 3 2 1
 - b. Comments/required actions:
3. *Solution Specifications and Constraints*
 - a. Adequacy: 5 4 3 2 1
 - b. Comments/required actions:
- ...

V. NEXT STEPS

Design reviews have potential to rigorously assess design team progress and provide teams feedback that will improve their design learning and performance. The three design reviews presented here identify critical junctures in design development where reviews can add significant value to design activity. Questions posed probe vital issues that will determine quality of the final design solution.

These design reviews have not yet been classroom tested, so let's test and refine them together. Design educators interested in collaboration are encouraged to contact the first author.

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Work in Progress: How Engineering Students Define Innovation

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Abstract— Innovation is defined in diverse ways in the literature and often assessed in ways synonymous with creativity. As these arguments continue it is also important to identify student perspectives. In this pilot study, we examine how engineering students define innovation. Fifty-four first-year engineering students were asked to define innovation in an open response survey. Their answers were first reviewed to identify emerging patterns and then a detailed coding method was used to categorize students' responses. The analysis examined students' focus on feasibility, desirability, and viability as well as other important aspects of innovative design. The findings from this open-ended survey will be used to develop an assessment tool that is easy to administer and score.

Innovation; Creativity; First-Year Engineering

I. INTRODUCTION

Innovation is everywhere. The preceding statement refers not only to the cornucopia of innovative products, systems, processes, and individuals we encounter daily, but also to the proliferation of literature on innovation in engineering design, organizational settings, and STEM education. We want our students to be innovative so that they can eventually solve critical technological, social, and environmental problems, contribute to new and unforeseen knowledge, and build connections where none previously existed [1]. But what does it mean to be innovative?

II. LITERATURE REVIEW

The term “innovation” has been defined broadly in the literature and has been conflated with both creativity and entrepreneurship [2, 3]. Definitions commonly include aspects of novelty and usefulness [2, 4, 5], but it is also important to acknowledge the importance of business, users, and society in the development, production, and acceptance of innovations. Innovations, therefore, must also be feasible, viable, and desirable [6].

Previous studies have investigated the innovative capabilities of engineering students [7], compare novices and experts [8], and how context and processes affect innovation and engineering design outcomes [9]. Engineering education literature, however, lacks an investigation of students' definitions of innovation. Before we can help students

understand critical aspects of innovation and develop innovative skills, we must understand how they conceptualize innovation. Thus, the purpose of this pilot study was to investigate how students define innovation in the context of engineering.

III. RESEARCH DESIGN

Participants & Data Collection. We examined how students define innovation in the context of a introductory engineering course. During the last regular course meeting, 54 FYE students (36 male and 18 female) out of a class of 115 volunteered to complete an extra credit activity. As part of this activity, students were asked to respond to the questions: “What is your definition of innovation? What makes something more innovative than another?”

Data Analysis. We performed a content analysis of student responses [10]. The analysis was iterative, moving from inductive to deductive stages so that themes would emerge from the data [10]. First, two researchers individually open coded a selection of ten student responses, producing a list of 51 unique codes. Among these codes, students defined innovation in terms of how innovation occurs, the types of problems requiring innovative solutions, characteristics of innovators and innovative products, and general definitions of innovation and innovativeness. Based on the original 51 codes that emerged from open coding, we developed an eight-item codebook (Table 1) to use during a second round of coding. Two additional codes— *synthesis/adaptation of existing designs* and *aesthetics*—emerged during the second round of coding. Both original coders made a third pass through the data to identify instances of both of these codes. During the second and third rounds of coding, it was occasionally difficult to distinguish *transcendence*, *synthesis/adaptation*, and *aesthetics* from *creativity* and additionally to distinguish *improves upon existing design* and *solves unsolved problem* from *usefulness*, so we combined these codes to develop a final five-item codebook (Table 1). After a final round of coding, in which codes were accepted only if both coders agreed on instances of a code, we calculated the number of students who identified innovation as any of the five remaining codes: *creativity*, *usefulness*, *feasibility*, *viability*, *desirability*.

TABLE I. INITIAL & FINAL CODES

| Code | Initial Codes | Final Codes |
|------|-----------------------------|--------------------|
| CRE | Creativity/Novelty | Creativity/Novelty |
| TRA | Transcendence | - |
| USE | Usefulness | Usefulness |
| IMP | Improves on existing design | - |
| SUP | Solves unsolved problem | - |
| DES | Desirability | Desirability |
| VIA | Viability | Viability |
| FEA | Feasibility | Feasibility |

IV. STUDENT DEFINITIONS OF INNOVATION

Almost all students identified innovative solutions as creative/novel (96%) and useful (85%). However, students were less likely to identify innovative solutions as desirable, feasible, and viable. Figure 1 displays the number of students who identified innovative solutions in each of the five categories.

Most student definitions coded as *creative* featured words like “new,” “different,” and “original.” However, innovative outcomes could simply be new to some context or adaptations or syntheses of existing solutions. Other student definitions categorized as creative included “revolutionary,” “push[ing] boundaries,” or “chang[ing] perceptions surrounding an established medium or field.”

Within *usefulness*, students often defined innovations in general terms, e.g. “effective,” “an improvement,” or “solves a problem.” Others were more specific using the terms “efficient,” “helpful,” “sustainable,” and “easy to use.” Other students specified that innovative solutions had to address “big” or “important” problems such as the “Grand Challenges.”

Among the remaining categories (*feasibility*, *viability*, *desirability*), students demonstrated less variation, listing these terms verbatim. Alternatively, feasible was listed as “practical,” “could be implemented,” or “reasonable.” Viability was often listed as “cost-effective” or “profitable.” Desirability was often listed as addressing “user needs” or “attract[ing] people’s attention.”

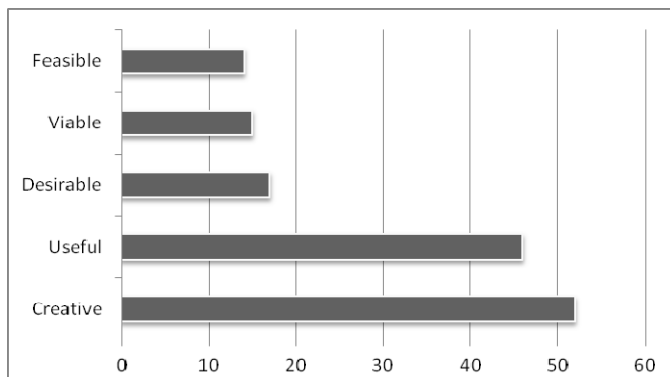


Figure 1. Number of Students Who Identified Each Construct Related to Innovation

V. PRELIMINARY CONCLUSIONS AND FUTURE WORK

By favoring creativity and usefulness in their definitions and demonstrating both variety and thoroughness in their conceptions of these constructs, students presented nuanced views consistent with literature on innovation [2, 4, 5]. However, students tended to overlook other critical aspects. Innovation requires creative thought to dream beyond existing solutions and useful solutions that fulfill some purpose, but additional barriers to innovation include whether a solution can be implemented, whether an organization has cause to implement potentially innovative solutions, and whether solutions will be accepted by potential users. Less than one third of students considered innovation in terms of feasibility, viability, and desirability, and when mentioned, these terms were accompanied with little elaboration.

Overall, these results reflect a strong consideration for the “big picture” of innovation, but little consideration of how innovation occurs from an industrial, economic, and societal standpoint. Thus, while continuing to inspire and discuss the importance of creative thought, instructors should encourage students to consider feasibility, viability, and desirability and promote a more complete interpretation of innovation. Our future goal is to conduct more in-depth interviews and develop a Likert-scale survey that can be used to compare different approaches used to support innovative design.

ACKNOWLEDGMENTS

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Work in Progress: Creativity, *Mindset*, and Implications for Engineering Design Instruction

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Abstract - As a design-based profession, advances in engineering rely, in part, on the creativity of its practitioners. Therefore, it is important to explore means by which creativity, along with other critical skills, can be nurtured. As part of our research on the teachable nature of creativity, we are investigating the relationship between a person's belief that intelligence and talent are either fixed or can be developed and his/her assessment of changes in his/her creative skills. Preliminary findings indicate that, as may be expected, students with a fixed mindset report no changes. Possible pedagogical implications are discussed.

Index Terms – creativity, engineering design, *Mindset*.

“...(E)ngineers create the world that has never been.”
Theodore von Karman [1]

INTRODUCTION

Creativity is vital to the process of innovation, and innovation is vital to meaningful and significant outcomes in virtually every profession and, eventually, to the ability of a society to be competitive locally, nationally, and globally. It is certainly central to the study and practice of engineering, a design-centric profession. [2] However, perceptions as to the nature of “creativity” – as either an innate talent or a skill that can be learned and/or improved – may affect the degree to which truly innovative solutions are developed and implemented.

The goals for this research phase are to investigate student perceptions and definitions of creativity and its nature. Our primary research goal is the investigation of the teachable nature of creativity, with the development of a methodology and curriculum for doing so. The benefits of explicitly addressing key skills critical to success in the engineering curriculum, such as spatial skills, are well documented; we would add creativity to that list.

This paper is organized as follows. Background information on the research population, environment, and methodology is provided. Next, the theory upon which this research is based, Dweck's (Achievement) Goal Orientation Theory, is reviewed. We end with a discussion of preliminary results, conclusions, and direction of future work.

BACKGROUND

Fourth-year students in the School of Engineering and Applied Science at the University of Virginia (UVa SEAS)

must write a thesis to meet school requirements for graduation. Another requirement is the completion of a year-long capstone design course. Many students base the former on their experiences in the latter.

The capstone design course in which this research is conducted is MAE 4670/4680, Creativity and New Product Development I and II. Enrollment in MAE 4670 in Fall 2011 is 46 students (15 females and 31 males), and 43 students in MAE 4680 in Spring 2012 (15 females and 28 males). One female and three males enrolled in the fall semester did not continue their enrollment in the sequence in the spring.

In this course sequence, students (re)learn¹ the engineering design process through the development of two products, an Engineering Teaching Kit (ETK; see, for example, [3]) and a patentable product. An ETK is a self-contained set of lesson plans based on national and state educational standards. Participants are engaged in a series of age-appropriate engineering design challenges that reinforce appropriate math and science concepts. The patentable product is typically a redesign of an existing product; the goal is to add or change functionality and increase usability and appeal while filling a defined unmet need. In both projects, students must determine the problem to address and the appropriate solution brainstormed, selected, prototyped, and evaluated according to the engineering design process.

Students completed three sets of surveys during the 2011-12 academic year. The first survey gathered data on their perceptions on creativity in general and the self-assessed level of their creative skills in particular, and was administered in October, 2011. The second survey is based on Dweck's *Mindset* [4 and 5], and collected data on their perception of the nature – malleable or fixed – of intelligence and talent. It was administered in December, 2011. The third re-surveyed the students on their self-assessed perceptions regarding creativity levels and whether they feel as though any gains came from participation in MAE 4670/4680, and was administered in April, 2012.

ACHIEVEMENT GOAL ORIENTATION THEORY/MINDSETS

Dweck proposes a social-cognitive approach to the analysis of motivation, (Achievement) Goal Orientation Theory in

¹ “Relearn” is used advisedly. Anecdotal data indicate that many SEAS students have little to no formal exposure to the engineering design process after ENGR 1620, Introduction to Engineering course in the fall of their first year and thus have not retained that knowledge. Students from the College of Arts and Sciences are also enrolled in the course sequence.

[6]. According to this theory, a person's motivation to achieve is driven initially by his/her perception of intelligence as either fixed or malleable; this perception in turn affects goal orientation, which is either learning/mastery (goal is to increase competence) or performance (goal is to gain/avoid judgment of competence) in earlier models; and expanded to learning, performance, work-avoidance (goal is to minimize effort), or a combination thereof in later ones. [7] The combined effects of goal orientation and level of confidence in present abilities lead to either an adaptive or maladaptive pattern of behavior with respect to (non)attainment of goals.

Following research and the maturation and generalization of these findings has culminated in the concept of "mindsets." A mindset is a belief about your skills and abilities. If you believe that a certain skill or ability is an innate talent and no amount of work will alter what you've been given, then you have a "fixed" mindset. If you believe that you can develop a skill or ability through practice and dedication, then you have a "growth" mindset. A growth mindset supports resilience and perseverance, qualities necessary for long-term success. [4 and 5]

Implications of this body of work are far-reaching. For example, a student's performance orientation that's rooted in the perception that intelligence is fixed can ultimately be a demotivating factor resulting in fewer opportunities for intellectual growth. Also, emphasis on either achievement or innate talent in praise can affect the recipient's perception of intelligence and goal orientation. The former supports a growth mindset and the latter a fixed one. [8]

PRELIMINARY RESULTS AND CONCLUSIONS

Thirty male students and fifteen female students responded to the first survey. Both genders had a modal response of 5 in their self-assessment of their creativity in comparison to others in general on a scale of 1 (not creative) to 7 (extremely creative). The top two categories of coded responses to the open-ended question "What does it mean to be creative? Please list three or more characteristics of a creative person." for both males and females are the abilities to think "outside the box" and to be inventive (new or novel product). Third place for males is the ability to be innovative (adapt or improve existing product); for the female respondents, the third most frequent response is an unconventional, "free spirited" nature. Collectively, both genders define creativity primarily as divergent thinking.

Nine females and seventeen males took the *Mindset* survey. With respect to intelligence, more females and males perceive intelligence as being malleable (growth mindset; 4 F and 6 M) than fixed (3 F and 0 M), with the rest as neutral on the subject. With respect to talent, the majority of respondents are neutral as to its nature (5 F and 9 M).

Five females and six males who took the *Mindset* survey responded to the third survey. As might be expected, respondents of both genders who have a fixed mindset with respect to intelligence report that they have not changed their perception of their creative abilities from the first survey (2

F and 1 M); respondents of both genders with a neutral or growth mindset report that they have changed their perception for the better, with participation in the class cited as having an impact on the development of their creative abilities from "somewhat" (2 F and 1 M), "half" (1 F and 1 M) to "a good deal" (3 M).

CONCLUSIONS AND DIRECTIONS FOR FURTHER WORK

An understandable reaction to these results would be to review the syllabus to ensure that all activities meaningfully support convergent, divergent, and logical thinking, which are the primary components of scientific creativity. [9] However, it is not enough to provide opportunities for growth; as indicated above, students with a fixed mindset are likely not to perceive improvement even if it occurs. Therefore, we must consider how to structure both language and activities to encourage adoption of a growth mindset, and identify an assessment instrument that measures creativity independent of mindsets so we can truly determine the efficacy of course activities. Finally, we need to determine how we will roll these findings into our design courses and "K-grey" outreach. Interventions regarding teaching and supporting creativity and fostering a growth mindset may be helpful in remediating the frequently reported shortage of students and professionals in STEM.

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Work in Progress: Educational Program Approach of Device Fabrication and Its Analysis for Engineering Experiments

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Abstract— In this paper, we discuss an educational program approach to device fabrication and analysis for an advanced course curriculum for technical training at the Okinawa National College of Technology (ONCT). Letting students have the opportunity to learn technical skills in engineering fields through engineering experiments is a key subject. We deal with two topics related to device fabrication and analysis: MOSFET and SAW transversal filter. In this paper, we describe that we carried out device fabrication and analysis as the subjects of the engineering experiments in a course. The students learned several techniques for device fabrication and analysis through these experiments.

Keywords— Enginireeing Experiment; Device Fabrication Process; Decice Analysis; MOSFET; SAW Transversal Filter

I. INTRODUCTION

Each national college in Japan offers two courses: one as a regular course for 5th year students and one as an advanced course for 2nd second year students. The advanced course at the Okinawa National College of Technology (ONCT) began in 2010 for bachelor degrees. The aim of this course is to educate and train students learning technical skills for engineering fields. In designing the course curriculum, it was decided that the purpose of the subjects of the engineering experiments is to teach measurement and design skills. Usually, the main purpose of the engineering experiments in a curriculum is to get empirical results by having students test various methods, tools, or technologies. Many universities tried various approaches to manage their students in their curriculums [1-4]. Recently in Japan, how best to teach technical skills in university and/or college educational curriculums has been focused on [5].

To meet these aims, most engineering experiments have been carried out as a part of the courses or the subjects. Also, the purpose of “project (or problem) based learning” is to acquire engineering skills, and to learn how to accomplish goals by oneself as well as through teamwork [6,7]. It is necessary for students to learn and obtain more practical and more technical skills as engineers.

In this paper, we discuss an educational program approach to engineering experiment subjects for technical training in an advanced course curriculum. We report the implementation and execution of device fabrication and analysis as themes of the engineering experiments. Students were motivated to put their efforts towards experiments to improve their own knowledge and skills through group work.

II. CONCEPTS OF THE ENGINEERING EXPERIMENTS IN AN ADVANCED COURSE CURRICURUM

A. Implementation of Device Fabrication and Analysis

The subjects of the engineering experiments in our advanced course are focused on training and acquiring technical skills. The subjects were designed to allow students to perform both device fabrication and analysis for practical engineering training in the experiment program. It is difficult for students to acquire technical skills with a single experience in class since operating the necessary equipment is complicated in device fabrication and analysis.

To give students the opportunity to operate the equipment used in the device fabrication process and the device measurement, we deal with two topics used as the engineering experiment subjects for advanced course students: MOSFET fabrication and SAW transversal filter fabrication. Figure 1 shows the experimental flow used in the device process and analysis program. The context of the experiments is explained to students in an introductory talk. Before performing the device process and analysis, teachers explain the experiment procedures and the principal properties of the devices. In practical experiments, teachers and students need to crosscheck the key points of the process and analysis procedures.

B. Subjects and Contents of the Experiment Program

In device fabrication, students repeat process procedures by performing two different kinds of device fabrication, such as MOSFET and SAW transversal filter fabrication. In addition, students reconfirm the process techniques used in the device

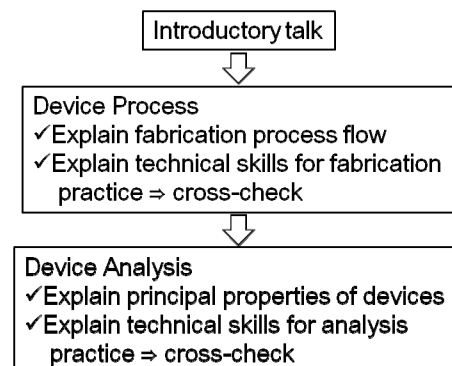


Figure 1. Experimental flow used in the device fabrication and analysis program

fabrication. However, the priority of the teaching points for each subject is different as follows.

The focus of MOSFET fabrication is to teach device fabrication processes. The device fabrication process for MOSFET consists of key device fabrication components, such as oxide formation, metal deposition, the diffusion process, and the photolithography process [8]. Therefore, the subject of MOSFET fabrication is a precise and suitable one for the engineering experiments of educational course curriculums.

The focus of SAW transversal filter fabrication is to teach how to analyze device properties. In particular, it is significantly important to learn how to use network analyzer equipment in order to obtain the frequency characteristics of devices. The calibration technique is one of the key techniques in device analysis. Also, a technique for probing a fabricated device is required to measure device properties.

III. EXECUTION OF EXPERIMENT PROGRAM

We spent 16 hours teaching the subjects of device fabrication and analysis of MOSFETs and SAW transversal filters. We made small groups of 4-5 persons. One student who had experience with fabricating devices in their graduate study was a supporter in each group and conducted the process procedures.

For the MOSFET, we focused on the device fabrication process. We spent 12 hours on device fabrication and 4 hours on device analysis. There were nine simply designed MOSFETs and four inverter circuits in a chip 10×10 mm in size. Students fabricated n-ch MOSFETs and measured the characteristics of the fabricated devices. During photolithography, students had a lot of trouble with the alignment process. The fabricated devices showed the principal characteristic of MOSFETs.

For the SAW transversal filter, we focused on the device analysis. We spent 8 hours on device fabrication and 8 hours on the theory and analysis of fabricated devices. Six pairs of interdigital transducers were formed by sputtering evaporation on a chip 13×15 mm in size. The fabricated transversal filters showed the well-known frequency characteristics based on the theory of surface acoustic wave propagation.

Most of students succeeded in fabricating and measuring the designed devices. However, some of them could not fabricate their devices due to not operating the equipment correctly. We carried out a class evaluation after the class in order to improve the educational methods.

IV. DISCUSSION

A class evaluation was carried out with the students to check the achievement level of the technical skills. Table I is a summary of a part of the class evaluations. The results of the class evaluation indicated that the students were satisfied with how much they had learned by fabricating and analyzing the electronic devices.

Device Process: Most of the students satisfied their achievement level for the device fabrication process. However,

the time originally allotted for the experiment program was exceeded since the students did not become accustomed to operating the process equipment for the device fabrication. Time-control was the one of the problems for MOSFET fabrication.

Device Analysis: Half of the students evaluated their achievement level for their knowledge of device properties with terms such as standard and average. Though the students had already learned device properties in their class, it was revealed that the students could not connect the measurement elements to the function of the measurement equipment.

TABLE I. PROGRAM EVALUATIONS

| Questions and achievement level |
|---|
| ✓ Do you think you achieved technical skill in the device process?: Good (62.5%), Standard (37.5%) |
| ✓ Do you think you achieved technical skill in the analysis technique?: Excellent (6.2%), Good (31.3%), Standard(56.3%),Poor (6.2%) |

V. SUMMARY

The device fabrication and analysis processes were carried out as the subjects of engineering experiments. In device fabrication, the key goals are to operate the process equipment of semiconductor devices and to learn device fabrication procedures. In device analysis, the key goals are to operate the measurement system and perform the probing technique. Most students felt that they had a good opportunity to acquire technical skills through learning the device fabrication process and device analysis. The main motivation for students was to prove their own skills and to put effort into the experiments. However, it was clear that they had some misunderstanding of the relation between the basic learning material in the textbook and operating real technical equipment. Therefore, we should improve the educational approach to teaching the technical skills used in electronic engineering.

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Engineering Matriculation Paths:

Outcomes of Direct Matriculation, First-Year Engineering, and Post-General Education Models

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Abstract—Longitudinal data from ten U.S. institutions are used to characterize outcomes of three matriculation models: Direct Matriculation to a specific major (DM), First-Year Engineering programs (FYE), and Post-General Education Programs (PGE). Both DM and FYE programs show high persistence rates, but FYE programs are less likely to attract transfer students and switchers. FYE graduates are the most likely to stick with their first choice of major (after completing FYE requirements), followed by DM graduates who begin in undesignated engineering (taking extra time to decide), then DM graduates who choose their major as part of the matriculation process, and then PGE graduates. FYE students also have the shortest time to graduation. We conclude that encouraging students to associate with engineering or an engineering discipline from the start, yet maintaining the curricular flexibility to allow alternate entry points onto the engineering path improves persistence, accessibility, effectiveness of major choice, and time to graduation.

Keywords— *First-Year Engineering, Persistence, Accessibility, Transfer Students, Major Change, Switching*

I. INTRODUCTION AND BACKGROUND

This study describes some of the advantages and disadvantages of different matriculation pathways into engineering, considering both first-time-in-college (FTIC) and transfer students. How FTIC students are admitted into engineering and subsequently matriculate into their engineering major varies by institution [1]. While the U.S. engineering education system has a multiplicity of practices, we limit our discussion to the matriculation practices of the institutions

included in this study. At institutions participating in the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD, described in the Methods section), FTIC students may follow one of six pathways into a specific engineering major. They are admitted:

1. to a formal First-Year Engineering (FYE) program that they must complete before declaring a major;
2. directly to a specific engineering major;
3. after a period as an undesignated engineering student;
4. after completing as many as two years of general education at their institution;
5. to institutions with a Mostly Common First-Year (MCFY) where they may declare a major preference, but they cannot advance until they have met common first-year requirements; or
6. to a university-level general studies program from which they may migrate into engineering.

In a formal first-year engineering program, students are admitted to the College of Engineering and take common first-year classes, including calculus, physics, chemistry, and an introduction to engineering sequence. Students in MIDFIELD FYE programs are advised by professional FYE advisors. Although a formal FYE program is not the predominant matriculation model, recent adoptions and planned adoptions of the FYE model provide evidence that their prevalence is growing [e.g., 2, 3, 4, 5]. During the years and cohorts in this

study, three MIDFIELD institutions had formal FYE programs, another began one in 2005 and a fifth will begin one in fall 2012. FYE programs provide early engineering experiences, inform disciplinary choice, and enable engineering faculty and staff to oversee the transition to engineering. Results of two national surveys of FYE programs describe the status of such programs across the country [6]. Upon completing the FYE requirements, students enroll in a specific engineering major such as electrical or mechanical. A summary of research and practice related to first-year engineering programs was created by the Foundation Coalition [7].

Four other MIDFIELD institutions admit qualified students directly to their choice of engineering major. Students majoring in engineering who are not sure which discipline they wish to pursue may be admitted as undesignated engineering students. The first-year curriculum at these institutions is nearly identical to that offered in FYE programs with respect to the basic math and science courses. All of the schools offer an introduction to engineering course or sequence although not all require students to take it. Students are already identified with their departments and generally are advised there. Undesignated students are generally advised by engineering student affairs but may be advised elsewhere in the university. These programs are defined as direct matriculation (DM) programs.

Although no MIDFIELD engineering college currently waits to admit students until after they have completed two years of general education, three colleges did so until the mid-1990's and thus their cohorts are included here for analysis. The comparison is useful even now because other universities around the country continue to use this matriculation model for their engineering students. In this model, students declare their major preference upon enrollment, but complete their first two years of general education in the arts and sciences college of the university before formally selecting an engineering major of their choice. In the first two years, these students are advised by arts and sciences advisors. To be eligible to select an engineering major, these students must take the engineering math and science courses as part of their general education core. These programs are defined as post-general education (PGE) programs.

We have termed a hybrid between an FYE program and direct admission as a "mostly common first-year" (MCFY). In these institutions, students identify with a preferred department and may be advised there, but they may not formally matriculate into their preferred major until they have successfully completed required first-year math, science and introduction to engineering courses. Of the three schools with the MCFY model in MIDFIELD, all have migrated or will migrate to a formal FYE program.

Clifford Adelman's metaphor of "paths" is used as a framework [8], because it captures the fact that there are many ways for students to navigate the process of getting an engineering degree. Note that this is somewhat in contrast to "pipeline" metaphors, which suggest only one entry point with many "leaks" or exit points [9]. In keeping with this paths metaphor, we discuss persistence (do students stay on the path?), accessibility (do students enter the path from other institutions and majors?), term of major declaration and

effectiveness of choice (when do students commit to a particular disciplinary path and how likely are they to stay on it through graduation?) as well as time to graduation (how long does it take them to reach their destination?).

II. RESEARCH QUESTIONS

The overarching research question for this study is "What are the advantages and disadvantages of these three matriculation models: first-year engineering (FYE) programs, direct matriculation into a specific major (DM), and post-general education programs (PGE)?" Key outcomes to be examined include persistence patterns of those who matriculate in engineering, i.e., those who start out on the engineering path; accessibility to those who matriculate outside of engineering (switchers) or outside of the institution (transfer students); the time at which students commit to a disciplinary path by declaring a major and the effectiveness of their choice; as well as time to graduation.

III. METHODS

These four matriculation models (FYE, DM, PGE, or MCFY) are mutually exclusive. Each cohort from each institution was categorized into one model group; MCFY were excluded from further study because the number of cohorts was not sufficient to protect institutional identity. These models represent the most highly-trodden paths, but individual students may follow alternate paths, which are still influenced by institutional structures and guides, some of which are described next.

Four schools admit students who do not meet college of engineering admissions requirements to a university general studies program. Students admitted to these programs who express an interest in engineering are advised to take the engineering math and science courses and may take the introduction to engineering sequence on a delayed basis. Upon successful completion of the engineering requirements, they are allowed to enroll in an engineering major. One FYE school, two DM schools, and one MCFY school offer students this option. Students who enter via general studies are included as "switchers," discussed in section IV.B. Another institution requires students who are only conditionally admitted to engineering to enter as "Freshman Engineering", which is classified as undesignated engineering in this study because they are not allowed to declare a specific major at matriculation.

The Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD) contains records for 977,950 unique students at eleven public institutions in the U.S. For reasons mentioned above, only ten are included in this study. This paper focuses on the subset of students in the included cohorts who ever declared a major in engineering and for whom we have six years of data (110,896). Of these, 72,728 matriculated in engineering as first-time in college (FTIC) students. The rest were transfer students.

While many institutions are not represented in MIDFIELD, the experience of MIDFIELD students is representative of the experience of a large fraction of U.S. engineering students attending large public institutions. A detailed description of the MIDFIELD dataset is available elsewhere [10].

Any semester or quarter in which a student is enrolled is counted as a term, including summer semesters. Since not all students enroll in every term, term counts do not necessarily correspond to calendar time. Consistent with previous literature, graduation is measured at six calendar years from matriculation [11]. For transfer students, this timeline is reduced by one year for every 30 semester credit hours the institution accepts as transfer credit.

Persistence rates are calculated based on FTIC students who matriculated in engineering (including first-year engineering and engineering undesignated); a student who graduates in engineering is automatically considered to have persisted through all terms. Accessibility is based on the number of engineering graduates who did not matriculate in engineering. Graduation was chosen over enrollment because it captures the product of access and retention.

IV. FINDINGS

Differences were observed between FYE, DM, and PGE programs on all outcomes examined.

A. Persistence on the Engineering Path

In comparing persistence, only FTIC students are included so that everyone has the same starting point. Although persistence rates are similar for FYE and DM, PGE programs lag behind as early as the fourth term and the gap grows over time (Figure 1). While 51% of FYE (N=38,062) and 50% of DM (N=28,173) engineering matriculants graduate in engineering in six years or fewer, only 32% of PGE (N= 6,493) students do so. Students may exit the engineering path early from the PGE programs because without engineering experiences they lose interest or discover other opportunities. Others may leave later because once they finally start their engineering classes they realize it was not a good match.

Comparing FYE and DM, the FYE programs lose a slightly larger percentage of their students in the first four terms than do the direct matriculation programs. We speculate that much of this is due the fact that requiring a change of major from FYE to *something* adds a gate to the pathway. That is, students must successfully complete a set of courses before they are

allowed to matriculate into a particular major while those who were admitted directly to a major who have not successfully completed prerequisite courses may still register without making satisfactory progress.

Losses between the twelfth term and graduation could represent students dropping out of engineering, leaving the institution, or taking more than six years to graduate. Some variation by race and gender is expected as there is with comparing outcomes at semester 8 versus six-year graduation [12] and this will be an area of future research.

B. Accessibility from Other Paths

To study the accessibility of engineering programs to students who start on other paths, all students who graduate in engineering within six years of matriculation are considered. While the structure and early engineering experiences of direct matriculation and first-year engineering programs may contribute to their higher persistence rates, it also appears that these “fenced” paths are not easily entered by those who do not matriculate in engineering at the institution. On average, 47% of engineering graduates in PGE programs are transfer students, compared to only 14% and 29% in FYE and DM, respectively. It should be noted however, that all of the PGE programs have strong transfer agreements with two-year colleges in their states. Figure 2 shows that two of the three FYE programs have proportionally fewer graduates who entered as transfer students than average. This is also important from a diversity standpoint because other work has shown that underrepresented minorities who transfer into a four-year institution are more likely to persist in engineering and outperform similar students who enrolled as freshmen [13].

Further, proportionately fewer “switchers,” or students who migrate into engineering from other majors within the institution (including undecided), are found at FYE schools (Figure 3). Overall, PGE programs have double the proportion of graduates (26%) who switched to engineering from another major as the other programs (FYE = 10%, DM = 12%). Here, all FYE programs fall below the average for all institutions indicated by the vertical line in Figure 3.

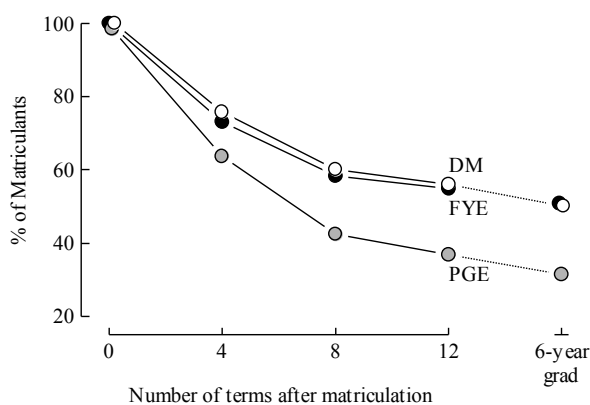


Figure 1. Engineering persistence patterns of engineering matriculants for direct matriculation (DM), first-year engineering (FYE), and post-general education (PGE) models.

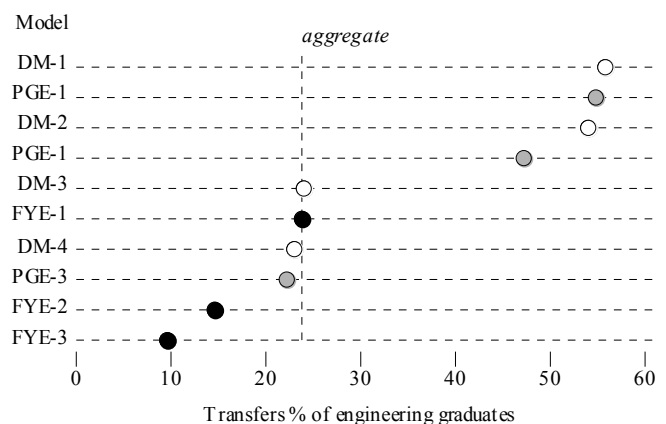


Figure 2. Engineering persistence patterns of engineering matriculants. To maintain institutional anonymity, model label numbers are not consistent across figures.

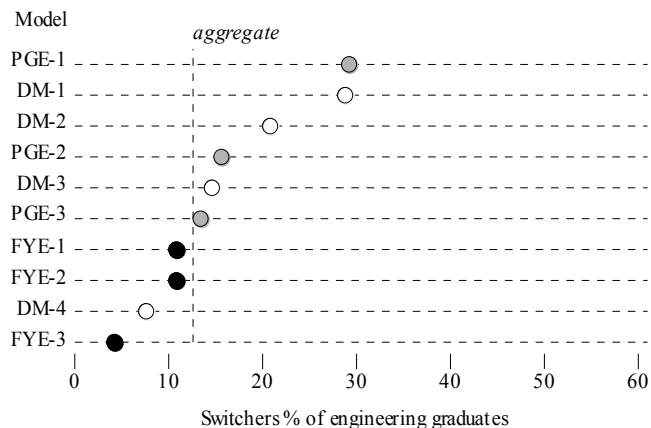


Figure 3. Engineering persistence patterns of engineering matriculants. To maintain institutional anonymity, model label numbers are not consistent across figures.

C. Term of Major Declaration and Effectiveness of Choice

As mentioned, one purpose of FYE programs is to inform disciplinary choice. While direct matriculation models do not require students to choose a discipline right away (they have the option to start as “engineering undesignated”), FYE students are not permitted to declare a major until they have learned about all of their options. This leads to the question: do students make more effective major choices when they after completing a FYE coursework than they would have at matriculation? We consider a major choice effective if the student graduates in the discipline. Note that different groups identify with a specific major at different points in the academic process. For FYE students this is the first major after FYE. For most DM and PGE students, this happens at matriculation. For students at DM and PGE institutions who matriculate as undesignated, we use the first major after they leave their undesignated status.

One potential drawback of giving students extra time to decide is that their connection with their future discipline is delayed, so we also examine the term when students declare their first major. When a student submits a change of major form, the major change does not take effect until the following term. Therefore, if a student selects a major during their second term (as expected in FYE programs), they are categorized as declaring their major in term 3. For this portion of the study we consider only FTIC students who matriculated and graduated in engineering in six years or less.

We first examine the timeline for FYE students declaring a major (Figure 4). Although FYE students are encouraged to declare their major by term 3 and most do, some spend more than one year in “first-year” engineering, possibly retaking courses or improving their grade-point average (GPA) to meet the standards of their chosen degree program. While the majority of students enter their discipline in term 3, cumulatively only 70% of the students have entered the discipline by term 3, then 90% by term 4, and 95% by term 5. Ninety-eight percent of graduates were in their discipline by the end of their sixth term (recall that this count includes any summer terms in which the student was enrolled). Whether a student is allowed to take courses in the discipline before

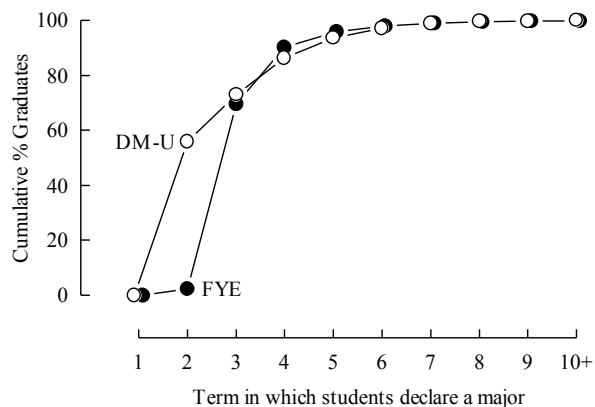


Figure 4. Term of major declaration for first-year engineering (FYE) graduates and direct matriculation graduates who entered as undesignated engineering (DM-U).

officially declaring a major varies by department. Once FYE students declared a major, 89% of those who graduated in engineering did so in the first engineering major they chose after FYE.

In the DM model, 22% of FTIC students who completed an engineering degree in six years started as undesignated engineering. Eighty-five percent of graduates who began as undesignated engineering students in DM programs graduated in the first major they chose. As was the case for FYE students, the selection of a specific major by undesignated DM students is distributed in time (see Figure 4), however the majority of students (55%) choose in their second term. Overall, only 78% of DM graduates stayed with their first major choice.

The record-keeping practices at the institutions with the PGE model make it difficult to identify students who indicated an interest in engineering but had not decided on a specific discipline. Future work will explore ways to identify these students and define their entry point into a specific discipline. We do know however, that only 60% of FTIC PGE engineering graduates remained in their matriculation major.

D. Time to graduation

Finally, we compare the average time-to-graduation for FTIC students graduating in each matriculation model (Table I). These estimates represent the number of regular semesters the student was actually enrolled. An academic quarter is 0.75 of a semester. A full summer term is 0.66 of a regular semester, and a half summer is 0.33 of a semester. The total credit hours earned for all academic work is also included in Table I.

TABLE I. AVERAGE ENROLLED TIME TO GRADUATION AND CREDIT HOURS EARNED

| Matriculation Model | Enrolled time to Graduation (semesters) | Credit Hours Earned |
|---------------------|---|---------------------|
| FYE | 9.0 | 128.8 |
| DM | 9.3 | 128.9 |
| PGE | 11.0 | 141.6 |

Although graduates of FYE and DM models earn the same number of credits, DM students typically require an extra 0.3 semesters to do so. PGE graduates are enrolled for 1.7 more semesters and earn more credits than both other models. This could indicate several things. The most likely possibility is that since more students change majors, some of their credits do not count towards their final major, and thus they must take more coursework overall. However, other possibilities include students taking more credits as part of a double major, a minor, or for personal interest, as well as differences in engineering curriculum requirements.

V. IMPLICATIONS AND CONCLUSIONS

Different matriculation paths appear to have advantages and disadvantages. FYE programs seem to be successful in helping students make informed choices about specific engineering majors, as evidenced by the high (89%) percentage of students graduating in their first choice. These programs also foster persistence within engineering as a whole. It is well known that advising is a key element in student retention, particularly of first-year students [14-16], so perhaps the professional advisors act as guides along the path to an engineering degree at least until a student is ready to pass through the gate to a specific major. FYE programs are also the quickest path to graduation in engineering. The drawback of these programs is that the common courses and experiences that tend to keep students on this path also seem to keep transfers and switchers out.

An advantage of direct matriculation is that students can identify with the major and its culture early in their academic careers through advising and possibly early introduction to the discipline. On the other hand, given the overall lack of familiarity with engineering in K-12 and the general public, students may be making their major selection based on limited information about the disciplines and what they have to offer. If there is a poor initial match, it may be difficult to switch to another engineering major because they may not have taken the appropriate courses for the new major. On a positive note, persistence is very high in these programs and students who enter as undesignated engineering are almost as successful at finding a good disciplinary fit as those in FYE programs. Also, transfer students are less likely to encounter the barriers created by institution-specific introduction to engineering courses.

The engineering persistence rates in Post-General Education matriculation models are troubling, but there are some positive aspects from which to learn, primarily that the common first and second year are more accommodating to transfers and switchers. Although the additional time to degree may be a hindrance to completion, the additional coursework and higher likelihood of changing majors may be enriching to the students. The additional time to degree and lower persistence rates could also be a result of the potential of being advised by people less familiar with engineering requirements and career paths. This may explain why all three schools in this study have moved away from a PGE model to either FYE or DM.

It seems that the ideal matriculation model allows students to associate with engineering or an engineering discipline from matriculation, yet maintains the curricular flexibility to allow alternate entry points onto the engineering path. Note that this work only examined a few of many possible outcomes. It is important to understand a broad spectrum of outcomes related to matriculation pathways, because if we understand what outcomes result and how they come about, it may be possible to design pathways that improve all outcomes rather than improve some at the expense of others.

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Work in Progress: Understanding Migration Patterns of Engineering Undergraduates: The Impact of Course Grades on Student Major Choice

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Abstract— Building on the work of others, we propose a different approach to studying the influence of letter grades on engineering students' major choice and migration patterns. As this work progresses, we will improve understanding of the effects of course performance, grading distributions, and early major intentions on the likelihood that students will persist in a given field.

Keywords- major choice; persistence; migration; grades

I. INTRODUCTION

Concerns regarding the retention rate of undergraduate engineering majors abound, particularly in light of the growing demand for a highly-skilled and diverse scientific and technological workforce. The Bureau of Labor Statistics estimates that between 2008 and 2018 engineering occupations will increase by 11.3%, versus all occupations, which will increase by only 10.1%. The combined science and engineering occupations, moreover, are projected to grow by 20.6% [1]. To meet this growing need for engineering professionals, it is critical for higher education institutions to find ways to improve the retention of engineering majors. While the graduation rate of undergraduate engineers is now similar to that of undergraduates in other disciplines [2], migration of engineering matriculants into other fields is relatively high. Among students who matriculated in a 4-year college or university in 2003 and declared engineering as an initial major, only 55.9% graduated in engineering as of 2009. Meanwhile, 22.3% migrated into non-science and non-engineering fields, 10.1% into physical, math, and computer sciences, 2.7% into agricultural and biological sciences, and 3.5% in social and behavioral sciences [1]. On the other hand, students who initially matriculate in non-engineering disciplines are unlikely to transfer into an engineering program due to factors such as stringent course requirements and sequences. The outflow of students from engineering with limited inflow of students from other fields contributes to the lower number of students completing engineering degrees. The migration patterns of science and engineering students have therefore inspired a body of research on precipitating factors such as poor academic preparation, "chilly engineering climate," difficult course material, poor instruction and

advising, and variations in student self-confidence [3-6]. Since course letter grades are an integral component of evaluation and assessment in undergraduate studies, here we investigate the complexity of its influence on student major choice.

The prevailing concern regarding course letter grades arises from the differential grading distributions that may exist between science and non-science majors at higher education institutions [7]. As Rask [8] puts forward, "if STEM [Science, Technology, Engineering, and Mathematics] departments grade lower than non-STEM departments, and the grade received is an important factor in the major decision, grading practices could be an important factor in the high attrition rates experienced in STEM majors." Rask shows that the absolute grade received is an important predictor of the likelihood of taking another course in the major the subsequent semester. Further, Ost [9] suggests that students are "'pulled away' by their high grades in non-science courses and 'pushed out' by their low grades in their [science courses]." Yet, the relationship between grading distributions, student letter grades, and major choice is complex. For example, when student effort and motivation are taken into account by proxy, letter grades are not necessarily predictive of student major persistence and the effects can vary by student gender [10, 11].

Thus, to further understand student major choice and migration patterns, we propose a unique approach that incorporates multiple sources of observable data on students' major intentions and actual letter grades, as well as calculations of students' expected performance. Our view is that students' decisions are based on the context of grade-related factors, including their own predictions of their likely performance in future discipline-specific courses. Our research findings will shed light on whether engineering programs can retain students through system-wide changes in grading practices, such as providing students with more information regarding course-specific and/or discipline-specific grading distributions so that students are able to more accurately assess their performance and aptitude. Additionally, our findings will contribute to the debate on whether standardizing grading distributions between science and non-science majors could reduce the number of students migrating out of engineering.

II. DATA

Empirical data come from the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD), and include individual-level demographic characteristics and detailed transcript records. The dataset is composed of 14 entering cohorts from 1990 through 2003 across 9 public four-year institutions allowing for a comprehensive examination of patterns in student major choice. We limit our study to first-time undergraduate students who complete a degree in the same institution where they matriculate. Therefore, students who transfer from another institution and students who leave the undergraduate program are not included.

The demographic variables comprise student gender, race/ethnicity, Citizenship, age at enrollment, year of entry, SAT scores, and initial and early major intentions. Course-related variables of interest include students' letter grades in introductory engineering courses and in gateway courses (first discipline-specific course often taken as an introduction to the field), as well as the proportion of "A's" and "C-'s" and below awarded in upper division courses for each engineering discipline by year.

III. RESEARCH QUESTIONS AND METHODS

A. *Are students more likely to select a major if they expect to receive relatively higher grades in the major's upper-division courses?*

Previous research has tended to focus on the actual letter grade received in determining student major choice. We take a decidedly different approach and examine whether students select majors based on their predicted future grades while taking into account students' initial or early major intentions. Since students are more likely to select leniently graded courses when grade information is provided [11], are students also more likely to select a major when they expect that they will receive relatively higher grades in that major? Conditional on major intentions and assuming that students gather data on grade distributions from various informal sources, we estimate the impact of expected performance and previous discipline-specific grade distributions on student major selection using logit and multinomial logit regression.

Expected performance is calculated using exact matching on gender and propensity score matching on race/ethnicity, SAT scores, high school grade point average, percentage of students enrolled in the free lunch program at the student's high school, college institution, year of college matriculation, and letter grades earned in general undergraduate introductory courses in mathematics, chemistry, and physics. The expected performance variable predicts, given a student's background and introductory grades, how a student will perform in a major's upper division courses based on how other students with similar characteristics have performed in that particular major. For each student, we calculate expected performance for each of the following majors: Chemical, Civil, Electrical,

Industrial, and Mechanical Engineering. Previous discipline-specific grade distributions include lagged variables for the proportion of "A's" and "C-'s" and lower awarded in upper-division courses. Findings from these analyses will help clarify the extent to which students consider future performance when selecting a major in light of initial major intentions.

B. *Do students' relative performance in gateway courses predict major choice?*

Among undergraduates who take at least two gateway courses in engineering, we compare their relative performance in the gateway courses to determine whether higher relative grades attract students to a major. That is, do students respond to grades as signals of their relative strengths and weaknesses? We use logit regression to estimate the effect of relative performance in gateway courses on migration patterns, taking into account early major intentions and background characteristics. Like previous research, we are unable to fully account for student effort or motivation when assessing the impact of actual grades on major selection. We argue, however, that students may be more likely to have similar levels of motivation across gateway courses since they are likely taking these courses with intentions to explore or to major in that particular engineering field. This is in contrast to potentially different levels of motivation that engineering students may exert between their STEM and non-STEM courses [8]. Likewise, engineering students may also exert similar levels of effort across gateway courses compared to the effort they may give non-STEM courses. Therefore, limiting the analysis to engineering gateway courses may constrain the range of motivation and effort and lead to new understanding of major choice. Research findings will help clarify whether relative grades influence students' persistence and major decisions.

IV. SUMMARY

We propose a different approach to examining the influence of letter grades on engineering students' major choice and migration patterns. Research findings will bring new understanding to the effects of course performance, grading distributions, and early major intentions on the likelihood that students will persist in a given field. These contributions will be useful to engineering faculty and programs in assessing grading practices and policies and in attracting and retaining larger numbers of undergraduates.

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A First Look at Student Motivation Resulting from a Pass/Fail Program for First-Semester Engineering Students

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Abstract – In 2010, administrators at Colorado State University implemented an experimental program allowing first-semester engineering students to take their entire course load for pass/fail grades, instead of the traditional A-F grades. Engineering educators were interested in the impact that this program had, and initially looked to GPA and grades. Realizing that those were insufficient to understand impact of the program, this study expands on previous work by obtaining a preliminary measure of students' motivation and correlating it with GPA and other variables of interest. Results indicate that the pass/fail students and traditionally graded students were very similar in terms of motivational qualities on average, but that motivational qualities showed relationships with semester GPA uniquely for pass/fail versus traditionally graded students. Also, student comments suggested that at the least they felt no harm was done by the program being offered and their enrollment or non-enrollment.

Index Terms – pass/fail, grades, motivation, student stress

INTRODUCTION

This paper explores the motivational impact of an experimental program implemented in the first-year engineering program at Colorado State University. During the Fall 2010 semester, the College of Engineering started an optional, experimental program for first-year students that would allow them to take their entire first semester's academic load as pass/fail (P/F). This was motivated by a growing concern that first-year engineering students were suffering emotionally from the rigor of the engineering curriculum. The premise was that relieving some of the pressure to perform, in terms of GPA (grade point average), while also providing more contact and support with engineering faculty and staff, could enhance student performance and relieve some related stress while they adapted to the college environment. The P/F experiment was continued with the entering first-year engineering students of Fall 2011, constituting the second cohort, who are the subjects of the research presented herein.

The authors of this work previously explored their differing opinions of the program as well as the difference in grades that students attained between those in the P/F and those who elected traditional A-F grading [1]. This previous work found that students who took their classes P/F earned significantly lower GPAs (scored before being converted to pass/fail grades) than those who took their classes for a traditional A-F grade. However, when broken out by course to see more detail, only certain courses showed significant differences in grades, suggesting that there was still more to the picture than grades alone could show. Therefore, the previous work concluded with future research questions, including the one for this paper:

How do student motivations for learning and motivations for grades affect both their choice to enroll in the pass/fail program and their academic performance?

Therefore, the goals of this paper were to:

- Attain a preliminary motivational evaluation of the first-semester engineering students
- Analyze data for relationships between the motivational variables and academic variables to explain enrollment in the program
- Analyze data for relationships between the motivational variables and academic variables to explain academic performance

BACKGROUND

1. The Pass-Fail Program at CSU

Colorado State University (CSU) is a public land-grant university with approximately 1,800 undergraduate engineering students and 500 graduate engineering students. High school students may apply directly into any of the majors in the college, or enter as undecided engineering students. A typical first-semester course load includes a department-specific introduction to engineering course or a college-wide engineering course based on the NAE's Grand Challenges, calculus, and a science course – often physics or chemistry.

The decision was made during the summer of 2010 to implement the new P/F program for the Fall 2010 semester, under the supervision of the second author of this paper. Administrative-level support for this effort was attained based on the knowledge that similar systems are in place at other successful engineering schools, such as MIT and CalTech. At CalTech, a no-grade policy was first implemented in 1964, and was quite successful [2]. More recently, P/F systems have been successfully implemented in medical schools [3] with the intent of reducing student stress. With this as a background, the CSU College of Engineering was given permission to move forward with an experiment during the Fall 2010 semester, despite the fact that this would violate several established university policies. As this was considered an experiment, exceptions to the pertinent policies were given by upper administration with the proviso that a comprehensive assessment plan would be implemented and results shared with the administration. During the first week of classes, first-semester engineering students were recruited into the program on a purely volunteer basis. The program included the following elements:

- A new, required, 1-credit seminar course was implemented to increase student-faculty contact. A senior faculty member coordinated multiple sections of this seminar and developed curricula that focused on connecting engineering concepts with math and sciences courses being taken by the students.
- Passing was defined by the university as S for a grade of D and above, and failing as a U for a grade of F.
- Students could choose to either take all courses P/F or all courses with traditional A-F grading. This decision had to be made by the university-established deadline.
- Faculty members were unaware of students' choice to participate. Faculty graded using typical A-F grading, submitted the grades, and the Registrar's Office converted the grades to S/U for students in the program.
- Students were allowed to recover grades with certain restrictions, including: a student must recover all grades and the decision was then irreversible.
- The program was only available for first-time, entering freshman in their first semester.
- Students who chose to participate in this program were allowed to maintain all University and College of Engineering sponsored scholarships and Honors standing.

II. Motivation Theories

Two motivation theories were used in this work to evaluate student motivation: self-determination theory and expectancy-value theory. These two were selected, of the many motivation theories in the literature, as they were most directly able to explain students' intentions and source of motivation for their actions, to best answer the research question for this work.

Self-determination theory

The first was self-determination theory, founded on the principle that motivation lies on a continuum from amotivation to extrinsic motivation to intrinsic motivation. Intrinsic has the most internalized source of motivation (e.g., passion, deep personal interest), whereas extrinsic has the most externalized source of motivation (e.g., parental pressures, financial pressures); amotivation is a lack of enough drive to act at all. Internalized motivation has been shown to produce the deepest levels of affective, behavioral, and cognitive engagement in tasks, including learning, and consequently the best productivity. Externalized motivation, on the other hand, not only attains lower quality engagement and shallow learning, but also moves more easily into amotivation when the external motivator is removed or temporarily not present [4].

There are three underlying motivational needs that affect the process of internalizing motivation: autonomy, competence, and relatedness. Autonomy requires not only choice but that the options align with internal values of the person. Competence is similar to self-efficacy in that it requires the perception of ability as well as opportunities to demonstrate that ability. Relatedness is a need to feel connected to others or something bigger than the self. Satisfaction of these needs, as perceived by the individual, leads to increasingly-internalized motivation, which obtains the aforementioned benefits [4].

Expectancy-Value Theory

Expectancy-Value Theory evaluates individuals' motivations based on their anticipation of positive outcomes (expectancy) and their desire to obtain such outcome (value). The evaluation of expectancy involves one's perception of their competence, at the time when the task will be undertaken. The evaluation of task value depends on the task's quality, which leads to an increase or decrease in probability that the individual will prioritize the task in comparison to others [5, 6].

The task value may depend on four variables: attainment value, intrinsic value, utility value, and cost. Attainment value is the importance associated with the outcome based on internalized value. Intrinsic value is that which stems purely from interest in and enjoyment from the engagement in the task. Utility value is the value associated with the outcome toward other future goals and interests. Finally, cost, in the sense of motivation, is associated with how the decision to engage one task may limit the ability to engage others and the effort required to do so [5, 6].

MOTIVATION INSTRUMENT

A survey instrument was created to measure a few basic aspects of first-semester students' motivation, containing 21 questions assembled from the principles of self-determination theory and expectancy-value theory. The survey was distributed to all 488 first-semester engineering

freshmen via email near the end of the semester, after attaining IRB approval. Ninety-eight (98) students responded (20%), and out of those, 82 were complete enough for use, providing an effective response rate of 17%. No demographic information was collected, but students entered their names, allowing us to connect their survey responses to their actual course grades and other enrollment information.

The instrument had questions in two categories and for both motivation theories. The categories of interest were motivation for getting good grades and motivation for learning and understanding engineering. Therefore, each was measured using both self-determination theory and expectancy-value theory.

For self-determination theory, questions were taken from the Self-Regulation Questionnaires for both Academic (SRQ-A) and Learning (SRQ-L) [7] and their wording was altered for use in our context. Responses were on a 1 to 5 scale, with 1 labeled as “not very true” and 5 labeled as “very true,” scored by combining questions for each category into the Relative Autonomy Index (RAI):

$$\text{RAI} = (-3) * \text{Amotivation} + (-2) * \text{Extrinsic} + (-1) * \text{Introjected} + (1) * \text{Identified} + (2) * \text{Intrinsic}$$

A negative RAI, therefore, indicates the individual has an overall external source of motivation relating to the category in question, whereas a positive RAI indicates that their motivation is largely intrinsic and from internalized sources.

For expectancy-value theory, questions were derived from the key variables of the theory, worded for use in our context. Responses were on a 1 to 5 scale, with 1 labeled as “not very true” and 5 labeled as “very true,” scored by combining questions for each category by adding them (with no weighting). A high score indicates the individual is likely to prioritize this task category over others, whereas a low score suggests the category is less important compared to others.

The instrument also contained questions about students’ views on how enrolling or not enrolling in the P/F program affected them. This information was used to measure students’ evaluation of the program and to ensure that with this experiment we were adhering to *primum non nocere* (first, do no harm).

RESULTS AND DISCUSSION

I. Fall 2011 Enrollment

In Fall of 2011, the term whence this study was conducted, there were 488 first-semester engineering students at Colorado State University. Of those, 51.2% (250) stayed in traditional A-F grading format but the other 48.8% (238) enrolled in the pass-fail (P/F) program.

II. Overall GPA Comparisons

As per our previous work, we compared the overall GPAs of both groups of students. We found a significant ($p < 0.001$) difference in the A-F students’ GPA at 2.80 and the P/F students’ GPA at 2.67. Again, and as discussed in our previous work [1], we felt that GPA did not provide sufficient explanation of students’ performance or experience in the program and hence collected data on motivation and individual course grades to supplement.

III. Engineering Courses

When individual course grades (for all 18 courses) were compared, rather than the collective, overall GPA, only 7 courses showed significant differences, partially due to the lower number of samples to compare (lower statistical N-value). The courses that had significant ($p < 0.05$) differences in grades between A-F and P/F students, always with the A-F grades higher than the P/F were: Chemistry 111 & 112, Math 124 & 126 (College Algebra), Math 160 & 161 (Calculus I & II), and Psychology 100.

IV. Motivation Scores

Across the board, the motivation scores were, on average, in the middle of their respective scales. That is, for students’ motivation for getting good grades and for learning engineering, both the self-determination theory questions and expectancy-value theory questions were ‘neutral’ in terms of motivation, indicating no strong biases toward intrinsic or extrinsic motivations nor toward high or low expectancy or value. Further, no significant differences were found between motivation scores for P/F and A-F students nor between motivation for grades and motivation for learning. However, this was merely a comparison of means, which collectivized the individual scores; to disaggregate and see deeper patterns, we performed correlations, which are discussed below.

V. Student Opinions of Their Choice

The survey also asked students for their opinions of how the pass-fail program affected them. That is, for students in the P/F program, we asked them if it benefitted them; for students not in the program, we asked if they felt they missed out or felt slighted by the program being offered. The results showed that, for students in the program, they did not feel it hurt them or their academic futures, and for students not in the program, they did not feel they missed out or would be hurt by their choice. This allowed us to conclude that, at least from the students’ perspectives, our experimental program was not harmful to the students nor their academic progress, which of course was our first and foremost concern during the experiment.

Additionally, we looked at correlations between these opinion scores and other variables measured. Table 1 below presents informative relationships observed between students’ opinions that their choice between P/F and A-F was a good choice (variable 1) and the second variable.

The relationships with GPA suggest that students had some reactions to their choice of P/F versus A-F in hindsight according to their academic performance. That is, students who chose the P/F program and ended up getting good grades were less satisfied (negative r) with their choice than those who got lower grades; the converse applies for A-F students in that the higher their GPA, the more satisfied they were with their choice of grading schemes.

Table 1. Correlations with Student Opinions

| Variable 2 | For which students | r (Pearson) |
|---|--------------------------------|----------------------|
| GPA | A-F students: P/F students: | 0.515*** -0.318** |
| Self-determined motivation for getting good grades | A-F students: P/F students: | N/S 0.368** |
| Expectancy-value motivation for getting good grades | A-F students: P/F students: | N/S N/S |
| Self-determined motivation for learning engineering | A-F students: P/F students: | N/S 0.383*** |
| Expectancy-value motivation for learning engineering | A-F students: P/F students: | N/S 0.316** |

$p < 0.10$ level (*), $p < 0.05$ level (**), and $p < 0.01$ level (***), N/S = not significant

The relationships between GPA and the motivational variables provide a deeper explanation of their experiences. First, the relationships between students' opinions and the 3 significant motivational variables for P/F students suggests that the more internalized their motivation and the higher priority that grades/learning were, the better the students' experiences were in the P/F program. However, since none of the motivation variables correlated significantly for the A-F students, it is reasonable to conclude that their opinions of A-F grading were already set when they entered college and that their motivational qualities had no effect on this opinion.

VI. Research Question

To answer the primary research question for this study, we performed statistical analyses including correlations between variables such as GPA, motivation scores, credit hours taken in the semester, and the specific course section taken. In order to process these data, however, survey results had to be combined with student academic data, which led to only 70 students' data being useful. Due to the high variances in the data and the split of these 70 data points into P/F and A-F categories, statistical comparisons became difficult. Therefore, for this data, statistical significance was considered up to the $p < 0.10$ level, instead of the common $p < 0.05$ level, meaning that we tolerated a slightly larger chance that the correlation was actually zero.

First, relationships were analyzed for variables that could explain why students chose to enroll in the pass-fail program. This meant that any variable that significantly correlated with enrollment in the program was of interest. Unfortunately, none of the other 11 variables had significant correlations, even at the $p < 0.10$ level. Therefore, we gained no significant insight as to why students chose to enroll or not enroll in the P/F program from this data. However, recall that the GPAs of P/F versus A-F students has already been compared, and that A-F students had significantly higher GPAs. Therefore, we added to the data the Colorado Commission on Higher Education's (CCHE's) Admission Eligibility Index, to see if enrollment in the program correlated with this college preparedness score. It did not correlate, suggesting that student readiness was also not a factor in students' decisions to take their classes P/F. Overall, this lack of correlation with P/F program enrollment suggests that students may have taken the program for deeper reasons than we studied, but at least that they didn't enroll just because they were less motivated to learn or get good grades nor were they less prepared for college.

Second, relationships were analyzed for variables that could explain the lower GPA for P/F students versus the A-F students. Informative correlations between GPA (variable 1) and the other variables are shown in Table 2 below.

Table 2. Correlations with GPA

| Variable 2 | For which students | r (Pearson) |
|--|--------------------------------|---------------|
| Self-determined motivation for getting good grades | A-F students: P/F students: | 0.344* N/S |
| Expectancy-value motivation for getting good grades | A-F students: P/F students: | N/S 0.331* |
| Self-determined motivation to learn engineering | A-F students: P/F students: | N/S N/S |
| Expectancy-value motivation to learn engineering | A-F students: P/F students: | N/S N/S |

$p < 0.10$ level (*), $p < 0.05$ level (**), and $p < 0.01$ level (***), N/S = not significant

These results show that only the students' motivations to get good grades actually have a relationship with their GPA. For the A-F students, the more internalized their motivation for grades, the higher their GPA; also, the more external their source of motivation, the lower their GPA. This correlates well with self-determination theory, which says that internalized motivation will always produce better quality results for the individual. For the P/F students, the higher their motivational priority was for grades, the higher their GPA. This is interesting as it shows that students in the P/F program didn't have to prioritize good grades like A-F students all did (since they could get a D and still pass), so the P/F students who did actually prioritize grades did better.

The follow-up to that was to see if motivation for learning was greater for the P/F students, perhaps showing that lowering the priority for grades increased the motivation for learning; however, none of the data analysis revealed any such results.

VII. Other Relationships

Other relationships were observed in the correlations that are worth noting, briefly, as shown in Table 3; note that values are only listed for “all students” instead of being split by P/F and A-F. First, a correlation was observed, in the population studied, between GPA and the number of credits students took. Of course, as this was a correlation, we cannot tell which way any causation would exist, but both cases are of interest. In one direction, this may suggest that students who took more credits got better grades, perhaps meaning that more responsibility led to more focus and effort, and better results. In the other direction, it may suggest that students who are stronger academically felt comfortable or compelled to take more credits. To supplement this point, it is noted that the correlation between credits taken and CCHE Index scores is also significant and positive, suggesting that this latter direction is a likely explanation.

Table 3. Other Correlations of Interest

| Variable 1 | Variable 2 | r (Pearson) |
|--|--|-------------|
| GPA | Number of credits taken | 0.201* |
| CCHE Index | Number of credits taken | 0.376*** |
| Self-determined motivation to get good grades | Expectancy-value motivation to get good grades | 0.501*** |
| Self-determined motivation to get good grades | Expectancy-value motivation to learn engineering | 0.332*** |
| Self-determined motivation to get good grades | Self-determined motivation to learn engineering | 0.518*** |
| Self-determined motivation to learn engineering | Expectancy-value motivation to learn engineering | 0.355*** |
| Self-determined motivation to learn engineering | Expectancy-value motivation to get good grades | N/S |
| Expectancy-value motivation to learn engineering | Expectancy-value motivation to get good grades | 0.485*** |

p<0.10 level (*), p<0.05 level (**), and p<0.01 level (***), N/S = not significant

As well, the correlations between the 4 motivational variables were observed. Data showed strong relationships between both theories in both categories, except for one, providing some evidence of validity for the motivational measures developed for this instrument. As well, seeing that

students’ motivations for learning and motivation for grades are highly correlated suggests that students may not distinguish highly between grades and learning. While this may seem like a logical relationship to many people, the authors of this work find this concerning, as the composition of a grade is often based on performance measures rather than learning measures. This could lead students to believe that they aren’t learning when they get bad grades, as well as other messages that professors might not intend to relay to students through their academic performance measures.

CONCLUSIONS

Overall, our findings suggest that students who chose to enroll in the P/F program were not very different from those who elected to get regular A-F grades. Their experiences at the end of the semester differed, and interestingly these opinions of their choice of grading schemes were in relation to how their actual grades came out.

More specifically, and most importantly, our study found that students’ motivations to get good grades had a significant relationship with their actual GPA performance. For the A-F students, they had no choice but to prioritize grades or risk hurting their GPA, so not surprisingly, the only relationship between their motivation and their semester GPA was in how internalized their motivation was for getting good grades. However, for the P/F students, their motivational prioritization of their grades was found to directly correlate with their GPA, suggesting that there was some freedom for P/F students to lower their priority of getting good grades and raise the priority of other things; we were unable to determine what other things that may entail.

Another interesting finding was that none of our data were able to explain why students enrolled or didn’t enroll in the P/F program. We expected that students who enrolled in the P/F program might have a lower level of motivation for getting good grades, or a higher level of motivation for learning about engineering (in contrast to focusing on grades alone); however, neither of these relationships panned out. Since some of the past research on P/F programs suggested that reducing focus on grades was good for students, we hoped to see more evidence of this in our study. Therefore, the concluding assumption is that students’ reasons for choosing one grading scheme over the other were other than what we observed, but at least they weren’t taking the P/F option simply because they were less academically motivated, overall.

We also found that many of the motivational variables correlated with each other, including between motivation for grades and motivation for learning, indicating that students didn’t have a lot of separation between grades and learning. Since we feel there is a significant and underappreciated difference in the two, we found this concerning. However, noting that our survey instrument was brief and preliminary, we suggest that a more thorough research investigation may

reveal better results for these observations, as well as the others.

Nonetheless, we were able to discern that, at least in the students' opinions, this experiment has not hurt them. While only a very few P/F students asked to restore their actual grades and GPA, thereby reverting their choice to take the P/F option, this was the exception and not the norm. Overall, however, we feel that the program has been beneficial, and plan to research it more deeply with the Fall 2012 cohort, as the experiment has been extended for one more year.

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I'm absolutely certain that's probably true: Exploring epistemologies of sophomore engineering students

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Abstract—Changes in students' personal epistemology are especially important for engineering educators to examine because they may affect the way students learn and their ability to adapt to engineering education learning environments and culture. Despite the large amount of theoretical research that has been done concerning students' conceptual change, little research has been done concerning their epistemological change. This study is a preliminary effort in identifying students' beliefs about knowledge and their effect on learning and successful comprehension of engineering concepts. The cohort consisted of 10 Civil Engineering students in a sophomore level Statics class, and each student participated in a 90-minute interview. The questions were based around an epistemological framework currently in development, which includes six separate dimensions but allows for examination of the ties between the dimensions. Analysis was completed in multiple stages, and involved two researchers co-coding for inter-rater reliability. Most students viewed knowledge as very simple, certain and objective. However, many students felt that different people had different knowledge of statics because of their different backgrounds and learning. These beliefs may be leveraged to support pedagogical practices of proven effectiveness such as peer-tutoring or other active learning methods.

Keywords- Civil Engineering, personal epistemology, Statics

I. INTRODUCTION

In order for engineering educators to understand how students develop into successful practicing engineers, researchers must understand the conceptual and epistemological changes that they go through in that process. Personal epistemology may have a strong influence on the way students learn and adapt to the learning environments and culture of engineering education, which makes it especially important to study. It could also be part of students' development as critical and reflective thinkers because it impacts the ways in which students evaluate their engineering knowledge.

II. PURPOSE

This study is a preliminary effort in identifying students' beliefs about engineering knowledge. The purpose of this study is not to build causal arguments, but to present data and preliminary conclusions exploring how students' epistemological beliefs, or personal epistemologies, manifest

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near the beginning of their pursuit of Civil Engineering education. The research presented here is part of a larger, longitudinal study designed to continue to explore students' beliefs about engineering knowledge as they pursue Civil Engineering into practice.

III. BACKGROUND

When researchers think about epistemology it is often in terms of the way it informs their research practices. Epistemology can inform the types of research questions researchers ask, the methods used to explore the answers to those questions and the answers that researchers consider valid [1]. Researchers have also begun to explore the ways that individuals incorporate these processes into their daily lives and information consumption through the concept of personal epistemology. Personal epistemology has also been linked to students' ability to experience conceptual change [2]. It is important for researchers to examine students' personal epistemologies and the ways in which they interact with student learning [3].

Several researchers have developed methods of evaluating students' personal epistemologies. For example, Schommer [4] developed the Epistemology Questionnaire (EQ) to explore personal epistemology. Several other researchers have since evaluated and refined the EQ and it encouraged the development of other questionnaires designed to examine personal epistemology. King and Kitchener [5] also developed a method to examine personal epistemology, which they call epistemic cognition. Their Reflective Judgment Model examined how people evaluated issues that are considered ill-structured, or problems about which "reasonable people reasonably disagree" [5, p. 37], through a structured qualitative interview process. Greene, Torney-Purta and Azevedo have also developed their own model of epistemic cognition, which utilizes three dimensions "Simple and Certain Knowledge, Justification by Authority, and Personal Justification," and developed a questionnaire to evaluate it [3].

Though many researchers have worked to develop frameworks of personal epistemology, there is much debate as to the reliability and validity of many of the frameworks as a whole [5]. Many of the personal epistemology frameworks and questionnaires have only been shown to be valid and reliable for a few of the dimensions that they consist of [3, 6, 7]. As a

result, continued work to develop valid and reliable methods of exploring personal epistemology is needed.

IV. THEORETICAL FRAMEWORK

Based on evaluations of the available frameworks of personal epistemology, our research group began to develop a framework which included many of the dimensions of personal epistemology other researchers have supported and validated through their research. In particular the work of Fitzgerald and Cunningham [8, 9], Mason et al. [10-12] and Hofer et al. [13-15] were influential. This framework was designed to incorporate the dimensions that other researchers have developed into a viable and, potentially, more complete personal epistemology framework that allows us to explore the many potential aspects of students' personal epistemologies without setting unnecessary limitations. Of the dimensions included in the framework, all but one (Social Processes of Knowing) were based primarily on the expert work that has already been done in the field of personal epistemology (see Montfort et al.'s Work in Progress titled "Theoretical Approach to Characterizing Changes in Students' and Engineers' Conceptual Understanding and Personal Epistemologies" in these conference proceedings for a more complete description of the foundations of the framework). It is this framework that the current study has been grounded in and the current study is part of the research process to test if the framework is a valid approach to explore engineering students' personal epistemologies. We consider a valid approach to be a framework that justifiably provides complete and accurate data about students' personal epistemologies in a way that allows it to be applied and tested by other researchers.

This personal epistemology framework consists of five dimensions. Each of these dimensions explores one aspect of personal epistemology that we have identified as defining the way that students understand and evaluate knowledge and knowing. The dimensions are Structure of Knowledge, Certainty of Knowing, Source of Knowledge, Justification of Knowledge and Social Processes of Knowing. Explanations of the dimensions are outlined in Table 1.

TABLE I. PERSONAL EPISTEMOLOGY DIMENSIONS

| Dimension | Explanation |
|-----------------------------|---|
| Structure of Knowledge | The ways in which students think about how knowledge is related and organized in a domain. |
| Certainty of Knowing | The ways in which students think about what knowledge in the domain is certain and how they attribute "truth" to knowledge. |
| Source of Knowledge | Where students think knowledge in the domain can come from. |
| Justification of Knowledge | The ways in which students think knowledge in the domain should be evaluated and the criteria for acceptable knowledge. |
| Social Processes of Knowing | The ways in which students think that different people know and how collective understanding affects knowledge. |

V. METHODS

This study employed a qualitative methods approach through the use of individual interviews.

A. Participants and Sample Selection

The cohort of students involved in this study consisted of ten Civil Engineering students. All of the students were sophomores enrolled in a combined Civil Engineering/Mechanical Engineering Statics class. Student participants were selected through preliminary interviews examining their personal epistemologies through a modification of Greene, Torney-Purta and Azevedo's Epistemic and Ontological Cognition Questionnaire [3] and conceptual understanding of Statics in combination with their performance on the Statics Concept Inventory [16]. A summary of these results are outlined in Table 2 and show a wide diversity among participants based on their conceptual understanding and personal epistemology. There are many different combinations of personal epistemology stances and conceptual understanding levels and Statics achievement. Students who a) agreed that Statics knowledge was simple and certain and b) had weak personal justification (meaning that they did not feel that they personally played an important role in the justification of Statics knowledge) represented radically different personal epistemologies than students who disagreed that Statics knowledge was simple and certain and who had strong personal justification. There was also a wide range of scores on the Statics Concept Inventory [16] and on Statics academic achievement. All of the students who were selected had at least a "C" grade in Statics to ensure that they could continue to participate in the longitudinal portion of the study. At the same time, we still selected students that ranged from the top 25% of the class to the bottom 25%. We also selected students that showed a wide range of conceptual understanding of statics from one student who scored close to a 92% on the concept inventory to one student who scored slightly over 4%.

B. Research Instrument

The interview protocol was developed based on the theoretical framework. It involved five sections of questions based on the five personal epistemology dimensions identified. Each section consisted of three to six statements reflecting an epistemological stance within that dimension. Students were asked to explain if they agreed or disagreed with that statement and why. Students were asked follow-up questions to clarify or expand on answers given in each section, as well as explore any relationships between the epistemological dimensions. All of the questions were asked with reference to Statics in order to provide domain specificity for the students' personal epistemologies, which is important to ensure the validity of student responses [3, 17, 18].

C. Implementation

Students participated in 90-minute interviews at the end of the term in which they participated in Statics. The interviews consisted of three sections, one being the previously mentioned direct personal epistemology section while the other two focused on student epistemologies in reference to other contexts. The interviews were conducted in the style of a

clinical interview [19]. The clinical interview was determined to be the most effective way to explore students' personal epistemologies because the individual understandings of knowledge and ways of knowing are "elusive" [20, p. 9]. Good clinical interviews are semi-structured and open-ended which allow participants to construct their own thoughts and pursue them while still maintaining comparable data. They also allow researchers to interpret meaning from statements made in the interview to construct an understanding of the participant's thinking as a whole [19]. In order to match the aspects of a clinical interview, these interviews were designed to have one interview protocol that was used with all participants. The questions in the protocol were developed to elicit a reaction to a statement about knowledge and knowing in each of the five personal epistemology dimensions. Participants were then asked probing questions to encourage them to explore in depth

the thoughts about knowledge and knowing that they were presenting.

D. Analysis

The interviews were coded using qualitative data analysis techniques. First, one researcher descriptively coded the interviews based on the responses the participants gave to each question. The researcher then went through the descriptive codes and developed a classification for each personal epistemology dimension for each student based on thematic analysis of the descriptive codes [21]. Another researcher completed the same process for four of the interviews and the results were compared for inter-rater reliability. After discussing the separate results and clarifying and the questions that arose, the researchers reached full agreement on the classifications of the students.

TABLE II. STUDENT RESULTS FROM SAMPLE INTERVIEWS

| Student | Gender | Previous Degree | Simple and Certain Statics Knowledge | Personal Justification ^a | Statics CI | Ranking Task on Beams | Statics Grade ^b |
|---------|--------|-----------------|--------------------------------------|-------------------------------------|------------|-----------------------|----------------------------|
| 101 | Male | Bachelor's | Agree | Weak | 33.3% | Correct | 4 |
| 102 | Female | None | Agree | Moderate | 25.0% | Correct | 3 |
| 103 | Male | Bachelor's | Disagree | Moderate | 41.7 % | Correct | 1 |
| 104 | Male | None | Disagree | Strong | 91.7% | Correct | 1 |
| 105 | Male | None | Agree | Moderate | 25.0% | Incorrect | 2 |
| 106 | Female | None | Agree | Weak | 37.5% | Correct | 2 |
| 107 | Male | None | Agree | Strong | 33.3% | Correct | 2 |
| 108 | Male | Associate's | Agree | Weak | 16.7% | Correct | 4 |
| 109 | Male | Associate's | Agree | Strong | 41.7% | Incorrect | 2 |
| 110 | Male | None | Agree | Weak | 4.2% | Incorrect | 3 |

a. Weak = no personal justification, Moderate = some personal justification, Strong = a lot of personal justification

b. Based on quartiles, 1 = top quartile, 4 = bottom quartile

VI. RESULTS

Based on the data analysis, three themes emerged that will be elaborated on in this paper. These themes were in the personal epistemology dimensions of Certainty of Knowledge, Source of Knowledge and Social Processes of Knowing.

A. Certainty of Knowledge

All of the participants felt that statics problems all had one correct answer and most felt that statics knowledge is certain. A typical answer was "...it always comes down to one number, one unit" given by student 102. This response shows that student 102 felt that Statics knowledge is simple and certain because it can always be simplified to a single, concrete answer. Several students introduced a caveat to this response though. One student (104) mentioned that there is a small range of correct answers available because of the slight errors introduced by things like rounding. His response shows that he still thinks that Statics knowledge is certain, by indicating that there are always correct answers, but he does imply that Statics knowledge is less simple by introducing the concept of error. Less than half of the students also mentioned that understanding of the subject was required for certainty in Statics.

B. Source of Knowledge

Most participants also responded that statics knowledge comes from observing the world, and most participants concluded that knowledge exists in the world, external to the knower. A typical response was:

104: "Maybe in a few years I'll make some observations that'll create knowledge... It's already there."

Interviewer: "Knowledge is already there?"

104: "Well, it's out there, we just haven't discovered it yet...Because it's not like we're changing any of the rules by knowing."

In this response, 104 shows that even though he thinks that it is possible to create knowledge in some way, Statics knowledge and the laws that make it up exist in the natural world and people's knowledge of them has no affect on what they are or how they work. In other words, whether people know Statics knowledge or not, it will exist in the world absolutely and immutably. He also shows that his version of knowledge creation is actually discovering knowledge that already exists in the world and is simply unknown to humans.

C. Social Processes of Knowing

Almost all of the participants felt that, though statics knowledge is universal in nature, different people could have different knowledge and/or understanding of statics. Over half of the students responded in ways that indicated that understanding is different between people. Student 109 gave a typical response for this stance:

I guess knowledge is the conceptual understanding--well no, just the understanding as a whole of a particular thing. So to have a different conceptual understanding that could happen because it could be that I figured it out differently and I see it differently. I know my math teacher, he looks at integrals and he sees it through paper, and I look at an integral and I understand it conceptually. So yeah, people could have different knowledge, if knowledge was defined as understanding of something.

Here, student 109 defines knowledge as understanding and asserts that different people can have different understanding of a topic, citing a personal experience to support that assertion.

Less than half of the participants felt that different people did have different knowledge of statics, without defining knowledge as understanding. Participant 103 responded with: "I think some people have more knowledge and I think some people think of things differently and sometimes one way of thinking is more beneficial than another." Here student 103 sets up his case that knowledge is different for different people by saying that people can have different amounts of knowledge and that people have different processes of thinking about things. He then goes on to further support that idea by saying that different people act differently and come to different conclusions based on their knowledge: "Different people are going to come to different conclusions and they're going to do things differently. Sure." He then concludes his point by asserting that even if people come to the same conclusion, they may reach it differently and they can never know if the conclusion is actually true:

103: "I think you can come to the same conclusions, but maybe the means that you take to get to those conclusions might not necessarily be done exactly the same. So yeah, I think different people might arrive-- I mean if it's a fact, it's kind of like you never know the truth, but people can arrive at something and if that actually turns out to be the truth, we just never know. But they both arrive there. They could do it differently."

Only one participant felt that correct knowledge was absolutely the same for everyone.

Interviewer: "Okay. If the people who studied statics in the past were different, our understanding would be different today."

104: "Well, if they weren't curious enough to go after that knowledge, we wouldn't have the same amount of knowledge. But as long as they were

doing their experiments correctly, they should've-- if it was completely different people doing it, they should've came up with the same knowledge. We've tested it often enough to prove it."

Interviewer: "Okay. So how would they have decided to do the same experiments? ...so let's say Einstein didn't come up with the Theory of Relativity, ...so you think that somebody else would've come up with it?"

104: "Eventually."

Interviewer: "Okay, would they have done it in the same way that Einstein did?"

104: "Maybe not-- okay, so maybe not quite exactly the same experiments but valid experiments, without any errors or anything like that. So reproducible experiments."

Interviewer: "And in the end we would still have gotten the Theory of Relativity?"

104: "Eventually, yeah <laughs>. At some point."

This participant's responses clearly indicate that he believes that as long as scientists were motivated and performing valid and reproducible experiments, they would absolutely have found the same knowledge that we have today eventually, whether or not the original scientists that developed that knowledge had done so.

As we will further explore in the discussion, this student's response about social processes of knowing directly matches with his beliefs about the source of knowledge and the certainty of knowledge, while most of the other participants had responses about social processes of knowing that did not align with their beliefs on the source or certainty of knowledge. Beliefs that knowledge is certain, external to the knower and the same for all knowers align with classifications of personal epistemology like Perry's dualism [22] or Greene, Torney-Purta and Azevedo's realism [3]. On the other hand, the idea that knowledge is different for different knowers is reflective of Perry's contextual relativism [22] or Greene, Torney-Purta and Azevedo's skeptic or rationalist [3] -- both of which are considered to be paradigmatically different ways of viewing the world from dualism or realism, respectively.

VII. DISCUSSION

Before beginning the discussion section we should note that this study asked students about their personal epistemologies in the context of Statics, not engineering in general. It is possible that the views represented here are specific to the domain of Statics. In that case, students may have more reflective or rationalist views about engineering in general. It is also possible that their views of Statics as simple, certain and objective are closer to being accurate than they would be of engineering in general. Statics is not currently a dynamic field, which may contribute to the represented personal epistemologies in that domain. Regardless of the relative stability of Statics as a field of study, however, it seems

unlikely to us that every issue in the field can be boiled down to a simple, singular and certain answer. Another result of these questions being asked about the domain of Statics, specifically the Statics course that the participants were taking at the time, is that there could be more complexity within the domain than we anticipated. It is possible that there are other sub-domains within Statics that the participants' personal epistemologies could vary over that were not captured by the generalization of the domain to their Statics course.

These concerns aside, the epistemological beliefs represented above could impact how well students are able to learn engineering. Both their ability to develop critical or reflective thinking skills and their ability to learn from traditional or constructivist engineering classrooms could be hampered by realist or dualist beliefs represented by belief in simple, certain and objective knowledge, which the majority of these students seemed to have.

One of the implications of their beliefs is that they may be lacking when it comes to reflective judgment and critical thinking skills. King and Kitchener define reflective judgment as using critical thinking and assessment of available information to inform decisions about knowledge [5]. If students are not thinking reflectively, it is likely that they are also not developing critical thinking skills and applying them to problems that they come across in engineering. King and Kitchener assert that reflective judgment occurs when students recognize that knowledge is not simple, certain and objective [5]. This implies that students are not developing the tools necessary to make critical evaluative judgments about ill-structured problems that will develop later in their academic and professional careers if they continue to view knowledge as simple, certain and objective.

It may be that students' epistemological stances on the certainty and objectivity of Statics could have a negative impact on their ability to be successful learners in traditional or constructivist classrooms. In traditional classes, there is limited epistemological training and basically no reason for students to question the simplicity, certainty or objectivity of the knowledge they are receiving because of the format of the class. As a result, this epistemological stance could limit students' desire to seek out new knowledge or be part of the knowledge creation process because they may not see any possibility for their involvement in knowledge creation in engineering. When they venture out into the workplace, these new engineers may have difficulty transitioning epistemologically to engineering practice where they would now be responsible for their own learning and for making critical decisions about difficult problems with no clear cut solution (e.g. how do you make a design decision when the process or acceptable results are not clearly stated in the code?). A constructivist classroom recognizes that students have previous knowledge that combines with what they are learning in class, that learning is a process of reorganization of knowledge and its placement within a context and that it is necessary for students to use their own metacognitive abilities to facilitate learning [23]. In this setting students are required to take part in making meaning of knowledge and building their own knowledge frameworks, but viewing knowledge as simple, certain and objective could limit their ability to do that.

The two students that gave responses that implied that either Statics or engineering knowledge might not be entirely certain, simple or objective both had previously obtained bachelor's degrees in other fields. This seems to support the assertion that students' epistemologies may change to a more relativist perspective simply through the college experience, which may mean that students' current beliefs about statics knowledge may change on their own with little negative effect on their ability to learn or become critical thinkers [20]. Because many of the students also mentioned that different people could learn or know statics differently, they may already be developing a more constructivist view of the world.

Most of the students interviewed believed that knowledge was simple, certain and objective while also believing that different knowers could know differently about the same topic. When trying to classify these students based on any of the common personal epistemology scales, this would put these students at both ends of a linear spectrum. Their beliefs represent extremely different viewpoints, both dualist or realist and contextual relativist or rationalist [3, 22]. These results imply that there is something more happening with students' epistemologies than just a linear transition from naïve to mature epistemological beliefs. As a result, one way to continue to improve upon the theories and frameworks of personal epistemology that have already been established would be to explore the nonlinearity of the spectrum of student epistemological beliefs.

VIII. CONCLUSIONS

The results of this study support two interesting conclusions. First, it appears that students have personal epistemology beliefs that may interfere with or limit their ability to be successful learners. These potential limitations are the result of student views of knowledge as simple, certain and objective and could affect their abilities to develop critical thinking skills and be fully successful in either a traditional or constructivist classroom. Conceptual change research has shown that simply refuting misconceptions is not enough to change student beliefs [24] and it is likely that there is a similar situation with beliefs about knowledge. Simply contradicting their epistemological beliefs may not be enough to change them. It may be important for faculty to work with students and train them to have more relativist or rationalist ways of thinking about engineering knowledge as they progress through their courses.

The second conclusion implied by these results is that a linear view of epistemology, from naïve to mature beliefs, may not encompass all of the potential combinations of epistemological beliefs students may have. Our data shows that students are able to have beliefs about the simplicity and certainty of their engineering knowledge as well as maintaining beliefs that engineering knowledge has social processes, which implies that their personal epistemologies have concurrent naïve and mature aspects. If we continue to classify personal epistemology based on a linear spectrum, it could limit the richness of our understanding. This conclusion opens up a new avenue of research into the multi-dimensionality of personal epistemology.

IX. FUTURE WORK

This study has highlighted some important questions that should be explored through future research.

- How do student epistemologies change over time?
- How are student epistemologies of engineering in general different than their epistemologies of Statics?
- How do student epistemologies and changes in personal epistemology relate to those of new engineers?
- Are student epistemologies of Statics detrimental to their ability to develop as critical and reflective thinkers in other areas of engineering?
- How do student epistemologies relate to their ability to successfully experience conceptual change?

We are beginning to explore these questions through a longitudinal study examining the personal epistemology and conceptual change of Civil engineering students from their sophomore year through their senior year and that of beginning engineers through their first two years in practice.

In the future, it would also be relevant to link these findings, as well as future findings about the development of personal epistemology through undergraduate engineering education, to other work that has explored student development in both their pre-college and collegiate experiences (e.g. [25] and [26]).

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Understanding Engineering Transfer Students:

Demographic Characteristics and Educational Outcomes

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Abstract—Transfer students make up a significant share of engineering college graduates, yet their persistence is seldom studied, largely because of the lack of longitudinal data. This analysis used longitudinal data from 11 universities enrolling large numbers of engineering students to investigate the demographic characteristics and educational outcomes of transfer students in engineering relative to non-transfers. We find that students who transfer to four-year engineering programs are more likely to come from under-represented minority groups (URMs) and less likely to be women, although both groups are over-represented at two-year colleges. The findings confirm existing research indicating that, on average, non-transfers outperform transfer students, and non-URMs outperform URMs. But we also find that URM transfers, and especially Black transfers, are no less successful than non-transfer students—indicating that the transfer pathway is an effective bridge to a four-year degree. This is partly true for women transfers who do as well as men but are outperformed by women non-transfers. Finally, we find significant variation in outcomes between full- and part-time students, which may be driving the observed differences by transfer status. Our results should inform debates regarding the efficacy of the transfer pathway in engineering, particularly for women and URMs.

Keywords—engineering; transfer students; persistence; student retention; STEM; higher education

I. INTRODUCTION

The need to increase the number of Americans joining the science, technology, engineering, and mathematics (STEM) workforce continues to draw national attention, most recently from the President's Council of Advisors on Science and Technology (PCAST). In the opening sentence of its latest report, the PCAST underscored the “need for approximately 1 million more STEM professionals than the U.S. will produce at the current rate over the next decade if the country is to retain its historical preeminence in science and technology” [1]. All five of the PCAST recommendations center on institutions of higher education, and one focuses in particular on partnerships between two- and four-year institutions to “diversify pathways to STEM careers.” In this paper, we explore one such pathway by focusing on students who transfer to four-year colleges with the intent to complete a degree in engineering.

Transfer students are a sizable, yet understudied, population that has the potential to increase the engineering workforce. Many of these students transfer from community and other two-year colleges in which women, minorities, and economically disadvantaged students are over-represented. For example, community colleges enroll nearly half of the nation's undergraduates and large shares of women (58 percent of community college students), minority (45 percent), first-generation (42 percent), and low-income (46 percent) students [2]. These are the very groups that are under-represented among engineers in the United States—and they constitute a potential pool of recruits for engineering and other scientific fields. Research on the effectiveness of the transfer pathway to an engineering degree is mixed, however. Some researchers argue that attending a two-year college lowers not only the probability of completing a bachelor's degree but also achievement through “transfer shock”, which they argue is commonly experienced when students transfer [3-7]. Some researchers add that transfer students are not as well prepared as non-transfer students to tackle college demands, particularly in STEM, and are therefore more likely to drop out. Others challenge these findings, particularly the effect of transfer shock (as student grades quickly rebound and even exceed those of non-transfers) and on the lower average achievement (they suggest that transfer students achieve higher academic performance and retention than do non-transfer students) [8-11].

Much existing research on transfer students is based on cross-sectional data and/or small data sets. We avoid both of these limitations by relying on a longitudinal data set that contains records for close to one million students in 11 institutions of higher education. By analyzing data on the large subset of engineering students, we are able to expand the existing literature by describing the characteristics and educational outcomes of transfer students compared to their non-transfer peers. In so doing, we contribute to the national dialogue on the effectiveness of this pathway to a degree in engineering and its potential to help address the need for more students, particularly women and under-represented minorities (URMs), completing degrees in engineering.

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II. ANALYSIS SAMPLE AND METHODOLOGY

Our analysis used records for 94,732 undergraduate students from the Multiple-Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD). MIDFIELD comprises a census of undergraduate students who attended 11 public institutions between 1988 and 2008. MIDFIELD institutions represent public universities that educate large numbers of engineering students (such as the Georgia Institute of Technology and the University of Colorado). The MIDFIELD database and sampling strategy are described in detail at <https://engineering.purdue.edu/MIDFIELD/p1.htm>.

From the 977,950 records available, we restricted our sample to those who (1) were domestic students (927,350), (2) were in the data set early enough for us to observe the possibility of graduation within six years (677,691), and (3) declared a major in engineering or otherwise expressed the intent to study engineering in the fifth semester of their programs (94,732). For transfer students, we estimated placement using transfer hours, assuming that 15 credit hours equals one semester; we also used the fifth semester as the reference point to capture most transfer students at the point of matriculation to ensure a valid comparison of transfers to non-transfers. This approach resulted in a sample of 21,542 transfer and 73,190 non-transfer engineering students included in this analysis.

We used standard *t*- and chi-square tests to establish whether any observed differences were significant, calculated Cohen's *d* and Cramer's *V* to estimate the magnitude of differences between groups irrespective of sample size, and used the Bonferroni adjustment to reduce the probability of false discovery due to the number of significance tests that were run. To facilitate replication of our work, we present unweighted and unadjusted results but replicated the comparisons of transfers to non-transfers by (1) weighing the data to account for different population sizes across institutions and (2) adjusting for clustering that might have led to underestimated standard errors. Results (available from the

authors) thus far indicate only one noteworthy change to the gender distribution by transfer status presented here (see Section III), and in a few other instances, slightly different point estimates.

Although our goal was to study the characteristics of and outcomes for transfer versus non-transfer students in engineering, it is important to note that transfer students are more likely to enroll in school part time than are their non-transfer peers. In fact, the proportion of students enrolled part time in the transfer population is four times that of the non-transfer population (30.7 percent versus 7.7 percent). Realizing that differences in outcomes between transfer and non-transfer students could be correlated with enrollment status, we also studied—and highlight here—meaningful differences that may be explained by enrollment status.

Last, it is also important to mention that, in studying student retention and graduation outcomes, we refer to students who neither graduated nor continued to be enrolled as dropping out or leaving the institution. We recognize, however, that some of these students (particularly transfer and part-time students) may, at a later time, resume their studies at the same or different institutions. Since we do not have enough years of data to observe these future outcomes, we restricted our findings to those that can be measured within the MIDFIELD institutions during the six years of available data.

III. WHO ARE THE ENGINEERING TRANSFERS?

Table I presents characteristics of engineering students by transfer and enrollment status. Results indicate that, on average, engineering transfer students are more likely to be male, older, and black, Hispanic, or Native American than are their non-transfer peers. Asians are equally represented across the two groups. This finding suggests that the transfer and non-transfer student populations differ in two key ways: the non-transfer population includes a larger share of Whites (77.9 versus 70.2 percent) and a slightly larger share of women (21.5 versus 19.3 percent) than does the subset of engineering transfers. Given that women and minorities account for large

TABLE I. CHARACTERISTICS OF ENGINEERING STUDENTS BY ENROLLMENT AND TRANSFER STATUS

| | Overall | | Full-Time | | Part-Time | |
|----------------------------------|-----------------|---------------------|-----------------|---------------------|-----------------|---------------------|
| | <i>Transfer</i> | <i>Non-transfer</i> | <i>Transfer</i> | <i>Non-transfer</i> | <i>Transfer</i> | <i>Non-transfer</i> |
| Age (in years) ^a | 21.8 | 17.9 | 21.3 | 17.9 | 23.5 | 18.2 |
| Gender | | | | | | |
| Women | 19.3% | 21.5% | 19.4% | 21.8% | 19.2% | 17.9% |
| Ethnicity | | | | | | |
| American Indian or Alaska Native | 0.5% | 0.3% | 0.6% | 0.3% | 0.4% | 0.2% |
| Asian or Pacific Islander | 8.0% | 7.4% | 7.8% | 7.3% | 8.4% | 9.0% |
| Black or AfricanAmerican | 14.5% | 9.2% | 12.9% | 8.5% | 18.0% | 16.9% |
| Hispanic or Latino | 4.4% | 3.0% | 4.2% | 2.9% | 4.8% | 4.2% |
| White | 70.2% | 77.9% | 71.9% | 78.8% | 66.3% | 67.5% |
| Other/Not Reported | 2.4% | 2.2% | 2.6% | 2.2% | 2.0% | 2.2% |
| Sample Size | 21,542 | 73,190 | 14,926 | 67,533 | 6,616 | 5,657 |

Note: Symbols flag Bonferroni-adjusted significant differences between transfers and non-transfers (*), within transfers comparing full- to part-time enrollment status (^), and within non-transfers comparing full- to part-time enrollment status (†) at alpha = .0002. We also report (M) medium and (L) large effect sizes (Cohen's *d* and Cramer's *V*).

^a For Age, we dropped three institutions due to missing data; although we are missing values for the remaining institutions, the percent missing does not significantly vary by transfer status, suggesting we can report these results without biasing our analysis.

shares of two-year college students, it would be reasonable to expect these groups to be disproportionately represented among engineering transfer students. Our results, however, challenge findings from the existing literature, which suggest that the students who succeed in transferring are not more likely to come from under-represented minority groups. These findings suggest that, at present, the transfer mechanism is more effective in facilitating access to four-year engineering programs for under-represented minorities than for women.

An analysis by enrollment status suggests that URMs, particularly Blacks, are less likely to enroll full time than are their White peers (results available from the authors). Among all engineering students, Black students are twice as likely to enroll part time as White students (22 versus 11 percent, after rounding). If we look at transfer students, the gap is similar—38.2 percent of Black transfers are enrolled part time compared with 29.0 percent of White transfers (a 9.2 percentage point difference). The literature suggests that enrollment status is often driven by financial considerations, which can have significant implications for academic performance and persistence. In the sections that follow, we explore these outcomes by transfer and enrollment status as well as gender and ethnicity.

IV. DO ENGINEERING TRANSFERS PERSIST AND PERFORM AS WELL AS THEIR NON-TRANSFER PEERS?

Table II presents retention and academic performance outcomes of engineering students by transfer and enrollment status. Overall, engineering transfers are less likely to persist in college (in engineering or in other fields) than their non-transfer peers: compared with 11.5 percent of non-transfers, 17.3 percent of engineering transfers drop out or leave within the six-year observation period without completing their studies. Indeed, results show that transfer students, on average, are less likely than non-transfers to graduate or continue studying engineering (75.5 versus 78.1 percent) or to graduate in engineering in six years including time spent at prior institutions (71.6 versus 73.3 percent).

Although these average differences in persistence are nominal in terms of effect size, they conceal meaningful variation in persistence by enrollment status. Full-time transfer students are more likely than part-time transfer students to graduate in engineering within six years (a 25.4 percentage

point difference), and the gap is slightly wider for non-transfer students (a 37.4 percentage point difference). In addition, students who drop out or leave the institution are disproportionately part-time students in both the transfer and non-transfer groups. As expected, this finding suggests that enrollment status is a key factor in explaining retention outcomes for both transfer and non-transfer students.

Although non-transfer students significantly outperform transfers in engineering and overall GPA, the performance gap between these two groups is negligible in engineering and small overall (a .05 and .07 grade point difference respectively). But once again, enrollment status appears to be driving the results. Full-time non-transfer students outperform part-time non-transfer students by almost one-fourth of a letter grade in both engineering and overall cumulative GPA based on a four-point scale (moderate effect sizes); the gap between full- and part-time transfer students is smaller but still significant and meaningful. There are no significant differences in academic performance by transfer status within the full- and part-time enrollment groups. These findings suggest that, on average, full-time engineering students outperform part-time engineering students irrespective of transfer status, thus challenging the research cited earlier, which suggests that transfer students are less prepared to tackle college-level engineering coursework.

V. DO OUTCOMES DIFFER BY GENDER AND ETHNICITY?

Given the observed differences in both demographic characteristics and persistence by transfer and enrollment status, we compared outcomes by gender and under-represented minority status to assess retention and academic performance within these groups. Table III presents the results overall and by transfer status.

Overall, women appear to have higher retention in engineering than men, though the difference is negligible. In fact, there are no significant differences in persistence by gender within the engineering transfer population. This finding is particularly important, considering that women are under-represented in engineering generally and within the transfer engineering population. This finding is also congruent with national research showing that the under-representation of women in engineering is a function of recruitment, not retention [12, 13]. Although women who do transfer to a four-

TABLE II. RETENTION AND ACADEMIC PERFORMANCE OF ENGINEERING STUDENTS BY ENROLLMENT AND TRANSFER STATUS

| | Overall | | Full-Time | | Part-Time | |
|------------------------------------|-----------|--------------|-----------|--------------|------------|-------------------|
| | Transfer | Non-transfer | Transfer | Non-transfer | Transfer | Non-transfer |
| Persisted in Engineering | 75.5% * | 78.1% | 83.0% * | 80.6% | 58.5% *(s) | 47.9% ^ (s), †(s) |
| Switched to Non-Engineering | 7.2% * | 10.4% | 6.4% * | 9.8% | 9.0% *(s) | 18.4% ^† |
| Left the Institution ^a | 17.3% * | 11.5% | 10.5% | 9.6% | 32.5% | 33.7% ^ (s), †(s) |
| Six-Year Graduation in Engineering | 71.6% * | 73.3% | 79.7% * | 76.4% | 53.2% *(s) | 36.0% ^ (s), †(s) |
| Engineering GPA | 2.88 * | 2.93 | 2.92 | 2.94 | 2.75 | 2.72 ^ (s), †(M) |
| Final Cumulative GPA | 2.93 *(s) | 3.00 | 2.97 * | 3.01 | 2.82 | 2.80 ^ (s), †(M) |
| Sample Size | 21,542 | 73,190 | 14,926 | 67,533 | 6,616 | 5,657 |

Note: Symbols flag Bonferroni-adjusted significant differences between transfers and non-transfers (*), within transfers comparing full- to part-time enrollment status (^), and within non-transfers comparing full- to part-time enrollment status (†) at alpha = .0002. We also report (s) small and (M) medium effect sizes (Cohen's d and Cramer's V).

^a "Left the Institution" describes students who are no longer found in the database. Such students may have transferred to another institution (possibly continuing in engineering), dropped out, or stopped out without having returned yet.

TABLE III. RETENTION AND ACADEMIC PERFORMANCE BY GENDER, UNDERREPRESENTED MINORITY AND TRANSFER STATUS

| | Gender | | | | | | | |
|------------------------------------|---------|-------|----------|--------------|----------|--------------|----------|--------------|
| | Overall | | Men | | Women | | | |
| | Men | Women | Transfer | Non-transfer | Transfer | Non-transfer | Transfer | Non-transfer |
| Persisted in Engineering | 77.2% | * | 78.6% | 75.6% * | 77.7% | 75.2% * | 79.4% | † |
| Switched to Non-Engineering | 9.5% | * | 10.5% | 6.9% * | 10.3% | 8.4% * | 11.1% | |
| Left the Institution ^a | 13.3% | * | 10.9% | 17.5% * | 12.0% | 16.4% * | 9.5% | † |
| Six-Year Graduation in Engineering | 72.3% | * | 75.1% | 71.5% | 72.5% | 71.8% * | 76.0% | † |
| Engineering GPA | 2.91 | * | 2.95 | 2.88 * | 2.91 | 2.88 *(s) | 2.97 | † |
| Final Cumulative GPA | 2.97 | *(s) | 3.03 | 2.92 *(s) | 2.98 | 2.97 *(s) | 3.05 | ^, †(s) |
| Sample Size | 74,806 | | 19,926 | 17,382 | 57,424 | 4,160 | 15,766 | |

| | Under-represented minorities (URMs) | | | | | | | |
|------------------------------------|-------------------------------------|----------|----------|--------------|----------|--------------|----------|--------------|
| | Overall | | URM | | Non-URM | | | |
| | URMs | Non-URMs | Transfer | Non-transfer | Transfer | Non-transfer | Transfer | Non-transfer |
| Persisted in Engineering | 66.5% | *(s) | 79.0% | 70.2% * | 64.8% | 76.3% * | 79.8% | ^, †(s) |
| Switched to Non-Engineering | 10.6% | * | 9.6% | 7.7% * | 12.0% | 7.2% * | 10.3% | † |
| Left the Institution ^a | 22.9% | *(s) | 11.3% | 22.1% | 23.3% | 16.5% * | 9.9% | ^†(s) |
| Six-Year Graduation in Engineering | 62.3% | *(s) | 74.3% | 67.1% * | 60.2% | 72.1% * | 74.9% | ^†(s) |
| Engineering GPA | 2.63 | *(L) | 2.96 | 2.64 | 2.63 | 2.93 * | 2.96 | ^ (M), †(L) |
| Final Cumulative GPA | 2.77 | *(M) | 3.01 | 2.75 | 2.78 | 2.97 *(s) | 3.03 | ^ (M), †(M) |
| Sample Size | 13,300 | | 79,316 | 4,168 | 9,132 | 16,848 | 62,468 | |

Note: Symbols flag Bonferroni-adjusted significant differences between transfers and non-transfers (*), within transfers comparing full- to part-time enrollment status (^), and within non-transfers comparing full- to part-time enrollment status (†) at alpha = .0002. We also report (s) small, (M) medium, and (L) large effect sizes (Cohen's d and Cramer's V).

^a“Left the Institution” describes students who are no longer found in the database. Such students may have transferred to another institution (possibly continuing in engineering), dropped out, or stopped out without having returned yet.

year engineering program persist as well as their male peers, they still lag behind non-transfer women. Results show that women transfers are more likely than women non-transfers to drop out or leave the institution (a 6.9 percentage point difference). Similarly, women transfers are outperformed by women non-transfers in terms of average GPA, although the effect size is small. Women overall, however, appear to outperform their male counterparts, though the gap is small. These findings indicate that women transfers do as well as men, but not as well as women who are not transfers.

More startling are the differences in outcomes by under-represented minority status. Non-URMs “out-persist” URMs on all measures, though effect sizes are small. About 66.5 percent of URMs persist in engineering compared with 79.0 percent of their non-URM peers. URMs are less likely than non-URMs to graduate with an engineering degree in six years (a 12.0 percentage point difference). And almost one-fourth of URM engineering students leave before obtaining a degree, irrespective of transfer status—double the proportion of non-URM engineering students. We find even larger performance differences in engineering and overall GPA by URM status. URM students do not perform as well as their non-URM peers, particularly in engineering, whereas on average, non-URMs perform one-third of a letter grade above URMs based on a four-point scale (large effect size). As discussed below, these findings are primarily driven by Black students.

Although URM persistence and academic performance lag behind that of non-URMs overall, URM transfers appear to

succeed in four-year engineering programs. They are as likely, if not more likely, to persist in engineering and to graduate with a degree in engineering in six years than are URM non-transfers (a 5.4 and 6.9 percentage point significant difference, respectively, though effect sizes are negligible). URM transfers also perform as well as non-transfers in both engineering and overall GPA. These findings are particularly important, as they suggest that the success of URM students in engineering programs is not dependent on direct entry into a four-year engineering program (transfer versus enrollment straight from high school). These findings are also relevant in light of previously cited research suggesting that, once students transfer, they suffer from “transfer shock”. URM students who transfer into four-year engineering programs perform as well as their non-transfer peers on average, despite taking fewer courses that would have been likely to boost their GPA. Future research will explore whether they experience transfer shock and recover, or whether they do experience transfer shock at all.

Given the significant differences in retention and academic performance by URM status, we disaggregated the analysis by ethnicity to better understand outcomes for specific ethnic minorities. Table IV presents these results overall and by transfer status. We find that Blacks are primarily driving the difference in persistence—25.6 percent of Blacks drop out or leave the institution compared with 14.1 percent of Hispanics, whose drop-out rate trails closely behind that of their White peers and is indistinguishable from that of Asian students. Blacks also lag significantly behind their peers in academic

TABLE IV. RETENTION AND ACADEMIC PERFORMANCE BY ETHNICITY AND TRANSFER STATUS

| | Whites | | | Asians | | |
|------------------------------------|---------|----------------------|--------------|----------------------|----------------------|--------------|
| | Overall | By Transfer Status | | Overall | By Transfer Status | |
| | | Transfer | Non-transfer | | Transfer | Non-transfer |
| Persisted in Engineering | 79.0% | 76.0% * | 79.8% | 79.1% | 78.9% | 79.2% |
| Switched to Non-Engineering | 9.7% | 7.3% * | 10.4% | 8.9% | 6.5% * | 9.6% |
| Left the Institution ^a | 11.2% | 16.7% * | 9.8% | 12.0% | 14.6% * | 11.2% |
| Six-Year Graduation in Engineering | 74.2% | 71.7% * | 74.8% | 75.4% | 75.8% | 75.2% |
| Engineering GPA | 2.96 | 2.94 * | 2.97 | 2.88 ^{^(s)} | 2.86 | 2.89 |
| Final Cumulative GPA | 3.02 | 2.97 ^{*(s)} | 3.03 | 2.98 [^] | 2.93 ^{*(s)} | 3.00 |
| Sample Size | 72,146 | 15,125 | 57,021 | 7,170 | 1,723 | 5,447 |

| | Blacks | | | Hispanics | | |
|------------------------------------|-----------------------|--------------------|--------------|----------------------|--------------------|-----------------------|
| | Overall | By Transfer Status | | Overall | By Transfer Status | |
| | | Transfer | Non-transfer | | Transfer | Non-transfer |
| Persisted in Engineering | 63.4% ^{^(s)} | 68.7% * | 60.9% | 76.3% | 76.3% | 76.3% ^{†(s)} |
| Switched to Non-Engineering | 11.0% [^] | 7.8% * | 12.5% | 9.6% | 7.8% | 10.3% |
| Left the Institution ^a | 25.6% ^{^(s)} | 23.5% | 26.6% | 14.1% [^] | 16.0% | 13.4% ^{†(s)} |
| Six-Year Graduation in Engineering | 59.0% ^{^(s)} | 65.1% * | 56.2% | 72.7% | 74.5% | 71.9% ^{†(s)} |
| Engineering GPA | 2.54 ^{^(L)} | 2.57 | 2.52 | 2.87 ^{^(s)} | 2.84 | 2.88 ^{†(L)} |
| Final Cumulative GPA | 2.70 ^{^(L)} | 2.70 | 2.71 | 2.93 ^{^(s)} | 2.89 (s) | 2.95 ^{†(M)} |
| Sample Size | 9,821 | 3,116 | 6,705 | 3,125 | 940 | 2,185 |

Note: Symbols flag Bonferroni-adjusted significant differences between transfers and non-transfers (*), between given ethnic group and White students ([^]), and between Hispanics and Blacks ([†]) at alpha = .0002. We also report (s) small, (M) medium, and (L) large effect sizes (Cohen's d and Cramer's V).

^a "Left the Institution" describes students who are no longer found in the database. Such students may have transferred to another institution (possibly continuing in engineering), dropped out, or stopped out without having returned yet.

performance. Black students earn an overall GPA of 2.70 on average, one-quarter of a letter grade behind Hispanics and one-third of a letter grade behind Whites based on a four-point scale. The gap widens considerably if we focus only on engineering GPA (and it results in large effect sizes). It therefore appears that Blacks are driving the gap between URM and non-URM students in both persistence and academic performance.

While the persistence and academic performance of Black students is of great concern, outcomes for Black transfers suggest that their success in engineering programs is not dependent on direct entry into a four-year engineering program. In fact, Black transfer students are more likely to persist in engineering than are Black non-transfers (a 7.9 percentage point difference). And 65.1 percent of Black transfers graduate with a degree in engineering in six years compared with only 56.2 percent of Black non-transfers. Last, there are no significant differences in academic performance between Black transfers and non-transfers. These findings suggest that the transfer pathway may be an effective mechanism for fostering the completion of college degrees in engineering among Black students.

VI. CONCLUSION

This analysis provides valuable information for policymakers, educators, and professionals seeking to expand the pool of highly trained engineers to meet the needs of the modern workforce. Although one of the functions of community and other two-year colleges is to act as a stepping stone to a four-year degree, the transfer mechanism appears to be more effective in facilitating access to and completion of

four-year engineering programs for under-represented minorities than for women even though both groups are over-represented at two-year colleges. Women transfers fail to enroll in and complete engineering programs at the same rate as those who enroll in college directly out of high school. Therefore, the transfer pathway does not appear to increase the supply of female engineers as much as it could.

Yet the transfer pathway does seem to be an effective means to an engineering degree for under-represented minorities. Not only are URMs well represented among transfer students, but URM transfers are more likely than non-transfer URMs to graduate in engineering in six years and perform as well in the same courses. These results suggest that, for under-represented minorities, success in engineering programs is not dependent on direct entry into a four-year engineering program. Still, despite the success of URM transfers, the broader problem of low academic performance and persistence among Black students merits further study to both uncover its causes and devise solutions [15].

Moving forward, we intend to develop models to test the effectiveness, efficiency, quality, and equity of the transfer pathway to a baccalaureate engineering degree, taking into account the factors and relationships revealed in this paper. Understanding the outcomes associated with the transfer population, both overall and for under-represented groups, is an essential first step towards understanding a population that holds promise with respect to augmenting and diversifying the engineering workforce.

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Work in Progress: Transfer Students in Engineering:

A Qualitative Study of Pathways and Persistence

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Abstract—Our paper presents preliminary results of interviews of 28 transfer students in engineering at two institutions and is part of a larger mixed-methods study on engineering transfer students. The two institutions differ on a key dimension: one has many formal articulation agreements and the other does not. We discuss the reasons students begin their studies at the sending institution and describe their experiences with the applications and admissions process at the receiving institution. We describe the “culture shock” students experience when adjusting to the academic requirements and social culture of the new institution; we also highlight the transfer student capital and strategies students use to adjust to the receiving institution.

Keywords—transfer student; articulation agreement; transfer shock; persistence; STEM

I. INTRODUCTION

Transfer students comprise a significant share of engineering graduates, yet the context of the transfer process and motivations for transferring are rarely studied. Research indicates that both institutional- and individual-level factors should be considered when investigating how to improve transfer student retention and completion [1, 2].

We present initial findings from the qualitative portion of a mixed-method study of the pathways, persistence and outcomes of transfer students in engineering using the Multiple Institution Database for Investigating Engineering Longitudinal Development (MIDFIELD). The quantitative portion of our study uses the MIDFIELD database, which includes records for 174,075 undergraduate students who matriculated into engineering, 35,152 of whom were transfers, at eleven public institutions between 1988 and 2008. The qualitative portion will ultimately comprise 80-100 interviews of engineering transfer students. Unlike prior work that focuses mainly on students who begin their studies at four-year colleges, this project extends MIDFIELD analyses in a new direction by examining the experiences of transfer students in engineering.

II. RESEARCH QUESTIONS

To more fully understand the experiences and motivations of transfer students in engineering, our analysis explores the following questions: (1) When and why do students choose to transfer? Why do they choose engineering?; (2) How do students describe the climate for transfer students at the receiving institutions? What challenges do they face?; (3) Do transfer students participate in special transfer programs?; Do

such programs help with the acculturation process?; and (4) What processes and structures help or hinder the transfer process? In this paper, we report the results of our interviews at two of the eleven MIDFIELD institutions.

III. RESEARCH METHODS

Campus representatives at two MIDFIELD institutions sent an invitation to all engineering students who had transferred into the institution in the two semesters preceding the semester of the interview. Interested students completed a survey to provide demographic and scheduling information. Participants were chosen from six engineering majors - civil, chemical, computer, electrical, industrial, and mechanical - and were diverse with respect to gender and ethnicity. Selected students were interviewed in Fall 2011 and in Spring 2012. We used a semi-structured interview protocol to learn more about student experiences with the transfer process. Interviews ranged from 19 to 65 minutes in length; the average interview lasted approximately 37 minutes. Participants were paid \$20 upon completion of the interview. Interviews were audio-taped and then transcribed verbatim and verified. We used a constant comparative coding method, whereby emerging concepts were constantly compared to data that had already been coded [3].

IV. INITIAL FINDINGS

A. Reasons Students Initiated Studies at Sending Institution

Students reported a variety of reasons for initiating their studies at another institution, including: (1) participation in a dual-degree program with the MIDFIELD institution; (2) scholarship restrictions leading to selection of the first institution (e.g., sports scholarship); (3) saving money; and (4) as a “backdoor” route to the MIDFIELD institution for students who were initially denied admission.

B. Assistance Provided by the Sending Institution

One institution has formal transfer agreements, such as 2+2 and 3+2 programs, with a large number of schools. Several students, particularly those enrolled in such programs, reported that staff, advisors, and professors at the sending institution were helpful with the transfer process. Many students who initially enrolled in a school without a formal transfer arrangement with either institution received little help with the process from the sending institution. Several students reported feeling pressured by the sending institution’s staff to remain at the school, rather than transfer.

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C. Experiences with the Transfer Process

Nearly all respondents described the application and admissions processes as smooth. This was especially true for students in formal transfer programs or those who had been accepted to the MIDFIELD institution as first year students, but opted to begin at another institution. Many benefitted from information posted on the university website, such as course descriptions and curriculum maps; several students relied solely on this information to ensure they met the transfer requirements. However, many said the credit evaluation and course selection processes were difficult to navigate. Those who visited the campus and talked to someone reported more positive experiences with the transfer process.

Students expressed mixed opinions about formal transfer orientation activities. Although the majority of students found the information about the basics to be useful (e.g., location of buildings, parking rules, etc.), many reported they could have benefitted from more information about their major and an opportunity to meet faculty and students from their department.

D. Culture Shock: The Academic Transition

Nearly all students, especially those further along in their coursework at the time of transfer, reported experiencing an “academic culture shock.” Students felt ill-prepared for the difficult courses and overwhelmed by professors’ expectations at the new institution. Some students were very pleased with the higher-order learning at the receiving institution. They were able to become involved in real-world problem solving that enabled them to extend their learning beyond the rote memorization emphasized at their sending institutions.

Several felt that native students at the destination institution had a “GPA advantage” over transfer students because their grades in general education courses boosted their overall GPA, whereas transfer students arrive with no GPA and must begin taking difficult courses right away. Thus, they do not benefit from the GPA “buffer” offered by what they perceived to be easier courses than those offered in engineering.

E. Adjusting to the New Institution

Several students reported feeling like they did not fit into the “student culture” in which the native students had been participating since their freshman year. Few students said they participated in programs designed specifically for transfer students, other than the regular orientation. For example, one student participated in a general minority transfer student program; another minority student participated in a transfer program in his major. Students used several strategies to acclimate to the new institution, including joining social organizations (such as fraternities), finding paid employment (both on-campus and off-campus), living on campus, and interacting with friends from high school or the sending institution. These strategies reinforce themes from Tinto’s research on the importance of social and academic integration for student retention [4]. Others expressed feeling isolated upon their arrival, especially those who did not have time to join social groups or to find employment. Many respondents joined professional engineering groups. Some said they joined mainly

for “resume building” while others gained more concrete benefits from joining the professional groups.

F. Strategies for Succeeding at the MIDFIELD Institution

Nearly all students reported forming study groups, either informally through friendship networks, or formally through engineering classes. One student said she didn’t know such groups were a part of the “engineering culture” at her institution. Thus, she floundered on her own during the first semester. Students who were involved with an independent study or research project with a professor reported smoother transitions as did students who found employment on campus.

G. Suggestions for Improving the Transfer Process

The interviews suggest that transfer students have unique experiences and needs that personnel who assist students during the transition process often do not consider. Students would benefit from opportunities to network with other students who have been through the transfer process. For example, a formal transfer mentoring program and a “transfer panel” of students could be useful. Students described the need for a more extensive orientation session. Students should be allowed to contact departmental advisors earlier in the transfer process, prior to transferring. And, the receiving institution could provide more information to transfer students prior to their arrival, much like the university does for native students.

V. FUTURE RESEARCH

Our study aims to understand the retention and success of engineering transfer students who comprise a significant share of engineering majors. While the study results reported here support the existence of “culture shock” among some students, the findings also highlight how students accumulate transfer student capital (TSC) to ensure successful transitions [5]. TSC is evidenced in students’ ability to access knowledge required to negotiate the transfer process, such as information about course prerequisites and about transfer agreements. In 2012-13, we will interview students at three additional MIDFIELD institutions, including those with strong and weak transfer agreements, and relatively high percentages (>25%) of transfers into their engineering programs. These data will allow us to compare across institutions, based on a number of factors, including major, presence of transfer agreements, participation in research or study groups and in programs for transfer students.

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Work in Progress: Development of a Metacognition Scaffold in STEM / P-6 Engineering Context: MCinEDP

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Abstract— A new model of metacognition scaffolding, *Metacognition in the Engineering Design Process (MCinEDP)*, which parallels instruction in engineering design processes (EDP), has been designed for use in pre-college, particularly 2-6, engineering classrooms. MCinEDP utilizes engineering as the context for implementation of metacognitive activities that are designed to aid students in building mastery of metacognition and to improve specific abilities in engineering design. This paper outlines the design process in order to reveal the intersection of instructional design theory, instructional design models, cognitive theory and learning theory that supported this project.

Keywords—metacognition, engineering design, K-6, scaffolding

I. INTRODUCTION

Schoenfeld (1992) wrote, “problem solving and metacognition ... are perhaps the two most overworked -- and least understood -- buzz words of the 1980's,” because, as he further noted, the definitions of metacognition were varied and disjointed to the point that the concept was difficult to use. Since that time, many models of metacognition have been devised and the construct has been studied in various subjects. While definitions varied, metacognition as monitor and regulator of cognitive processes has been a central theme [2] through most. The model of this paper, *Metacognition in the Engineering Design Process (MCinEDP)*, borrowed from that notion and teaches children a simpler version, stating that metacognition is “thinking about thinking.”

MCinEDP utilizes engineering design as the context for implementing activities designed to aid students in building mastery of metacognition. Students learn that metacognition is knowledge of one's own cognitive processes, strategies, implementation and regulation. Specific questioning and instruction in cognitive strategies is scaffold in MCinEDP. Metacognition instruction, teacher questions, student metacognition sheets and social interactions are outlined in the Teacher Guide that serves as an implementation resource.

Not only are we interested to find if the model is effective, we also want to learn more about metacognition in elementary design contexts. This study starts at the beginning design stages and has progressed through field testing and revisions. Further research will investigate metacognition in elementary students in general, using a comparison group while evaluating the model with a treatment group in a pilot study

that will determine effectiveness and further opportunities for improvement.

II. BACKGROUND

A. Instructional Design

The design process used for MCinEDP is based on the ADDIE model (Analysis, Design, Development, Implementation and Evaluation), an iterative and cyclical process of ID that is common in the instructional design (ID) field today [3]. Experience teaching elementary school students in design processes and attempts at implementing metacognition instruction informed the analysis stage of development. Further, literature review extended into the design stage. The development and implementation stages have included formative evaluation that included field testing in grades 3-5 engineering classrooms with an expert K-6 engineering teacher.

B. Metacognition

John Flavell is cited in most metacognition literature and, despite the many studies that have come since, his work in the 1970's still influences many, including this model. He wrote that cognitive monitoring and regulation are areas that children are limited in but can be taught through metacognition experiences focused on person, task and strategy [4].

Model development evolved through consideration of many existing models of metacognition, including Flavell's, from which all were based on regulated learning, strategic questioning, critical thinking, reflective judgment, iterative learning, purposeful strategy selection, and social metacognition. The MCinEDP model intersects with scaffolding of self-regulated learning, the LEGACY learning cycle of adaptive instruction [5] and EDP instruction utilizing ill-structured design problems [6]. This scaffolding intends to facilitate metacognition without overtaxing cognitive load [7].

III. MCINEDP

A. Contribution

While a considerable amount of literature and research investigates the use of metacognition skills in reading and mathematics [7-8], science and engineering are largely ignored by the conversation. Situating the scaffold in an engineering context builds on the National Research Council's

guiding principles for engineering education by promoting engineering “habits of mind” in reflective, technology design applications [9].

There are a few research studies involving the use of metacognition and measurement of cognition with college level engineering students [9-11], yet thus far, none specifically deals with elementary level engineering. Improving metacognition in other domains has been found to improve learning abilities [4, 7-8]. The importance for scaffolding of metacognitive skills increases even more in the advancement of online and self-regulated learning, and domain-specific instruction supports metacognitive skills that are generalizable to other content areas [12]. MCinEDP differs from other models and studies of the target age group, in that scaffolding and in-time prompts are present throughout. Contrarily, another study uses software for design logs which are later used for post hoc reflection [13].

B. Model

MCinEDP involves student reflections at three stages of the five-stage EDP [14]. These Steps are labeled Plan, Monitor, and Evaluate (Figure 1). The students are instructed to consider the Aspects of Person, Task or Strategy in terms of thinking and not physical actions, or the next step of the EDP.

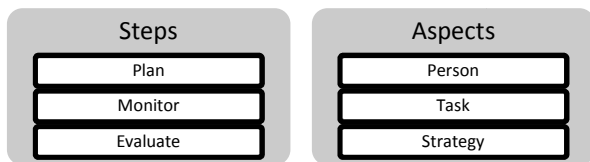


Figure 1 Students examine the three aspects of their progress throughout all three steps of the MCinEDP, individually, by responding to written prompts.

The prompts for metacognition are also influenced by Jonassen’s seven steps of solving an ill-structured problem based on framing a problem, monitoring strategies and adapting the solution [15], or in this case, adapting the metacognitive knowledge. In planning (Figure 2), students reflect on prior knowledge (person), goals, framing the problem (task) and what they need to do or learn to solve the

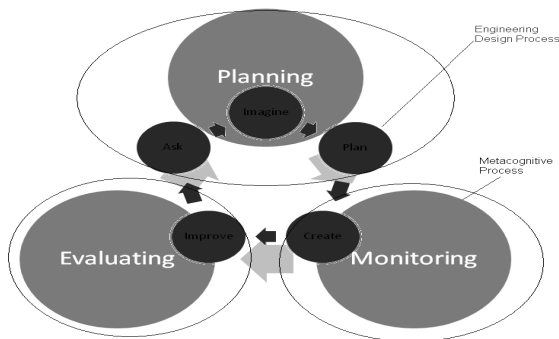


Figure 2 The three phases of MCinEDP align with the five stage engineering design process[16] (Ask, Imagine, Plan, Create, Improve), as well as others, that are used in elementary schools.

problem (strategy). Monitoring occurs when building a testable model in the EDP, and students evaluate their planning before modifying strategies or reframing the

problem. During evaluation, students reflect on their thinking and metacognition throughout the project and identify opportunities for improvement. At each stage, and particularly in evaluation, the students discuss their metacognition responses such as strategies, goals, and prior knowledge. In addition to the socially constructed metacognition in each project, the classroom will occasionally write and improve a letter to future classes to teach them about their metacognition experiences.

IV. CONCLUSION AND NEXT STEPS

The implementation and evaluation phases of the project will include mixed methods to determine the effectiveness of the model. Pre and post student reports, observations, teacher and student interviews, and in-depth content analysis of student products will be used for the evaluation that will also be used for further refinement of materials prior to an additional round of evaluation.

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Animated Engineering Tutors: Middle School Students' Preferences and Rationales on Multiple Dimensions

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Abstract— The goal of the study was to explore middle school students' preferences for an animated engineering tutor, and investigate their rationales for their choices. 77 middle school students participated in the study, and provided their preferences and rationales on various dimensions of an animated engineering tutor such as gender, age, personality, and clothing. Results showed that for teaching engineering in a computer-based instructional module, students preferred an animated engineering tutor that was similar to their age, matching their own gender, with a fun personality, and that speaks slowly.

Keywords: *animated pedagogical agents; engineering education; preferences; engineering tutor*

I. INTRODUCTION

How can we help middle school students learn about engineering, focus their attention on relevant parts of a computer-based engineering instructional module, and keep them motivated to learn throughout the program? One technique used in multimedia research that could be applied to engineering education is to use visual presence of animated pedagogical tutors within the instructional module to facilitate students' engineering learning and influence perceptions of the learning experience.

An animated pedagogical agent (APA) is a human-like or otherwise animated on-screen character appearing in a computer-based instructional module [1][2][3]. Common objectives of pedagogical assistance provided by an APA are to keep students focused on important elements of the learning material, to keep them motivated, and to provide context-specific learning strategies [4]. By establishing a social interaction between learner and agent, APAs may maintain learners' engagement in a learning task, ultimately fostering student learning [5][6][7][8]. According to the persona hypothesis, the visual presence of an APA in computer-based learning environments can increase learning outcomes and positively affect learners' perceptions of the learning experience [9][10].

While designing an engineering instructional module for middle-school students, the animated engineering tutor that is present in the module may be a role model for students. Students perform in a certain way because either their behaviors are prompted, modeled, or valued by significant others to whom they feel or want to feel attached or similar [11]. In science and engineering this may suggest that relatedness, the need to feel belongingness, similarity, and connectedness with others, is centrally important for internalization, and improving learning. Sorge, Newsom, and Hegarty [12] examined the attitudes of Hispanic middle school students towards science and scientists, concluding that most of the middle school students in the study had difficulties perceiving themselves as scientists mainly due to a lack of exposure to role models and negative media stereotypes. Students develop a stereotypical image of a scientist as they get older and scientists drawn are predominantly male [13]. In order to increase minority involvement in science, students need early exposure to role models and after-school programs [14].

A. Agent Similarity Hypothesis

APAs have both internal and external properties which influence student learning [15]. The internal properties of APAs are related to the instructional methods used by the agent in facilitating learning. Instructional methods applied through APAs may include directing learner attention through gestures [16][17], visual signaling, coaching, delivering feedback messages, verbal guidance, and modeling [18][19][6]. External properties of APAs relate to the image and voice of the agent, and include agent characteristics, such as gender, age, ethnicity, clothing, appearance and tone of voice.

According to the similarity attraction hypothesis, humans are more attracted to others who appear and behave similarly to themselves [20]. The similarity attraction hypothesis in the

context of learning with animated pedagogical agents would predict increased learning and more positive perceptions the greater the similarity between the learner and the agent.

Previous research has explored various agent similarity effects. Kim and Wei [21] conducted a research study with high-school students to examine learners attributes (gender and ethnicity) and their preferences for a pedagogical agent. The results indicated, first, that students preferentially chose a same-gender agent, and Caucasian students chose a Caucasian agent and Hispanic students chose a Hispanic agent significantly more frequently than a different-ethnicity agent. In studies [22][23] it was found that animated agents who match the observer in race and gender can have greater impact on women in increasing their interest in and reducing their stereotypes about gender in engineering fields.

Capobianco, Diefes-Dux, Mena and Weller [24] found in draw-an-engineer tests that 58 % of elementary school students drew the engineer as a male, whereas 18 % drew a female, and 24 % drew a group or a person without discernible gender. A study conducted with college students [25] stated that a majority of students reported a preference for agents that were similar to them, at least in terms of gender, a majority reported a preference for avatars that were “like” them, suggesting that students may also want to match other characteristics, such as hair color and race, perhaps sexual orientation, or even hobbies. As humans often treat computers as social entities, social accounts of interaction such as the similarity attraction hypothesis may be relevant to computer-based instructional environments. How people perceive agents may influence both the self-perception and perception of others using a particular agent as well as message perception and retention [25].

A study conducted by Moreno and Flowerday [26] randomly assigned learners to a choice condition, in which learners selected an agent from 10 options, differing in gender and ethnicity, or a non-choice condition, in which learners were assigned to an agent. Results first indicated that overall learners did not more often select an agent that matched their gender or ethnicity, but students of color were more likely to select an agent with the same ethnicity than their Caucasian counterparts. Next, the results did not indicate positive effects of gender similarity or ethnicity similarity on retention, or transfer learning measures, nor on program ratings. Furthermore, the students who were able to choose had lower scores, lower transfer scores, and lower program ratings when the agent matched their ethnicity.

Behrend and Thompson [27] did not find positive effects of gender similarity and surprisingly found a negative effect of ethnicity similarity on utility ratings of the agent. However, these two effects were shown to be additive for engagement of students; the highest engagement ratings were obtained in the group where both gender and ethnicity was matched to the

learners gender and ethnicity. But, the learning outcomes were not significantly influenced by gender or ethnicity similarity. Kim and Baylor [6] found that Caucasian students rated Caucasian agents as more engaging and affable, whereas African American students rated these characteristics higher for African American agents. Kim and Baylor did not find better learning, self-reported self-regulation or self-reported satisfaction for agents who matched the learners in gender or ethnicity.

Rosenberg-Kima, Baylor, Plant and Doerr [22] in experiment 2 explored participant perceptions of engineering (self-efficacy, interest, stereotypes, and utility) after learning with one of eight agents differing on three factors (age, gender, and ‘coolness’). Rosenberg-Kima, Baylor, Plant and Doerr [22] expected that participant perceptions would be most impacted after viewing an agent they considered that was similar or aspired to (i.e., young and ‘cool’). Results supported this hypothesis; the two conditions (male and female) with young and ‘cool’ agents led to higher self-efficacy and interest ratings than the remaining six conditions. Lee, Liao, and Ryu [28] explored gender similarity by using computerized voice only. The authors showed that male participants rated a male agent’s voice more likeable than a female agent, whereas no difference in voice likeability was found for female participants. A similar pattern was found in participants’ ratings of voice credibility, content quality, and self-confidence in the topic discussed (e.g., skin care and makeup or dinosaurs). In these studies, learning outcomes were not measured [22] or [28].

Our current study examines middle school students’ preferences for an engineering animated tutor on multiple dimensions and their rationale for attractions to those dimensions for an engineering tutor. If we were to teach middle school students about engineering, who would they be more motivated to learn engineering with and why? Stereotypes and preconceived notions may be crucial to interpreting a character’s purpose in a computer-based learning module. Engineering is mainly viewed as a male-dominated field. So what would be the middle school students’ choice for animated engineering tutors? Who would they feel more comfortable with, and be more eager to learn from? Who would capture and keep their attention? This current study focuses on furthering the research by targeting middle-school students’ preferences for an engineering tutor, and contributing to the body of research not only by investigating gender and gender match-no match preferences, but also by investigating further characteristics of an animated engineering agent, such as teaching style, age, outfit, talking style, and preferences for a cartoon or a realistic looks, as well as the rationale that leads to these preferences.

B. Research Questions

1. What are students’ preferences for an animated engineering tutor?

2. What are the rationales for students' choices for specific tutors?
3. What are the preferred attributes of an animated engineering tutor for middle school students?
4. What are the rationales for the preferences for specific attributes of an animated engineering tutor?

II. METHOD

A. Participants

The participants were a total of 77 middle-school students at a public school in the Southwestern U.S with the mean age of 12.83 years ($SD = 0.84$). There were 35 (45.5%) males, and 42 (54.5%) females.

B. Materials and Procedure

Each student was provided with a survey form that included pictures for three agents that were of various age and gender. Students were asked who they would prefer to learn about engineering from (Which of the below would you want to teach you about electric circuits in the computer?) and asked to list three reasons for their choice. The survey had an image of old male agent, a young female agent, and a young male agent displayed side-by-side (see Fig. 1). Additionally, the survey form had six forced-choice items and each of these items had an open-ended portion for students to explain their choices in detail. These six survey items asked students their preferences for an animated engineering tutor on various dimensions, (e.g., I learn better from my engineer teacher if s/he is girl/boy, young/old, dresses serious/dresses cool, talks fast/talks slow, fun/serious, cartoon human/real human). Also, students' own gender and their choices for the agent gender were captured to conduct further statistical analysis.



Figure 1. Agent choices in the survey

C. Data Coding

Quantitative and qualitative data analysis techniques were used to analyze the collected data. Frequencies were obtained from student choices for each agent and analyzed quantitatively for significant differences between choices. Qualitative data that were obtained from the students open ended-responses analyzed by two researchers. During the analysis, researchers identified characteristics of the agents noted by the students. Any characteristic that was noted only once and did not fit into any already existing category was collected in the "other" category. As soon as a particular characteristic was noted twice or more frequently, a category was established. From the initial investigation seven superordinate and 30 subordinate categories emerged, and the data were coded into the seven superordinate categories that are displayed in Table 1.

Under each of these superordinate categories listed in the Table I, each superordinate category included various numbers of subordinate categories. For example under the "personality" superordinate category; personality_cool, personality_comfortable, personality_fun, personality_interesting, personality_nice, personality_interested, personality_relatable, personality_smart, personality_trustworthy, personality_good subordinate categories emerged.

TABLE I. AGENT PREFERENCE SUPERORDINATE CATEGORIES

| Superordinate Categories | Subordinate Categories | Example Statements |
|--------------------------|--|--|
| Age | Young Old | He looks younger He is older he may know more She seems more of my age |
| Appearance | Dress Pretty Professional Real | She has cool shoes He dresses like us He knows how to dress |
| Personality | Comfortable Cool Fun Good Interesting Interested Nice Relatable Smart Trustworthy | He looks like someone to trust She looks like she is interested Because he looks like someone I would get along |
| Gender | Male Female Opposite | She is a girl He is the opposite sex Women know a lot of thing |
| Speech | Boring Clear Slow | It looks he doesn't talk fast She talks at the right speed Talk clear |
| Teaching | Comprehensive Effective Examples Friend Gesturing Patient Understands | He is smarter as a teacher He looks like a person who explains things to you He might teach me a lot |
| Other | All other characteristics | Feels more better Because I don't know her, and I would like to know what she likes The others do not influence me |

III. RESULTS

A. Preferences for a Specific Agent:

Twenty-eight (36%) of the students chose a young male agent to be their engineering tutor. Thirty-six (47%) of the students preferred a young-female agent. Thirteen (17%) of the students preferred an old-male agent as tutor.

B. Rationales for Preferences for Each Agent

Young-male agent: When the open ended responses were analyzed the following categories were frequently cited for students' rationales for choosing the young-male agent (each student was able to list three categories); "teaching_effective" (13 students), "personality_cool" (11), age_young (9), "appearance_dress" (9), "personality_smart" (7), "appearance_real" (6), "personality_nice" (4), personality_relatable (3), "personality_fun" (3), "gender_male" (3), "personality_trustworthy" (2), "personality_interesting" (2), "teaching_comprehensive" (2). There were students who noted less frequent traits for young-male agent choice, such as having "personality_good" (1), "gender_opposite" (1).

Young-female agent: When students' responses to open-ended questions were analyzed, the following categories emerged as most frequently cited for preferring the young-female agent; "gender_female" (16 students), "teaching_effective" (14), "appearance_real" (13), "personality_smart" (11), "appearance_dress" (5), "speech_clear" (5), "age_young" (4), "personality_cool" (3), "appearance_pretty" (2), "personality_nice" (2), "teaching_friend" (2), "personality_trustworthy" (2), "personality_interested" (2). There were students who noted less frequent traits for young-female agent choice such as; "personality_comfortable", "teaching_patient" (1), "personality_fun" (1).

Old-male agent: When students' responses to open-ended questions were analyzed, the following categories emerged as most frequently indicated as a reason for their choice for the old-male agent; "teaching_effective" (13 students), "personality_smart" (8), "appearance_professional" (4), "teaching_examples" (3), "age_old" (2), "personality_cool" (2), "personality_fun" (2). Some students who indicated less frequent traits for old-male agent choice, such as "speech_clear" (1), "speech_slow" (1), "personality_good" (1) and "personality_nice" (1).

C. Overall Preferences and Comparisons

Agent gender preference: Forty participants (52%) preferred a female engineering agent, and thirty-seven participants (48%) preferred a male engineering agent. Overall, male and female students demonstrated a significant preference toward a pedagogical engineering tutor that matched their own gender, $\chi^2(1) = 21.75, p < .001$. Thirty-two of the female students (76%) chose a female agent; twenty-seven of the male students (77%) chose a male agent for their animated engineering tutor. The learners were more likely to choose either a young female or young male agent for their

learning interactions, $\chi^2(2) = 10.62, p = .005$. Thirty-six (47%) of all students reported preferring a young female agent and twenty-eight (36%) of the students reported preferring a young male agent. Example student rationales for choosing matching gender were "I am a girl too", "boys are better than girls", "they [boys] are easy to understand", "I would feel more comfortable", "I am a boy too", and "they [boys] would be cooler."

Agent age: Overall, students preferred a young agent over an old agent for their learning interactions, $\chi^2(1) = 17.78, p < .001$. Fifty-seven (74%) of all students reported preference for a young agent. Thirty-six (86%) of the females chose a young agent, whereas twenty-one (60.0%) of the male students chose a young agent. The preference for a young agent among female students was significant, $\chi^2(1) = 21.43, p < .001$, while there was no significant preference among male learners. Students had various rationales for preferring a young agent such as "[young] up to date", "I can relate to them", "they don't need to stop and think", "he understands us because he is young," "it would be like a friend teaching me," and "old people don't get my attention."

Agent personality: Overall, learners are more likely to choose an agent with a 'fun' personality, compared to a more 'serious' personality, $\chi^2(1) = 12.48, p < .001$. Seventy percent (70%) of all learners reported preference for an agent with a fun personality. Thirty-four (81%) of females preferred a 'fun' agent, whereas twenty (57%) of male students preferred a 'fun' agent. When broken down by the learner gender, the difference in number of males preferring a fun agent over a serious agent was not significant, $\chi^2(1) = 0.71, p = .40$. However, female learners did demonstrate a significant inclination toward a 'fun' pedagogical agent, $\chi^2(1) = 16.10, p < .001$. Example student rationales for choosing a fun personality agent were as follows; "serious is boring", "fun is good", "I learn more", "make you laugh", "make subject fun", "to make the learning process fun", and "it will make learning easier."

Speech pace: All learners are more likely to choose an agent with slow speech pace for their engineering domain learning interactions instead of fast speech pace, $\chi^2(1) = 31.18, p < .001$. Sixty-three (82%) of the learners reported preference for an agent with slow speech pace, and fourteen (18%) of the students reported preference for an agent with fast speech pace. Rationales for choosing a slower speech pace over a faster speech pace were as follows; "so I could understand it", "that is good that he talks slow", "slow is better", "so I can hear everything they are saying", "explains more clearly", "so he explains it step-by-step", and "it lets me memorize."

Clothing: There was a marginally significant preference, across all participants, for animated agents with dress described as 'cool', compared to agents with 'serious' dress, $\chi^2(1) = 3.75, p = .053$. Forty-seven (61%) of all learners

reported a preference for an agent with ‘cool’ wardrobe, whereas thirty (39%) of the students preferred an agent with a “serious” wardrobe. Example student quotations for reasons for choosing an agent with cool clothing instead of serious clothing were as follows; “I dress cool”, “she looks great”, “makes me want to pay attention”, “class would go easy”, “more fashion the better”, “they look pretty”, and “so you could learn fast.”

Cartoon image or real human image: Overall no significant differences were found for the choices for a cartoon or real human image. Forty-two (55%) of the students preferred a cartoonlike image for the engineering animated agent. Rationales for choosing a cartoon-like image over a real human image were as follows “cartoon humans grab my attention”, “it would be fun and educational”, “funny” and “engineer teachers look like a cartoon”, “I would focus more on the problems”, and “it’s cool and funny”. Thirty-five (45%) of the students preferred a real-humanlike image for the engineering tutor, and the rationales for choosing that were as follows; “serious”, “helps us understand more”, “so I can ask questions back at her”, “they explain better”, “to explain easier and no distraction”, “it would look better”, and “it would be more realistic.”

IV. CONCLUSION

The present study showed support for the similarity hypothesis, concluding that middle school students tend to choose animated engineering tutors that are similar to them in age and gender. Students may feel more comfortable learning a perceivable difficult topic such as engineering, from a peer like agent that is similar to them. It is clear from students’ responses to open-ended questions that they feel close to same-age and same gender agents. As engineering is perceived as a difficult topic [29][30][31], middle school students tend to choose a fun personality engineering tutor compared to a serious one, primarily to keep the topic interesting and enjoyable, as well as a slow rate of speech to help them to follow easier and understand better.

Our results indicate that for middle school students, the use of a peer-animated engineering tutor agent that is similar to the students may improve interest and students motivation for learning. More research is needed to determine the effects of cool, young, same-gender, and fun-personality animated engineering agents on actual learning outcomes for this population.

The findings of this exploratory study shed light on future instructional modules that focus on teaching pre-college students about engineering fields and the design of recruitment materials. Computer-based and print-based, engineering outreach materials should be designed in a motivational manner by including suitable animated engineering tutors to capture students’ attention and continuing motivation to learn from those agents.

V. FUTURE RESEARCH

We will build on this study to develop a computer-based preference survey to investigate students’ preferences for animated engineering tutors in more detail. The proposed computerized survey will aim to reach to a broader audience, including elementary, middle, and high school students. The categories that most frequently emerged in this study for choosing a particular agent, will be used as a base for the computerized version of the survey, while categories that occurred with low frequencies will be excluded. Specifically only one participant noted agents’ personality as being “comfortable” as a reason which will be excluded.

Based on the present study, frequently stated categories will be used to prompt student responses in the computerized survey. Specifically, after students watch an introductory module on engineering disciplines that includes the different agents, students will be asked for their preference for an animated engineering tutor. Also they will be asked what they most and least liked about the displayed agents. The following options will be given for most liked categories for the agent: smart, young/old, male/female, realistic, professional, slow speech, fast speech, helpful, cool, dress, clear voice, nice, fun, interesting, trustworthy. The following choices will be given for the least liked attributes for the displayed agent: smart, young/old, male/female, realistic, professional, slow speech, unhelpful, boring voice. An old-female animated engineering tutor will be added. Students’ preferences and opinions towards this old-female agent will be investigated.

Additional future research directions are to employ these agents in computer-based engineering instructional modules [1-3, 32] and study their effectiveness in specific pedagogical functions, such as signaling [17], prompting [33], and practice guidance [34].

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A semantic enrichment experience in the early childhood context

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Abstract— Current society is characterized by an increasing interest in the provision of high-quality Early Childhood Education and Care (ECEC) services. In this area, we developed a platform aimed to create an effortless communication channel among parents and educational professionals. Parents and educators are provided with technological tools to increase the performance of the educational process in a holistic manner by means of automatic alert mechanisms and recommendations according to personalized information within the system. The next phase in the progression of our platform has been reusing information freely available on Internet to enrich the local Knowledge Base of the platform. This paper discusses the approaches used to complement the platform initial local data with information available on different Internet sources in order to improve the performance of the developed platform services.

Keywords - Early Childhood Education and Care; Knowledge Based Systems; Linked Open Data; Semantic Enrichment

I. INTRODUCTION

Over the last years, the use of new technologies in the education field has improved the democratization and the universality of the educational environments. Even during the childhood stage, focused on Early Childhood Education and Care (ECEC), the application of software tools is causing a growing interest. In this context, we developed an ECEC platform [1][2] which allows parents and educators to collaborate and to cooperate in order to create a high quality learning environment for the child. With our solution, parents and educators have a natural communication channel and smart assistants being able to generate automatic alerts and recommendations according to child's evolution. With this purpose, the information of the system has been semantically modeled in such a way that, according to the predefined semantic rules, it is possible to apply reasoners to extract conclusions about the child's condition and current evolution.

In our platform, software assistants infer (similar to human reasoning) complex and intelligent recommendations based on the context of the child. Initially, the information treated by these assistants consists of community-generated data, i.e., data introduced by the users of the system (families, caregivers, teachers, etc.). The platform has been specially designed to early childhood schools and to parents with children enrolled in these centers. It provides services for both the care and education of the child. Among these services, we can highlight:

the blogging service, allowing centers to publish multimedia information about the daily activities; the educational resources recommender service, which allows retrieving resources tailored to the capabilities and progress of each child; and alerts and monitoring services focused on major factors in this stage, such as health and food issues.

The next step in the evolution of our platform is reusing information freely shared on Internet to enrich the Knowledge Base (hereafter KB) of the intelligent assistants. To this end, we propose the use of the available data under the precepts of the Linked Open Data Initiative (LOD) [3], which seeks to create an interconnected space of “machine-understandable” information from different sources. Using this approach, local data are complemented, increased and linked with data from different repositories and contexts. This enrichment can improve the performance of the developed services and get new features and functionality not previously envisaged.

Since currently the LOD network does not yet have many data nodes (it is in its early stages), we have also considered the possibility of extracting relevant information from different traditional web portals on the Internet.

This paper presents the strategies used to enrich the local data managed by our ICT platform smart services through the use of data available in external sources. Particularly, the paper focuses on the enhancing of the following services: a) educational resources recommender, b) nutritional monitoring service and c) health monitoring service. Previously, section 2 discusses the LOD network as a global knowledge base and briefly describes its previous uses for the enrichment of semantic data, and section 3 briefly describes the key issues of the original ECEC platform. Sections 4 and 5 describe how the platform was enhanced and the steps taken to enrich our data with the various external sources and the effects of the achieved enrichment. Finally, Section 6 outlines the main conclusions of this work.

II. LINKED OPEN DATA AS AN ENRICHMENT RESOURCE

The World Wide Web is a universe of information that, since its inception, has been specifically designed to be friendly and readable for a human being but, in consequence, it is illogical and meaningless for a software agent, which makes it difficult to automate the processing of web pages. In order to solve this problem, Tim Berners Lee has initiated and

promoted a social movement oriented to the global freely-available publishing data on the Web in a standard and machine-processable format. This initiative is known as Linked Open Data (LOD) and seeks to turn the Web into a vast interconnected information space, known as the Web of Data. The chosen publication format is based on the RDF metamodel, which allows to represent statements in the form of triples (subject, relation, object). The LOD initiative is constantly growing. In September 2011, it had 295 nodes linked together and more than 31 billion of RDF triples [4]. Among these nodes we can distinguish two types: area specific nodes, focused on a specific topic (such as music, books, health, statistics, etc.) and multidisciplinary repositories, whose most outstanding element is the DBpedia [5], a pivotal centralizing node that maintains information extracted from Wikipedia.

In this ocean of inter-connected information, an intelligent application (or Knowledge-Based System) has at its disposal a huge supporting KB, which can be interpreted and used in the most convenient way for providing rich and accurate user services. These applications are known as Linked Data applications. A simple example of these is the DBpedia Mobile [6], an agent for mobile devices that provides the user with a map of his position including information, extracted from the DBpedia node, on nearby locations. Moreover, there are applications that combine and supplement their own semantic data establishing connections with web-based open data. This is known as “enrichment”. In this area there are several successful projects among which we mention two. The first one, promoted by the BBC, it is aimed to create a website about music, BBC Music [7], which includes ad-hoc generated data enriched with information of albums, discographies, biographies of singers, etc., from LOD nodes as DBpedia, Music Brainz [8] or Echo Nest [9]. The other notable example is the Linked Movie DataBase semantic repository [10], specialized on the cinematographic area, in which adding a new record (film, actor, director, etc.) it is automatically generated a link to an equivalent record, one that refers to the same object, in other LOD repositories such as DBpedia.

Currently, in the field of education (especially in higher education), there are many semantic tools that try to personalize and customize in an intelligent way each course based on the user profile. These are the applications known as Semantic Web-based Educational Systems (SWBES) [11]. The use of semantic technologies in this field to create, query and manipulate knowledge in a standardized way helps to reach the goal of enhancing and improving the student's educational experience. Under this approach we can find projects such as MAPLE (Mobile, Adaptive & Personalized Learning Experiences) [12], that allows to customize the learning environment by local exposure of information following the precepts of the Linked Data initiative. Also noteworthy is the development of new Intelligent Tutoring Systems (ITS) based on semantic technologies. These ITS individually infer what (and/or how) resources must be presented to the user. This is the case of projects such as [13].

It must be noted that this kind of educational platforms base their operation just on the information generated by their user's communities. Thus, the automatic use of information from

external sources such as Linked Data nodes is a very novel approach. However, as above mentioned, its application allows to have global, detailed and virtually unlimited information which can be used to enhance and improve processes and outcomes. For this reason, in this paper we describe the process used to enrich the educational platform, which we have previously created for the field of early childhood education, with data from different sources, particularly from Linked Data nodes.

III. THE ORIGINAL PLATFORM

The provision of a holistic platform oriented towards the childhood education and care has led us to generate a natural way of communication linking the families and the educators. By means of the tools provided by the platform, they can collaborate and cooperate to improve the quality of the attention and the education received by the children. The key supporting feature of our platform is the capacity to generate results (alerts, recommendations, observations, etc.) in an automatic manner.

To achieve this goal, it was developed a semantic model to express all the relevant pieces of information in the system, i. e., the KB. To complete this task, several modules were developed using the support of OWL. This RDF-based language guarantees the syntactic interoperability and enables the use of certain searching mechanism such as SPARQL to conduct systematic searches. Also, it was developed a set of semantic rules that make possible for inference engines, such as Pellet, Jess, or RacerPro, to extract complex conclusions about the evolution of the children (e.g., alerts about inappropriate menus for celiac child and suggestion about an alternative dish) according to the information stored in the KB.

In order to facilitate and boost the use of the platform a multichannel web-based interface specially designed for “connected TV” (through Wii or GoogleTv) and for mobile devices (smartphones and tablets) was developed. For that purpose, the platform is composed of two logic layers: the business logic layer (BLL) and the presentation layer. In the BLL, a number of services are installed to support further services offered by the platform. Each application processes the relevant information for its purposes by means of inference engines and a Linked Data explorer. The latter recovers information from the KB using SPARQL queries. In the presentation layer, the information is adapted to an output data flow tailored for the specific target device in use.

IV. ENHANCING THE PLATFORM

The initial platform included a closed KB composed by the data provided by the system users. The primary task of this contribution is oriented to complement this initial set of knowledge with the freely available information on the Web. Therefore, the authors developed a module for the enhancement and enrichment of the original system capable of discovering, and processing knowledge from the Internet and adding it to the KB under the form of RDF sentences. These features are implemented by means of three agents that tackle information from different sources.

The main mechanism to enrich the platform is the use of Linked Open Data repositories. The applied philosophy is based on searching and linking records related to the same concept from different repositories, including ours. This is also known as Record Linkage [14]. To carry out this task, it was developed an agent, called LOD Enrichment Agent, in charge for gathering new knowledge by means of launching periodically a semi-automatic tool based on SILK [15]. Using SILK, this agent creates new links among records using the relation `owl:sameAs` according to the level of similarity of the checked properties. This is achieved with a proper definition of concepts and properties to be compared using a specific declarative language (LSL) inherent to the frame of SILK. This configuration must be conducted by an expert in the domain well aware of the needs of the system and the involved repositories. As a result of the use of this tool properly configured, new RDF triples are created and inserted into the KB resulting in a better base for inference processes.

Another mechanism to enrich the information within the system is based on processing information from APIs of pre-selected web platforms. The information recovered from a query to a specific API is compliant with the ad-hoc provider model. Therefore, for each one is required to make a custom parsing of the response to get the requested information. To server as a proof of concept, it was developed the software to make use of a particular API, the Smart Indexer. This agent performs requests using a HTTP channel and processes the response from the server to get the new knowledge.

Finally, it was developed a Web Parser. This agent behaves as a crawler that explores a set of pre-configured pages expressed in HTML. Upon its examination, it is created the appropriate set of new RDF triples with the new knowledge to be added on the KB. This process, usually referred to as Web Scrapping [16], is based on a pre-configuration of the HTML entities with the relevant information for the custom purposes.

As shown on the Fig. 1, the presented architecture enables the provision of a set of complex and add-value services in a seamlessly manner to the rest of the modules as the only impact is on the KB that is eventually enriched.

V. ENRICHING THE KNOWLEDGE BASE OF AN EARLY CHILDHOOD EDUCATION PLATFORM

In this section we will focus on describing as we have enriched the local data, especially with information from the Linked Data network, and what improvements this means for our platform services. Particularly, we will focus on three basic user applications offered by the platform: the resources educational recommender, the monitoring food service and the monitoring health service. These three applications manage key factors in the education of children and the effects of enrichment have been a marked improvement on their performance and functionality.

A. Educational resources recommender

This application seeks to get, from the large collection of educational resources of the platform, a list of individual recommendations based on the child's evolution. To do that, the application is based on the child's profile to select the resources to work with, in order to achieve new competences. In the short time, from the history of already fulfilled activities, a specific smart agent selects those resources allowing a thematic continuation, thus favouring the consolidation of concepts (e.g. if the child has made a farm animal activity, the following recommended resource could be focused on wild animals, but always tailored to his educational needs). This ensures that the chosen activity gives the child the essentials and the concepts needed in his current state of development.

Initially, for each educational resource, it is stored a group of basic data (name, description, type, etc.) and a set of tags to identify them (source tags). These tags can be introduced by any platform user. This is known as social indexing or collaborative folksonomy [17]. To enrich this initial data, we have followed three different approaches:

- In order to complement the collaborative folksonomy tags, we made use of the well-known WordNet lexical database [18]. This database provides an API to query those terms (synonyms, hypernyms and hyponyms) related to a particular concept. On this basis, the system periodically runs an automated process to get

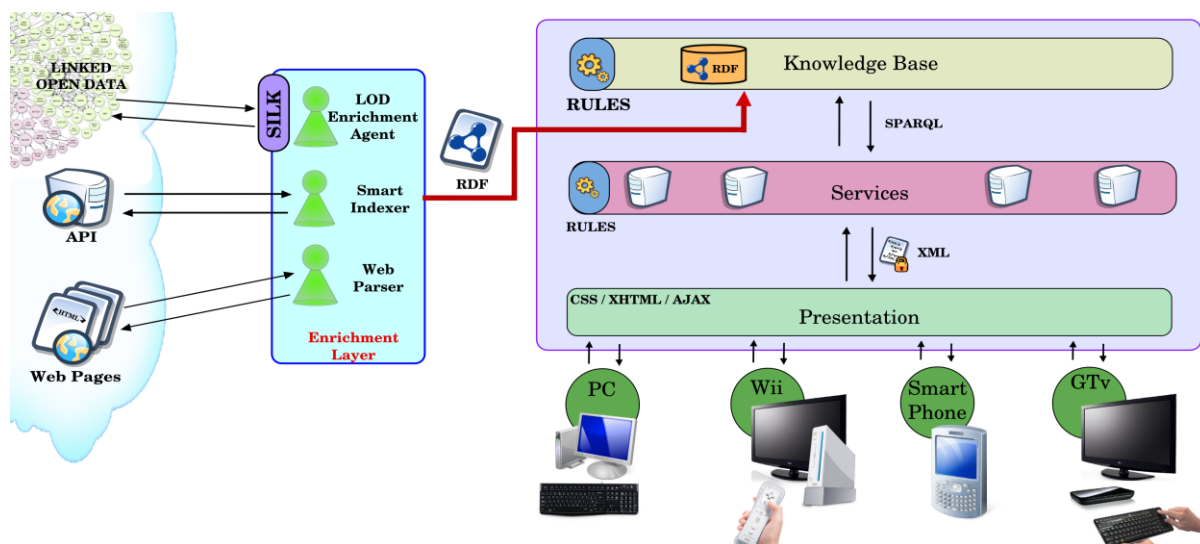


Figure 1. High level platform architecture after enrichment modules

new lexical terms related to each source tag. Thus, it is possible to get derived tags that complement the existing ones. This is what we call a “smart folksonomy”. Thus, the agent controlling the recommendations can list educational resources sharing at least one tag with the already viewed resources. Furthermore, these recommendations are sorted by the number of tags matching the source resource. An example of this process is showed in Fig. 2. It can be noted that two Learning Objects initially labeled by the community with different tags ("pet" and "fish" respectively) are not in any kind of relationship. Then, using the Smart Agent Indexer new tags can be obtained from the tags introduced by the community. For this, the agent gets terms derived from the original tags through WordNet API queries. With these new tags, the system gets more information on resources and can detect new relationships (in this case the Learning Objects share the "animal" tag).

- Using the DBpedia Linked Data node, we have obtained additional information (descriptions, images, etc.) related to the source tags of each educational resource. To this end, the SILK application has been configured to link the local tags with the analogous DBpedia records, particularly, to link local tags with those DBpedia records with a equal or similar textual name (`rdfs:label`, `skos:prefLabel`, etc.). On Fig. 3, it is shown a snippet of the configuration SILK file for this purpose. Reader can note: a) on line 12, the definition of the property to link similar records under the `owl:sameAs` property; b) on lines from 13 to 22, the concepts to be compared, namely any from DBpedia and `brc:TagConcept` from our KB; c) on lines from 29 to 32, the properties for each concept to be checked and the heuristic for the comparison (`rdfs:label` from DBpedia and our KB using the Jaro distance in our

case); d) on line 51, it is set the threshold to accept the match as correct (97% in our case).

- Currently, there are a number of web pages, as PBSKids (c.f. <http://pbskids.org/>) or BestKidsApps (c.f. <http://www.bestkidsapps.com/>), that list and meticulously describe different digital applications, particularly applications for mobile devices (games, interactive stories, music videos, etc.). These pages are organized as paged catalogue of entries, in this case, applications. Each page contains a limited set of result with fixed fields of information and links to navigate among results. Taking advantage of this information, it was developed an ad-hoc HTML parser. Thus, with the information gathered with this technique, a ser of RDF records inserted into our KB has been created. Therefore, it is possible to launch it periodically to update our KB with the description of hundreds of up-to-date digital applications. In this way, we increase our resource library with new external applications available at Android Market and iTunes. On experimental tryouts, it was launched on several web portals related to mobile applications for kids and the KB grew by 127% more with the new records.

The enrichment process has allowed the intelligent agent to have more available information (more tags per resource), therefore, its recommendations can be more accurate. Additionally, the user has more detailed information about each resource. Thus, the educator or the parent can better understand the nature and objectives of each resource and, consequently, accomplish a better choice, which ultimately results in an improved educational experience for the child.

B. Monitoring food application

The food monitoring and control application provides assistance services to the educational centres, helping them to create and configure the school menus; at the same time, the system helps the families giving them some advices and information about how to improve their children's diet. The application focuses on three key factors: the recommendation of complementary food, the nutritional information on menus and the monitoring and conflict detection in the diet of children with some kind of intolerance (diabetes, allergies, etc.).

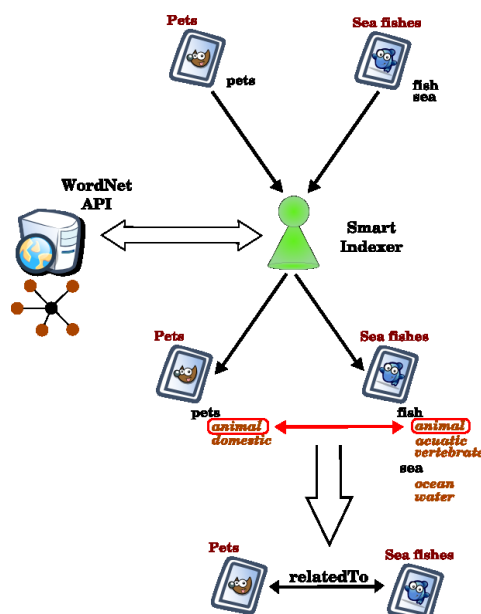


Figure 2. Functional diagram of the intelligent folksonomy. Here, the Smart Indexer agent gets (from Wordnet) derived tags from the source tags.

```

12: <LinkType>owl:sameAs</LinkType>
13: <SourceDataset dataSource="dbpedia" var="a">
14:   <RestrictTo>
15:     ?a rdf:type owl:Thing
16:   </RestrictTo>
17: </SourceDataset>
18: <SourceDataset dataSource="local" var="b">
19:   <RestrictTo>
20:     ?b rdf:type brc:TagConcept
21:   </RestrictTo>
22: </SourceDataset>
...
29: <Compare metric="jaroSimilarity" optional="1">
30:   <Param name="tag1" path="?a/rdfs:label" />
31:   <Param name="tag2" path="?b/rdfs:label" />
32: </Compare>
...
51: <Thresholds accept="0.97" />

```

Figure 3. Extract from SILK configuration file for comparison of two different datasets based on their properties.

To enrich the initial data generated by the community we have used the information available in the U.S. Department of Agriculture Database for Nutrition Information (USDA-DB). The USDA-DB is a well-known and reputable source of nutritional information. Once obtained, this information was transformed to RDF statements using the terminology defined by an ontology specially designed for this purpose. Finally, a local LOD-like node was created and linked to external repositories DBpedia and Agrovoc [19] (this last one is the largest agricultural thesaurus in the world). The methodology used to link the information is based on the location of the food and nutrient records published on these repositories that had their equal in our node. To automate this process, we use the SILK tool properly configured to meet the particulars of this context in a similar manner to the previous case. In this way, we can obtain, for each food registered in our platform, their nutrients and the number and proportion it comprises. Additionally, it is gained access to the virtually unlimited information provided by the connections to the DBpedia and Agrovoc (descriptions, images, links to other registries and repositories, etc.). The interested reader can find a more detailed description of this enrichment process in [20].

The enrichment process has meant a qualitative step in the functionality of this application by making it possible for new, more detailed, information that would be unthinkable to recover from data introduced by the user community. Particularly interesting is the information about the nutrients, and their proportion, of each of the menu and recipes foods.

With these data, an agent can generate a detailed report with the approximate amount of calories, proteins, fats and lipids present in each of the dishes and on the menu as a whole. In our platform, this new information is showed to the user in an intuitive color scale (Fig. 4). Furthermore, with this knowledge and the information about the nutrients to which the child is intolerant, the agent can infer whether a menu food is incompatible and then alert parents and educators. This is done using a set of explicit logical rules expressed in SWRL [21], which is used by the inference engine of the agent. Here is an example of the defined rules:

$$\text{Ingredient}(?i) \wedge \text{component}(?i,?cm) \wedge \text{Child}(?ch) \wedge \text{componentIntolerance}(?ch,?cm) \rightarrow \text{ingredientIntolerance}(?ch,?i)$$

$$\text{Food}(?f) \wedge \text{ingredient}(?f,?i) \wedge \text{Child}(?ch) \wedge \text{ingredientIntolerance}(?ch,?i) \rightarrow \text{foodIntolerance}(?ch,?f)$$

Another feature offered by the platform is the configuration of alternative menus in case of conflict: it is possible, from a complementary food ontology, to propose the user the substitution of one conflicting menu food by another one tolerated by the child (e.g. change milk cream by soy cream in case of lactose intolerance). For this, SPARQL CONSTRUCT statements with specific rules are used.

With all these mechanisms, the system also generates recommendations for home menus. It configures a list of menus that has a composition tolerated by the child and supplements the daily recommended amount of nutrients to food received in school.

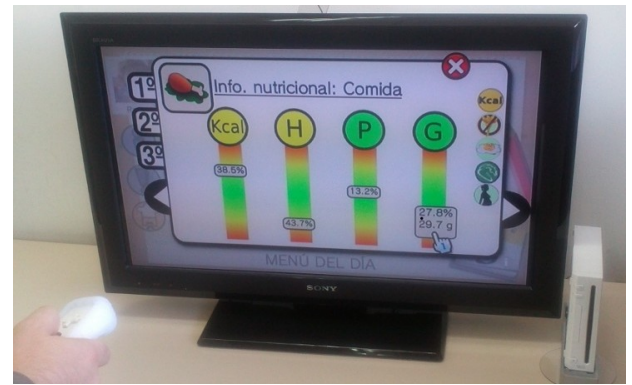


Figure 4. Screenshot of the platform user interface for Nintendo Wii where the basic nutritional values of a particular menu are shown.

C. Monitoring health application

This application is aimed to help both families and centers on the communication and management of the health of children by providing an environment where it is possible to register and obtain information from different medical events. The application is focused on three key factors: healthy history log (diseases, allergies, immunizations, etc.), agenda of medical treatment scheduling and dosage, and complementary navigable information about these questions (diseases descriptions, medical prospects, diseases symptoms, etc.).

To enrich the initial data generated by the community, we have identified three Linked Data nodes including reusable information of medical/health nature. These are the DBpedia and Freebase [22] multidisciplinary nodes, where we can find information on both diseases and drugs, and the DailyMed repository [23] of medical nature, which keeps detailed information about an extensive list of medications. Having identified those useful nodes, the SILK tool is configured so that, each time a new disease or drug is recorded on the platform, an automated process is launched in order to search for disease registries (on DBpedia and Freebase) and drugs registries (on the three repositories). Particularly, searches try to localize registries that have as name (property: *rdfs:label*, *DailyMe:name*, etc.) a word syntactically similar to the name of the locally registered disease or drug.

In the Knowledge Base of the original platform, it was recorded information provided by families and educators about the diseases and the period of time during which the child experiences them. Also it was stored information about the drugs (just the name), doses and times to be administered. This allows setting up an agenda that provides educators and families information and access to health events that should be conducted and the results thereof (Fig. 5).

Nowadays, after the enrichment process, we have achieved to add new significant information on these events and data elements, providing users with accurate descriptions of diseases and their symptoms, adding digital versions of prospects and allowing the browsing of related information (similar diseases, images, etc.). This allows the background support for health education of users, resulting in better care and attention to children. An example of this improvement can be seen in the episode that a child is diagnosed with a rare



Figure 5. Screenshots of the platform user interfaces for Nintendo Wii and tablets where the health management tool is showed.

disease. In this situation, both the educators and the parents can be learned with the contextual information provided by the platform, where they can find a description of the disease, symptoms, possible adverse effects, etc.

VI. CONCLUSIONS

Most of the educational platforms developed to date seek to provide the user with an improved educational experience through automated services that use and interpret the information generated by the user community (mainly, teachers and families). This data generation process is slow and tedious, and usually very low verbose. Thus, the approach described in this paper proposes and focuses on the use the free information available on the web to supplement and extend the knowledge base on the system in order to get an effective and useful enrichment of the information. This external data is generated both by typical web users and by subject experts. Particularly interesting are the data published in an easily processable format, such as the information published under the requirements of the Linked Open Data initiative.

Once the knowledge base is enriched, the smart services have much more information that allows to: improve performance, get new features not originally provided, and provide more and better information to the user. In short, the enrichment processes applied in educational ICT-based platforms can be an outstanding way to enhance the educational experience of the end user.

Currently, the enhanced KB is being used in a local scenario by real families and teachers. This is possible due to the support of a pilot project conducted on local schools that are collaborating with this project.

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Work in Progress: Analysis of Change in Engineering Construct Knowledge

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Abstract— Interview transcripts from students (grades 2-4) were examined to measure change in understanding of engineering constructs using a coding scheme that is in development. The participants were students of teachers from a large, urban school-district that participated in two summer teacher professional development (TPD) engineering education academies and received continued support from a university center devoted to P-12 engineering education. To analyze the interviews, the overarching themes were broken into eight constructs that were points of focus during the TPD. Sample results show change in all mean scores. The inter-coder reliability for this iteration of scheme development was 91.3%. Scored level of understanding of the constructs (on a scale of 0-3) produced 75% agreement. The coding scheme continues to be refined in an effort to provide a form of evaluation of TPD and teacher effectiveness that identifies weaknesses in curriculum design and implementation.

Keywords- *engineering constructs, interview analysis, teacher professional development, pre-college engineering, K-6*

I. PURPOSE OF STUDY

Engineering continues to find a place in national curricula through policy and funding movements as well as through a growing presence in state and national standards [1]. Meanwhile, the National Research Council (NRC) suggested careful integration driven by empirical evidence [2]. This study is integral to the empirical framework used to examine student engineering construct knowledge (ECK). The primary purpose of this study is to understand the impact of two summer teacher professional development (TPD) academies (over consecutive years) and ongoing support from a university research center devoted to P-12 engineering.

This interview analysis of ECK extends previous research on K-6 engineering by providing insight into initial levels and change of ECK. Rating the level of change and identifying how the change is present informs TPD practices, redesign of existing curriculum and design of new curriculum.

Previous research has looked at conceptualization of engineers by students [3-5] and change in knowledge in broad general areas related to engineers and engineering [6, 7]. More specifically, this coding expands on the evaluation of student context maps. These maps showed elementary students most often used general engineering and engineering design frameworks of expression [8]. This qualitative analysis of student reflections helps to “capture richer descriptions and experiential narratives to depict more fully and to help

understand” [9 p.42] what is being learned in K-6 engineering classrooms and to improve epistemic developments as called for by the NRC [2].

II. METHOD

A. Participants

Three cohorts of elementary school teachers in grades 2-4 (2008-9: N=32; 2009-10: N=36; 2010-11: N=30) from a large, urban school-district participated in a week-long TPD academy during one summer and a three-day follow-up academy the following summer. Four or more students were randomly chosen from select teachers’ classrooms to participate in pre-post interviews. Pairs of interview transcripts, pre-post, were purposefully chosen from this collection of interviews for preliminary analysis and inter-coder agreement so that the students included in this study were in engineering classrooms for the first time.

B. Intervention

The curriculum used in the teacher academies stressed the roles of engineers, engineering design, problem solving and technological literacy. Activities were designed so teachers could actively participate in learning, as their students would, when the classroom-ready activities were integrated into their science and math curricula. Model-Eliciting Activities (MEA) [10], *Engineering is Elementary (EiE)* units [11] and a modified version of the *EiE* engineering design process were used across grade levels to provide consistent engineering curricula. Other design challenges and technology-defining activities were provided to grant a variety of activities supporting the emphasis on problem solving [12]. Teachers were instructed to use a minimum of one design challenge, one *EiE* unit, one MEA and the provided technology-defining activities in their classrooms over the course of the school year.

C. Defining Constructs

The primary objectives of the TPD were to: 1) Convey a broad perspective of engineering; 2) Examine differences between engineering and science; 3) Develop comfort in discussing engineering with elementary students; 4) Engage students in complex open-ended problem solving [13]. These objectives align with curricular suggestions from reports from the National Academy of Engineering, national technology standards, and engineering standards from states such as Massachusetts and Indiana [1].

These objectives yielded the overarching themes of the academies that focused on roles of engineers, engineering design process (EDP) and technological literacy. To analyze the interviews in this study, the overarching themes were broken into eight constructs that were points of focus during the TPD: 1) What engineers do; 2) Types of engineers; 3) Purpose of EDP; 4) Parts of EDP; 5) Teamwork; 6) Use of math; 7) Use of science; and 8) Technological literacy.

D. Coding and Analysis

The transcripts were analyzed using mixed methods. Using Nvivo qualitative analysis software [14], words or phrases fitting one or more of the eight constructs were manually coded into one or multiple constructs. Coders then assigned scores on a four-point scale to quantify the level of understanding. The scale ranged from 0-3 with the following criteria: 0) no mention of construct; 1) awareness of constructs minimal or incorrect; 2) some understanding of construct; 3) understanding construct evident.

The independent coding between two coders was then compared using the software to compute inter-coder agreement for both construct identification and for assigning scores to the level of understanding. The coders were selected based on experience in engineering education: an undergraduate research assistant majoring in engineering and a graduate student that works in engineering education. Both had instructed multiple TPD academies and were familiar with the subject matter that informed coding decisions.

In the preliminary analysis, pre and post interviews from ten students were coded and rated. The inter-coder agreement for the rating of the understanding was 75% agreement. However, the inter-coder agreement for the coding of the constructs was 91.3%.

III. RESULTS AND DISCUSSION

The coding scheme was able to identify levels of change in all eight constructs when comparing pre and post interviews. However, due to the iterative nature of the coding design process, those results are too preliminary to report and only help guide the refinement of the criteria for both measures. The sample results did show the largest change in the constructs related to EDP Parts, EDP Purpose (Change = 1) and What Engineers Do (Change = 1). There is a decrease in mean scores for Types of Engineers and Teamwork.

IV. CONCLUSION & NEXT STEPS

The inter-coder agreement for construct coding was promising, yet improvements to the coding criteria are being made and additional coders will then perform similar analyses. The agreement level for rating the understanding indicates more than desired subjectivity and scoring levels will be better defined for the next step. Additional data from knowledge tests will be used to compare the construct knowledge to the overall knowledge for further validity. A larger sample size (15-20% of the total 338 interviews conducted over the three years of the study) will be used to ensure coding reliability.

It appears that this study will be beneficial in identifying the strength of the TPD and the teacher implementation and

will help identify strengths and weaknesses in specific construct areas. The final results of the study should be beneficial in helping to revise interview protocols in order to gain a better understanding of construct knowledge.

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Work in Progress: Serving Rural Communities: A K-8 LEGO Robotics Case Study

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Abstract— In this paper we describe approaches to better assist teachers in rural areas to participate in an annual LEGO robotics competition offered at Texas Tech University. While local schools have a student mentor visiting the robotics teams on a weekly basis, schools that are more than 20 miles away from Texas Tech University do not benefit from this service. Although there is a significant amount of literature available on LEGO robotics, teachers and students seem to prefer personal interaction. We propose daylong fieldtrips and webinars to partly overcome distance and still provide direct interaction.

Keywords—component; K-12 Engineering Education, LEGO Robotics, teacher professional development

I. INTRODUCTION

Since 2006, the Whitacre College of Engineering at Texas Tech University (TTU) in Lubbock, TX, serves as a local hub for the Get Excited About Robotics (GEAR) [1] LEGO robotics challenge. In this annual 8 week competition students from elementary and middle schools design, build, and program a robot based on the LEGO MINDSTORMS NXT kit [2]. Each year, the robots have to perform a series of pre-defined tasks described in the annually changing challenge. The theme of the challenge motivates the use of robots in areas such as farming or an energy corporation. Over the last 6 years the challenge has grown from one local participating elementary school to over 500 students from about 40 school from all over the Texas High Plains, and beyond, see Figure 1. Over the last two years the number of participating schools which are over 50 miles away from Lubbock has continuously grown. While local schools are served by an engineering student who mentors the GEAR team and meets with the students at the school once a week as part of a service learning project associated with a college wide Introduction to Engineering course [3], this approach is not feasible with schools further than 20 miles away due to travel cost and time constraints. Apart from a group of schools in the Midland/Odessa area these schools are mostly located in scattered small rural communities and have a large percentage of socio-economically disadvantaged and Hispanic students.

The challenge of disseminating STEM content into after school informal learning activities in 4-H Clubs in rural areas was described in [4], where the major challenge faced was training of the 4-H staff interacting with the participants.

Successful teacher professional development via video-conferencing was reported in [5], where the benefits of a feedback channel and a learning environment close to traditional face-to-face instruction were emphasized.

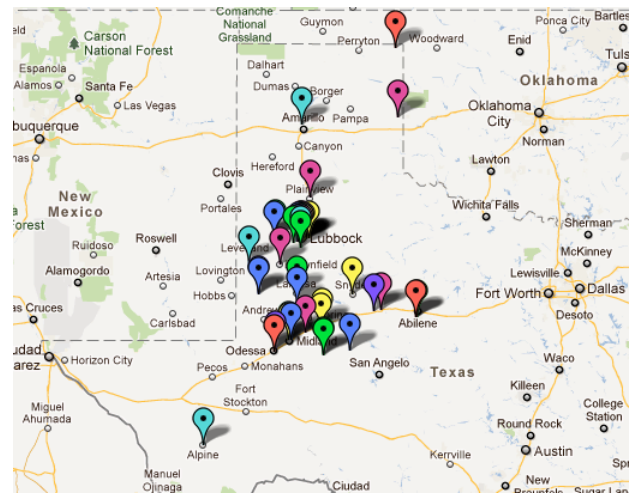


Figure 1. Schools participating in Lubbock GEAR competition.

In this paper we describe approaches taken to better serve rural communities that alleviate the burden of travel but still promote the interaction with engineering faculty and students who are content experts and serve as role models for participants.

II. LEGO ROBOTICS FIELD TRIPS

Day-long LEGO robotics field trips hosted on the TTU campus have been proven a successful recruiting tool to expand participation in robotics competitions such as GEAR. Students together with a teacher participate in a day-long hands-on robotics workshop held at the Whitacre College of Engineering (WCOE). The workshop starts with participants familiarizing themselves with the LEGO MINDSTORMS NXT kit through the building of a standard robot according to instructions. They next learn the basic steps of the NXT-G programming concepts in order to rotate the wheels or an arm, collect sensor inputs (light, sound, ultrasonic, touch), and play sounds. The field trip instructors are TTU engineering professors assisted by engineering undergraduate students. The instructors first

explain the usage of the software for a given example and students copy this example and try it. They are then asked to apply the learned concepts to a slightly different / more complicated problem.

After a lunch break participants visit a robotics research lab in the Computer Sciences Department on campus and then spend the afternoon accomplishing various tasks with their LEGO robot such as navigating through a maze using the touch sensor, building a burglary alarm system based on the ultrasonic sensor input, tossing tennis balls into a goal. These tasks are organized in a set of stations each mentored by a student.

Teachers easily commit to this field trip format since no prior training is required on their side. In addition, it promises to be a fun hands-on learning activity. They are generally surprised about the accomplishments of their students throughout a single day and leave the campus inspired and confident that they could organize a robotics team at their school. The field trip thus not only provides an educational hands-on experience for the students but also for the teachers. During the field trip teachers also learn about professional workshop opportunities and useful resources available online.

While students still have to travel to campus, the block format provides a better value for the travel expense and fits into the format of fundable activities at the schools. Field trips have also been arranged for schools participating in our GEAR competition.

III. MENTORING THROUGH VIDEO CONFERENCING

We offered on-demand video conferencing through Skype [6] during the 8 weeks of the GEAR challenge last year. Every afternoon, experienced engineering students were signed-in on Skype during the afternoon and available to answer questions. However, participants did not take advantage of this opportunity. Partly, this was due to internet access restrictions at the schools, partly participants did not feel the need of having a mentor and preferred to independently work on their problem until it was solved. Some students/teachers did request help by email and were provided answers.

IV. WEBINAR BASED TEACHER WORKSHOPS

During our GEAR robotics competition we offer a series of teacher workshops. These workshops are hands-on in nature and start with a New Teacher Workshop which explains the format of the GEAR competition at TTU, showcases some of the challenges that the robot had to accomplish in a previous year, and then has a hands-on component where teachers program a pre-built LEGO MINDSTORMS NXT robot to perform specified motion and to react to sensor input. Finally,

teachers typically accomplish to solve 1-2 tasks of the previous year competition. In collaboration with National Instruments [7] we also offer hands-on workshops customized to specific questions solicited from teachers. This workshop mostly consists of hands-on programming and problem solving accompanied by explanations from the instructors. While these workshops were originally offered as on-campus workshops only, we have also offered them in mixed format (participants on campus and at home watching streamed content) as well as webinar format only. In the mixed format, a problem was explained and then participants in the classroom and at home had time to solve the challenge. At the end of a given time period, the challenge was wrapped up and explanations to a solution were presented.

A first webinar-only new teacher workshop was offered this year for teachers who were not able to participate in the on-campus workshop. Participants could voice their questions either using their built-in microphone or by entering them in a chat window and took advantage of it.

V. CONCLUSIONS

Our first experiences with offering webinars were encouraging. The bidirectional interaction offered seems to provide a substitute for face-to-face communication and teachers can easily participate in evening webinars from their homes thus circumventing IT restrictions existing at their schools. We plan to hold a webinar-only LEGO robotics teacher training workshop in the fall for teachers new to the LEGO MINDSTORMS NXT kits. They will be accompanied by the offer to bring students to the Texas Tech Campus for hands-on field trips.

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Work in Progress: Exploring Programming Anti-patterns as Emphasis on Creativity in the Teaching of Computer Programming

Programming Anti-patterns as Emphasis on Creativity

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Abstract—Computer programming is a creative activity. However, while computer scientists have devoted their work to solving complex problems and developing new technology, few have written on the creative process behind their innovations. This work explores programming anti-patterns as beneficial detour to the creation of good programming designs. Examples of programming anti-patterns are: failure to combine linear traversal and a flag variable to search a given value in a uni-dimensional array; to draw wrong analogies from natural language; not consider uncommon cases in a solution; to overlook minor parts of the problem; to assume that a program construct will work in the same manner in all situations; not be flexible in understanding new code, not being aware that there are many different right solutions to a problem. In this research, the teacher of introductory programming course promotes discussions among students involving the bad and good features of program anti-patterns, when there are programming anti-patterns code examples and discussions based on situations having the potential to prevent programming anti-patterns, when programming anti-patterns describe a lack of programming skill. An initial experiment showed improvements in creation of good program designs by students, when the teacher boosts discussions exploring program anti-patterns.

Keywords—programming anti-pattern; creative programmer; collaborative programming

I. SCIENTIFIC AND EDUCATIONAL FEASIBILITY OF THE PROJECT, EXPECTED OUTCOMES AND EVALUATION PLAN

Computer science is a creative field to work, innovation is a necessary condition to create new products and technology and creativity is evident in software design processes. Although in computer programming creativity is required, pedagogic methods applying tasks that address creative aspects of programming are scarcely reflected in computer science education. Students should be fostered to develop and apply

their creativity and computer science education researchers and teachers should approach creativity more often.

Our approach is under a creative perspective for programming. In this research, the teacher anticipates programming anti-patterns in order to encourage better critical analysis and creation of programs by means of explorations of good and bad features of a program anti-pattern. Sax and Dix [1] has investigated the exploration of bad ideas as a way to support creativity in human-computer interaction. They advocate that bad ideas encourage both divergent thinking and a more structured analysis of the problem, pulling the designer to a new and unpredictable place within the design space.

In this research, students are motivated to discuss about what is bad concerning a programming anti-pattern, why this feature is illogical, inadequate, and ill-crafted, if there is a good design possessing this feature, if so what is the difference, and if there is a situation where it could be considered well-crafted. Students also discuss about what is good concerning a programming anti-pattern, why this feature is logical, adequate, and well-crafted, if there is a bad design possessing this feature, if so what is the difference, and if there is a situation where it could be considered ill-crafted.

Here we apply collaborative programming. In collaborative programming, a group of students jointly perform the same task. Computer programming has traditionally been taught and practiced individually. Nevertheless, computer science educators have recently adopted different collaborative learning practices such as programming in pairs and team projects. By means of these collaborative activities, students can produce better programs and improve their performance and programming skills [2]. However, the teacher must help the students to develop the collective ability to use dialogs for learning, fostering productive interactions during argumentation in instructional settings. Discourse must be

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facilitated aiming creative and innovative processes and products.

Collaborative programming combined with programming anti-patterns examination, constitutes a potentially powerful learning method for computer programming that provides profitable exploration of possibilities among the participants and provide a framework for social interaction that favors fruitful idea generation and program design discussion.

In this research, we expect students to produce program codes correctly in a greater percentage. Also, we aim student's better programs understanding as a result of discussions concerning a great repertoire of not perfect program solutions. We expect to prevent students misunderstandings as well, going further in discussions based on situations having the potential to prevent programming anti-patterns, scrutinizing previous recurrent students bottlenecks.

For at least four semesters of computer science introductory courses, there will be one class taught by traditional method (control group) and another one taught by the proposed method (treatment group). Students performance will be confronted by questionnaires measuring their understanding of program codes, their grades, the percentage of the occurrence of correct and incorrect code generated by the students, as well as the percentage of the occurrence of programming anti-patterns classified by different types.

II. IMPORTANCE TO THE EDUCATION COMMUNITY

Traditional teaching proceeds by generating programs that meet problem constraints and best fit good design constraints. An usual approach is to guide students toward effective strategies for programming. However, understanding such strategies and program design demands a high level of comprehension and abstraction [3]. Novices are supposed to make connections beyond the scope of question, be able to transfer knowledge to a new situation, make a lot of interconnections among program components, and to integrate language constructs in a logical way in order to provide a computational solution to a problem.

Our motivation for the application of programming anti-patterns is that novice programmers usually cannot find their way out confronting a programming problem. They sometimes say "I don't even know how to fail." On the other hand, there are better students able to produce fully correct or almost right solutions. Recurrent and almost right solutions are then used to help students that the answer is blank or totally wrong.

To overpass student's cognitive load and lack of programming knowledge and skills, instead of considering bad designs as problems to be overcome, students are encouraged to analyze and discuss them. Student's bad program design is related to the student prior knowledge, contains correct parts, and is a naive solution. So, programming anti-patterns are easier to be understood and their exploration serve as springboards for the understanding and creation of good programming designs.

III. PROJECT STATUS AND PRELIMINARY RESULTS

During one semester of an introductory programming course, two classes containing forty under graduate students from food engineering course were analyzed considering students' generation of language-based anti-patterns, such as wrong program sequence. Second, we analyzed design problems, i. e., students' inability to properly combine, specialize, optimize, and students' incapacity to visualize details during correct code adaptations. Third, we checked students' skills to develop solutions to new problems, measured by means of the quantity of innovative program code generated.

The programming anti-patterns considered in this research were: inability to combine language features generating new programs; incapacity to improve programs; difficulties in identifying particular cases of known problems; bad usage of previous knowledge during programs interpretation; difficulties in delimiting control structures; inability to predict unexpected cases in a problem; incapacity to understand the sequence of a program; difficulties in decompose a problem in sub-problems; incapacity to identify and correct errors in programs; incapacity to understand step-by-step the program code; false belief that programming constructs have the same form in every program; false belief that there is only one correct solution for a computational problem; failure to combine correct program code; failure to adapt correct program code; failure to generalize examples to conceive a correct program code; failure to detect details during correct program code adaptation; inability to understand the program code considering correct program code combinations.

The experiment results showed that in the second class, where the teacher facilitated discussions involving programming anti-patterns, the occurrence of programming anti-patterns and code adaptation problems was smaller and the occurrence of innovative program code generated was bigger as shown in Table I.

TABLE I. STATISTICAL OVERVIEW OF THE RESULTS OBTAINED

| Data Considering Programming Anti-patterns Application | Percentage of Occurrence |
|--|--------------------------|
| Programming Anti-patterns and Code Adaptation Problem | 40.00% smaller |
| Innovative Program Code Generated | 20.00% bigger |

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Instilling a Software Engineering Mindset through Freshman Seminar

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Abstract—Student retention is a challenge faced by all engineering programs. Our first year software engineering students have schedules filled with computer science, mathematics, science and humanities. The lack of any exposure to engineering meant some students, expressing a dislike for software engineering, left the program before they had any exposure to the discipline.

To address this issue, we created a one credit Software Engineering Freshman Seminar, which all entering students take in their first term at RIT. This lets us insure student/faculty contact early in the program, as well as providing an opportunity to introduce engineering concepts and practices early in each student's program of study.

This paper discusses the seminar's current incarnation. In particular, we focus on those aspects of the course which help students identify with software engineering as a profession. The challenge we face is achieving this goal with students whose technical knowledge and skills are modest. We have settled on an approach that provides experience with teamwork, requirements elicitation, and the effects of change, and addressing professional ethics. These in-class activities are complemented by an assignment to interview a practicing software engineer and to write an interview summary for discussion.

This activity ensemble serves to disabuse students of the notion that software engineering is little more than programming, or that the discipline is identical to computer science. Should a student exit the program at this point, at least he or she knows a bit about what they are leaving behind.

Keywords—*first-year seminar; software engineering; teamwork*

I. INTRODUCTION

In 1996, the Rochester Institute of Technology (RIT) launched the first undergraduate software engineering program in the United States [1][2]. From an initial class of 15, the undergraduate program has expanded to a current enrollment of approximately 375 students. While the Department of Software Engineering has grown to encompass a masters program, the undergraduate program remains the focal point of the department's identity.

Engineering programs seek to prepare engineers who can define, design, develop and deploy useful, cost-effective, and maintainable systems; this is no less true of software engineering than of more traditional disciplines. Traditional

engineering builds upon (but is distinct from) natural sciences such as physics and chemistry. Similarly, in our view software engineering has its foundations in computer science, but it is no more the case that computer science encompasses software engineering than it is that chemistry encompasses chemical engineering.

The proof of our philosophy is in its results. First, software engineering is recognized as an engineering discipline by ABET, and the first graduates of an ABET-accredited baccalaureate software engineering program came from RIT. In addition, software engineering students have great success both on co-op and after graduation. Across the broad range of undergraduate computing programs at RIT, our students have the highest median co-op wages and the highest median salary upon graduation. Students and graduates work for firms large and small, and in domains spanning embedded systems, as at Goodrich Aerospace and Harris RF Communications, through end-user focused firms such as Microsoft, Apple and Google. All in all, our program provides a solid foundation for entry into and continual growth within the world of professional software development.

II. THE FIRST YEAR CHALLENGE

While our program is successful overall, we face the challenge of instilling a sense of engineering practice and professionalism, along with the distinctive perspective of software engineering, in our first year students. The challenge is made more difficult by the fact that entering students are often confused as to where software engineering fits within the larger framework of computational studies. Software engineering's recent emergence as a discipline distinct from computer science, combined with a first year program of study that is heavy in math, natural science, computer science, and the liberal arts, serves to exacerbate this confusion. In the end, first year students who leave software engineering often did so as a result of this confusion – they had little knowledge of or appreciation for the distinctive nature of software engineering.

To address the challenges and confusion outlined above, our program includes a one credit hour course providing a broad perspective on the discipline for entering students; over time, this Software Engineering Freshman Seminar[3] has evolved into the one we present in this paper. While tuning and tweaking is regularly taking place, the general structure, topics, and flow of material has stabilized. As a consequence, students completing the course have a grasp of some key software

engineering concepts and practices, and can appreciate the role of their foundation studies as preparation for the software engineering courses that follow.

III. COURSE GOALS

The overriding course goal is reducing first year attrition in our program. We know that attrition after the second year is less than 10%, especially after students complete our Engineering of Software Subsystems course, where software design principles and patterns are first discussed in detail. We decided a bridge was needed to see students through the first year of the program, where math, science and liberal arts courses predominate, into the second year where software engineering *per se* becomes the curriculum's focus. Our hope was to forestall student departures because "I don't like software engineering" or "I want to do something besides just programming." Certainly students should be free to pursue interests elsewhere, but we'd prefer they do so based on an accurate perception of the discipline. Misperceptions, whatever their cause, should be eliminated.

Our bridge comprises two courses, the seminar described in this paper and a Personal Software Engineering [4] course taken at the beginning of the second year. Both serve to forge bonds between software engineering majors and the faculty in the department, and to provide distinctive engineering experiences in conjunction with foundational studies. In this our program is in line with many similar efforts in other engineering programs [5][6][7].

For the seminar, we decided to focus on three elements of software engineering practice that undergird our program and that can be imparted to students with modest technical background: product requirements and design, teamwork, and professional communications. We also saw this as an opportunity to introduce students to ethics and ethical professional behavior. Activities throughout the course illustrate and reinforce these concepts.

With one exception, requirements and design activities do not involve software. In part this is a concession to the fact that many students are software development naïfs, and requiring them to do development in both the seminar and introductory computer science would create an unreasonable load. As important, we wanted students to realize that many engineering problems they will encounter (as well as their resolution) require more than the creation of executable code. Thus the requirements and design activities involve paper mockups and Lego based exercises rather than executable programs. Even the one exception, requiring teams to provide enhancements to Java classes, is small enough so as not to obscure the concepts being taught.

Our program, in contrast to many computing programs, is heavily team-based. Indeed, with only two exceptions, all courses in the program have at least one (and usually several) team-based projects. In light of this, an early exposure to both the benefits and costs of working in teams gives first year students a leg-up on what they will be doing later on in their studies. It also serves to counter the "lone hacker in a cubicle" perception of software development so prevalent in the culture at large. In any event, by the end of the seminar most students

are comfortable working on teams, solving problems larger than they could address on their own.

The ability to clearly and concisely communicate ideas is as critical to a software engineer's career as his or her technical skills. Indeed, one impetus for developing the curriculum was recognition of the divergence between the preparation of graduates from previous computing programs and the needs of industrial software development firms; poor communication skills were at the core of the problem. Thus our courses require significant written documentation and frequent oral presentations. It is natural to reflect these demands in the seminar course, though at somewhat reduced formality. Once again, such activities serve to distinguish software engineering from other computing disciplines.

Finally, as we are educating future professional engineers, it is incumbent on us to reinforce the professional responsibilities and ethical demands of the discipline; there is no reason why this education cannot begin at the outset of each student's studies. Of course professional ethics is an area that is notoriously difficult (and dull) to teach via lecture; such approaches often come off as special pleading. In our approach, we try to balance the need for teaching specific ethical principles with experiences in which students explore the ethical ramifications of specific technical decisions. Unintended consequences, such as epileptic seizures due to rapidly flashing game screens, provide a rich environment in which to discuss professionalism.

To provide this view of the breadth of software engineering, we defined the following learning outcomes for the Software Engineering Freshman Seminar.

A student will be able to:

1. Identify the principles of the Software Engineering ethics (e.g. Code of Ethics as recommended by the IEEE Computer Society and ACM)
2. Identify the major activities of Software Engineering
3. Identify strategies to address issues that can arise in a team project.
4. Identify the difference between Software Engineering and other computing disciplines.
5. Apply general concepts to a specific process step, namely execute a project test plan and, acting as the quality assurance group, assess the effectiveness of the test plan for the development team.
6. Explore and describe the responsibilities, working environment, skills and technologies of a software engineering professional.

With this background information on our course goals, it is appropriate to turn next to the specific topics and activities – the tactics, if you will – by which we strive to achieve these goals.

IV. TOPICS AND ACTIVITIES

The seminar is heavily oriented towards active learning, as we've found that this engages students in the material for each

session. This engagement leads to insight and interest in software engineering, with the consequence that students acquire a broad perspective on the discipline.

Given the team-based nature of the curriculum, it is no surprise that most of the work in the seminar requires working in teams of 3-5 students; to help students become acquainted, we usually vary the teams from one exercise to another. While most exercises are completed during class, a few span multiple meetings, and require the team to meet outside the class period. Once again, this reflects a situation they will encounter throughout their software engineering studies.

One issue we frequently have to address is the lack of (graded) group work in high school. Even in situations where collaboration is encouraged, at the end of the day most assignments entering students are familiar with had to be completed individually. To counter this mindset, we purposefully focus on the degree of collaboration within teams, and downplay individual assessments based on project outcomes. It is true, of course, that peers and instructors evaluate individual contributions when grading projects in later team-based courses, but in the seminar it is more important to have students feel comfortable being assessed as a group. We seek to encourage open, collaborative approaches to problem solving as the norm across all the exercises.

The learning outcomes from the previous section are addressed across the 10-week course, with the emphasis varying among the activities pursued in any given week. Initially the focus is on perceptions of the software engineering discipline, followed by activities related to various phases in a software development process (e.g., lifecycle activities), capped by interview sessions with students returning from co-op and a sample of software engineers from local industry. For convenience, we classify activities as non-software (applicable in any engineering context), software (focusing on issues of particular importance in software engineering), and the "real world" (via interaction with practicing professionals). The following subsections expand on activities in each of these classes.

A. Non-Software Activities

1) *Planning and Team Collaboration*: In this activity, while we stress the importance of team collaboration and communication, we also want the students to recognize the importance of careful planning. Such planning can mitigate the unexpected consequences that often prove costly at later stages of development.

The stated objective is the construction of the tallest Lego tower, using the kit provided. Often teams immediately begin assembly, following the first idea from an outspoken team member, and paying little attention to the future. As the towers grow, a rule change is introduced: Team members are only allowed to use their left hands. Students quickly realize that they can no longer function autonomously; rules and protocols are required for the team's work to continue.

Finally, the requirements are changed - each team is given a set of wheels and told their tower must move across a table prior to its height being measured. Naturally, those with flimsy,

unstable towers must rush to reinforce their constructions - this is a valuable lesson on premature optimization in the face of continuing changes.

At the conclusion of this activity, all students observe the performance of each tower - whether it passes the acceptance test and only then whether it is the tallest. We often hear comments such as "we did not think of doing it that way" or "we probably should have spent more time planning what we were going to do". Once the tests are completed we have a class discussion in which the students are asked to reflect on the activity as it relates to software products with which they are familiar.

2) *Disruptive Teamwork*: In this activity, teams of 4-5 students are set to the task of preparing a short presentation on a software engineering topic. Unbeknownst to most of them, one member of each team is a "mole," selected by the instructor. The moles are pulled aside on some pretext, and told to be disruptive during their team's meeting. Typically instructors give a variety of disruptive roles from which to choose. The goal is to introduce common team problems and see how the team as a whole reacts.

We are continually impressed by the thespian abilities of our moles and the energy they put into their roles. In the past, we've had moles who demand to be in charge of the team, who tried to get their colleagues to watch YouTube videos with them, who challenged each and every idea other team members proposed, and who even entered the team space, put their head on the table, and went to sleep. As one might expect, by the end of the 30 minute team session the other team members are annoyed (to put it mildly).

At the conclusion of the exercise, the teams reassemble in their classroom. The instructor then exposes the mole on each team, as well as the particular disruptive behavior each mole was assigned. Groups then work on the *real* presentation: How they handled their "problem" member and what they might do in a similar situation in the future. Presentations are followed by a class-wide discussion of the advantages and disadvantages offered by teams.

3) *Professional and Ethical Responsibilities*: The session on professional and ethical issues is preceded by an out-of-class assignment to read and comment upon the Software Engineering Code of Ethics developed by the ACM and the IEEE Computer Society [8]. In the class session, this is expanded upon via a short lecture on related topics, including health and safety, moral and government guidelines, and ethical behavior in the workplace.

Students then form teams and develop a short skit on one of the specific topics covered in the Code of Ethics or in class. Students generally have fun with this assignment and their skits usually illustrate their topic effectively (and often humorously). Following each skit, a focused discussion takes place related to the skit's topic. In particular, students are asked to reflect on real world situations related to the topic and how they might deal with the resulting situations.

B. Software Activities

1) *Defining and Describing Software Engineering*: One of the earliest activities centers on the meaning of software engineering as a discipline. Students are asked to work in teams to create a short presentation or brochure to be delivered to their former high school. Teams are given an example presentation (one used during open houses, and familiar to many of the students), along with an outline of topics to consider for inclusion. The topics include the differences between software engineering and other computing disciplines, the relationship between software and our rapidly changing world, and the range of career opportunities within the field.

We know that students are largely ignorant of the ethical issues involved in plagiarism [9]. The presentation provides an excellent venue, early in their studies, to present these issues, along with advice on how to avoid plagiarism. As part of the activity, students are required to provide proper citations, and we also offer guidance on abiding by rules of ethical academic behavior.

Given the proliferation of internet resources of widely varying quality, we also introduce students to ways of identifying credible, trustworthy, and informative sources. Key points include verifying the original source of a work, determining the work's publisher, and finding the last revision date.

Having spent a week on this activity, several are selected to make a formal presentation. A resulting class discussion on the merits of the content, style and sources increases student appreciation of the software engineering profession's place in the context of an expanding and ever changing technical world.

2) *Challenges of Requirements Elicitation*: At the midpoint of the term, students participate in a second Lego project, this one to build a house to a customer's specification. The goal is to expose students to the difficulties of both eliciting and conforming to customer expectations.

At the outset, each team is provided with the basic requirement that the team must build a Lego house satisfying a customer's requirements. Instructors and course assistants prepare by identifying a simple set of requirements such as a minimum of two rooms, a window in each room, a roof, etc. Elicitation spans three iterations; during an iteration, each team has the opportunity to ask three specific questions (queries like "what do you want the house to look like?" receive short, direct and ambiguous replies).

Teams soon realize that they must carefully consider which questions to ask and how to frame them in order to maximize the useful information received. Course assistants enjoy acting as customers during this activity, and revel in truthfully answering questions so as to reveal as little information as possible. Question: "Does the house have windows?" Answer: "Yes, the house has windows."

At the end of the 30 minutes devoted to the activity, each team shows the house they built and how it meets the requirements as they understood them. Normally, no two houses are even vaguely similar, reinforcing the problems of

obtaining accurate and useful information from customers. Students see firsthand how requirements can be interpreted in radically different ways. Overall, the exercise reinforces the importance of maintaining a continuing conversation with the customer, while working to ensure the real requirements are understood and the customer's desires are satisfied.

3) *Software Process Methodology*: We introduce the notion of a development process via a version of the Extreme Programming (XP) game, using a variant of Joe Bergin's coffee machine planning game[10]. XP is used because it allows teams to make headway in the face of changing requirements; in particular, it emphasizes evolutionary development with small, incremental releases.

Each student team designs a vending machine on paper, where the machine must conform to prioritized, predefined user stories. Students in each team assume one of three distinct roles: customer, developer, or monitor. Customers establish machine feature priorities using their own opinions combined with an estimate from developers as to the effort needed to include the feature. Developers add features to the vending machine from most to least important; in the second and later iterations, this includes integration and refactoring of what was done previously. Moderators are part coach, part referee, monitoring communications between customers and developers, and ensuring the process stages are properly time boxed.

At the conclusion of the exercise, student teams compare the resulting systems, recognizing that they all started with the same user story set. The class ends with discussion of the process, what went well and what caused problems, and the effect of the different roles on estimation and prioritization.

4) *Team Design and Implementation*: The longest activity, spanning two weeks, is the Robocode[11] project. Robocode itself provides a framework for simulated battles between programmable, robotic tanks. In addition to the battlefield, automated scoring, and various graphic and sound effects, Robocode provides an API for creating new tanks.

In this activity, we introduce pair-programming, and have pairs of students develop their own unique robot from a skeleton we provide. In the first class, each team sketches the behavior they want to implement, and then works on its tank for the remaining time. Near the end of class, all the teams' tanks (as well as a few from the Robocode library) are placed in the arena and the battle begins. After all the flashes, sounds, and mayhem subside, students see where their robot ranks.

Between class sessions, and at the start of the second week, each pair hones its robot based on the first week's results. At the end of the second week, another section-wide battle is waged, with each section's winning robot submitted to the final battle royale at the end of the term. The team that emerges victorious from the final battle has its robot memorialized by a small trophy with a toy tank on top.

The goal of this activity is less about improving student programming skills than it is about working in pairs to develop a software system over several iterations. In addition, planning an adaptive strategy to exploit other tanks' weaknesses reinforces the need for a well-considered and flexible design.

5) *Cross-Team Testing*: Near the end of the term, teams of students from the seminar pair with teams from our second year Introduction to Software Engineering course in a cross-team testing exercise. Each seminar team acts as an independent test team, performing acceptance tests from a test plan prepared by their paired second year development team. We encourage the test teams to take initiative, and expand testing of functionality and usability beyond the boundaries of the test plan.

Both the first year and second year students gain valuable lessons from this exercise. The first year students gain testing experience, and see for themselves the significance of usability design and the importance of validation. In particular, the acceptance test drives home the connection between requirements and black box testing; students realize effective testing does not require access to the source code. The second year teams, in addition to the obvious benefit of having their test plan exercised, see actual users struggle with or delight in the systems they produce.

C. Exposure to the Real World of Software Engineering

Near the end of the term, we turn our attention to software engineering in the world outside of RIT. The primary vehicles for this are a panel discussion with upper-division students and local software developers, as well as a paper summarizing an in-depth interview with a software engineer in industry. These activities are designed to expose students to the real life activities of software professionals, to foster increased interest in and curiosity about the profession, and to clarify any remaining misconceptions regarding work in the field.

As preparation for the panel session, each student submits a set of questions they would like answered. They know that the panel will consist of upper-division students who have completed several co-op blocks, as well as practicing professionals, many of whom are alumni of the program. As a consequence, the questions range from the mundane (“how do I find housing while on co-op?”) to the profound (“what non-technical skills do you find most useful?”). On the whole, our experience has been that students appreciate the opportunity to learn from those with experience, and as a result have a better idea as to whether or not software engineering is the career for them.

The interview paper requires students to find a software developer to interview, to arrange an interview by email or (preferably) over the phone, and to summarize the interview and their analysis of it in a written document. We place a few restrictions on the selection of an interviewee: the person must be engaged in software development or management, may not be a close relative of the student, and may not be selected by more than one student. Occasionally students are unable to find anyone; if the instructor is persuaded that the student made an honest effort, the instructor may tap into his or her professional network for a colleague who will agree to be interviewed.

To overcome student inertia, we provide an initial set of generic questions to help frame the discussion. However, students must supplement what is provided by specific questions of their own. In the best of all worlds, the students have a conversation with the person they select, and such

conversations frequently lead to wide ranging discussions that enhance the student’s understanding of software engineering.

Each student submits a transcript of the conversation and a document reflecting on what he or she learned. Students often describe their preparation, thoughts, and expectations prior to the interview, along with unexpected discoveries as a result of the interview.

The “final exam” is actually a class-wide, collaborative reflection on the course as a whole and the interviews in particular. Once again, students are divided into groups, where they compare experiences and compile a list of observations as to what they have learned during the term. When the class gets together again, teams share these observations. Occasionally instructors impose some structure on the proceedings, such as having teams create mind maps for the course; other instructors take a more freewheeling approach in the interest of spontaneity. Whatever the approach, the class usually ends on a high note with students able to articulate what makes software engineering different.

V. EVALUATION

Part of our curriculum internal assessment is based on student feedback. The opportunity to provide course-specific feedback is afforded to students at the end of each school term via an online anonymous survey. Table I contains student course evaluation data from the last two years when we ran the version of Software Engineering Freshman Seminar discussed in this paper. The columns range from Strongly Agree (SA) to Strongly Disagree (SD) from left to right.

The feedback received in the course’s latest incarnation helps validate both the individual class activities as well as overall student learning. Recurring themes are an appreciation for hands on team activities in a software engineering context, the understanding of how software development benefits from process, and the importance of communication between teams and customers.

TABLE I. STUDENT COURSE EVALUATION DATA

| Question | SA | A | N | D | SD |
|---|------|------|------|-----|-----|
| I learned a lot in this course. | 17.7 | 54.4 | 19.7 | 7.5 | 0.7 |
| In general, the out-of-class assignments were relevant to the course. | 38.8 | 49.0 | 8.8 | 2.7 | 0.7 |
| In general, the in-class activities were relevant to the course. | 53.1 | 37.4 | 5.4 | 4.1 | 0.0 |
| Overall, I would recommend this course. | 43.7 | 33.8 | 16.9 | 3.5 | 2.1 |

Following are representative samples of written feedback we have received:

As I understand it, what I just took in this course was already a rework. Keep it!!! This "intro" course to software engineering was fantastic! It was really great, my favorite course by far!

I enjoyed Software Engineering Seminar and I think it made me feel certain that I'm in the right major, and that I have a thorough understanding of

what Software Engineering is like outside of the classroom.

This course was very informative, and fun. This is a great course and it gives you a great idea about what Software Engineering is like and starts to prepare you for what lies ahead.

We continually struggle with how to impress upon our entering students that software engineering is much broader than the programming they may have done through high school, and even the material they will see in introductory computer science courses. This is a reprise of the concern expressed at the start of the paper that students leave the program before they have seen any engineering. In particular, they need to see that software engineering will not relegate them to a lifetime of low-level coding.

For most of our students, this realization does not really set in until after they have been out on co-op. Our hope is that Software Engineering Freshman Seminar helps students move towards that realization at the outset of their college studies. Based on the following comment, our hope for the course was met, at least for one student:

I felt this interview was very useful. It opened my eyes to how great SE-101 [Software Engineering Freshman Seminar] was. I'll admit I didn't feel like some of the projects were that useful. Until this interview I was a little disappointed we didn't do more coding in class. However, I found that we actually covered the most important topics, like communication, and working with others. It really opened my eyes to what software engineering is really like.

For many students, this first introductory experience reaffirms their desire to pursue a career in software engineering.

VI. FUTURE EVOLUTION

We expect the seminar course to continue evolving in the future. In particular, RIT's impending switch from academic quarters to semesters has forced us to reconsider some of the pedagogy. Our present 10-week course with one two hour meeting per week will expand to a 15 week course with one or two meetings per week. Activities which currently require a full two hours to complete will have to be rewritten or replaced in light of these constraints.

A particular challenge will be process activities, such as the XP game, that require extended time to be effective. One possibility, inspired by field trips in biology and zoology, is to schedule one or two long activities for a weekend, with, of course, sufficient food and refreshments to entice students to participate. The feasibility of such an approach is up for discussion.

We also see a role for expanded coverage of intellectual property issues. Currently we only address these in the context

of proper citation of other's work, but much more could be included that is accessible to first year students. Certainly software engineers need be cognizant of the role played and restrictions imposed by copyrights, trade secrets, and patents.

VII. CONCLUSION

When the term software engineering was first coined, it was mostly an aspiration and a metaphor. Over the past 45 years the term has come to signify a new and exciting engineering discipline. The seminar course we've described is one way in which that excitement can be communicated to the next generation of professional software developers.

ACKNOWLEDGMENTS

We would like to acknowledge the many student course assistants who have helped run this course. They have not only engaged students during class time, but also were responsible for creating content for two of the class sessions. Another invaluable service that they provide is to aid our freshmen students in their adjustment to college life. We regularly note interactions between the course assistants and students in the seminar that are more about how to navigate the ins and outs of the RIT campus and systems than how to set the color of the team's Robocode tank turret using Java.

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An approach for teaching algorithms and computer programming using Greenfoot and Python

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Abstract - The difficulty in learning and teaching the algorithms and programming subjects is a major concern for managers and teachers of Computer Science (CS) undergraduate courses. These are foundational subjects for CS professionals, yet continue to present a high degree of difficulty in learning for students. This paper presents two experiences we conducted with Computer Science beginner students related to the teaching of computer programming. Results obtained were positive and encouraging in a way that continues to be used with new students in CS courses. We are convinced that other actions like this one are vital for interdisciplinary work, preventing student evasion resulting from the learning environment, casting them as process actors. Algorithms and computer programming are becoming evermore necessary tools for academic and professional development.

Keywords – *programming teaching; algorithms teaching; introductory computing courses; Greenfoot; Python.*

I. INTRODUCTION

Teaching algorithms and programming concepts for first year students of Computer Science courses has always been a great challenge for universities. It is common for students to feel different level of difficulties and several of them abdicate from their courses. The difficulty in learning and teaching algorithms and programming is making managers and teachers of CS undergraduate courses concerned. These subjects deal with key contents for the formation of the CS professional and present a high degree of difficulty in learning for students.

Study habits focused on memorizing and trouble in understanding the wording of problems are some of the factors pointed out as responsible for a high failure rate and consequent withdrawals from algorithms and programming courses.

One of the obstacles for programming teaching is the concept of problem complexity, which must be given a computerized solution. After understanding such a problem, students must design an algorithm through a step-by-step procedure for solving the problem in a finite number of steps. The algorithm does not depend on the adopted programming language during this design phase.

New Computer Science students usually have difficulties in understanding and abstracting the problem logics and transforming it into a step-by-step sequence in order to develop the algorithm later [1].

The primary target of initial programming courses is algorithm design. As these are considered core courses for the CS undergraduate, it is extremely important that students can clearly understand all the concepts covered. However, these courses have the highest failure rates in Computer Science courses.

This fact is due to two factors: a) the paradigm created inside and outside classrooms makes students come to first classes with the fixed opinion that this course will be a great obstacle, extremely difficult to be overcome; and b) some teaching methods used by teachers to present the concepts, because understanding how the computer executes its tasks requires much abstraction ability from the students [2].

Several reasons for student failures in learning algorithms and programming concepts have been described [3]:

- Undisciplined study habits focused on memorizing;
- Unstructured previous knowledge, especially for mathematics and logics domain;
- Non-motivating teaching approaches;
- Taught contents are irrelevant to students' day-by-day lives;
- Difficulties in understanding problem wording;
- High levels of abstraction.

Algorithms learning difficulties faced by first year Computer Science students are many and very well known by researchers. It is especially important that students can clearly understand the problem and the kind of solution required by this problem. After that, student must devise a set of steps to solve the problem. To achieve this goal, it is necessary to rearrange thoughts, which requires much attention and concentration from the student. In the first semester of the course, most beginner students have no prior programming knowledge. Every new concept is a new fright that is really new and requires a different dynamic and logic reasoning.

This is certainly a challenge for teachers of programming everywhere. Some problems may have higher complexity level that makes it difficult for students to think about their solution, and applying programming concepts which are not completely clear for beginner students is not an easy task for them, as for most students they have their first contact to those concepts in the university.

As pointed by [4], students are not motivated or challenged to solve problems with wording like this: “enter five names and grades of students and show the room average, the lowest and the highest grade”. This wording just increases the difficulties listed before, because the problem does not call students’ attention to go into its solution.

About the lack of motivation of students due to complexity and non-attractive problems, even a case with more involvement of the teacher with his students can not improve the situation, because teachers are not able to give attention to all the students and some of them will be set aside, increasing the discouragement environment, very properly to evasion and failures.

In order to arousing more interest from students, it is necessary to suggest other situations which are more usual to their daily activities, and that also challenge them to give a solution to the problem.

According to [5], all students have their own learning potential, different skills, they can learn but in different levels. Even so, algorithm classes are taught as if every student would learn in the same way. It would be extremely important to give students the possibility for each one of them to work those contents in accordance to their own learning rate, in an individualized way.

A proposal for helping the solution of this problem is the adoption of teaching support tools, which use animation and interaction to allow beginner students a better understanding of the contents. Examples of these tools are Greenfoot and Python.

II. GREENFOOT

Greenfoot is a tool developed to allow Computer Science students to get knowledge about Object-oriented Programming (OOP). Greenfoot was a joint production between Kent University researchers, in England, and La Trobe University, in Australia, and it has a differential characteristic related to the development of graphical applications like games creation in 2D environment.

Using the animation and interaction of objects, it is possible to create mini-worlds and represent their objects graphically. Greenfoot makes the objects’ graphical view easier and controls the execution of several tasks. All these can be viewed in a two-dimensional environment, making the understanding and interaction between the objects easier.

Greenfoot has a typical software development environment, with several functions like “edit”, “compile”, “run” the source-code created by the student. The most differential characteristic from other environments is the direct interaction, for example: when an object is instantiated, it is possible to put it anywhere in the “world”, and when a method is called, this action is immediately viewed.

According to [6], this tool can be used for initial and advanced programming courses in universities. Its design and use simplicity draws the attention of those students who are not yet familiar to programming, making the task for teachers easier.

III. PYTHON

Python is an open source high level computer programming language, developed in the end of the 80’s in the Netherlands, by Guido Van Rossum, and was published for the first time in 1991. As any other language, Python aims for software quality, though it was designed to facilitate computer programming learning.

In accordance to [7], Python has some characteristics that make it a good language for programming learning: its syntax is clear and objective; its dynamic typing makes variables automatically determined on execution time; its interpreter returns immediate feedback due to potential errors.

IV. BACKGROUND AND RELATED WORKS

Some authors have discussed about teaching algorithms and programming courses in the first year of Computer Science, emphasizing the high level of difficulty students address [8]. This problem is the reason for the development of this project. We have to conduct this research and carefully analyze the results looking for effective solutions, because learning algorithms and programming is of paramount importance for undergraduate courses with focus on software development. It is common for students to really learn computer programming during the second or third year of Computer Science course, which brings to a great concern about students’ learning rates on those courses whose core is teaching algorithms and programming concepts.

Over the last decades, universities have started their programming courses using algorithms development, as they are the basis for computer programming. It is necessary to change this traditional way of teaching programming, turning into other approaches that can arise more interest from students, working with their daily examples which make them feel challenged to solve the problems [4].

The use of computer graphical tools is a good approach to reach this. Besides drawing students’ attention for being different from pencil and paper, a computer environment can provide challenging situations like in a game, allowing interaction of student to the program under development and presenting its result instantly.

An important research related to our work [9] was conducted at Denver University. They used Greenfoot and other tools with the objective of stimulating students in the

courses of Sciences, Technology, Engineering and Mathematics. That project had an interdisciplinary learning basis approaching drawing to arts, design and computer programming. They described that Greenfoot was chosen because of its functionality and easiness of teaching introductory programming and games design. The research consisted in providing a set of classes to students so that they could develop their own games. At the end, students had to answer a questionnaire and report how important that experience was to them. Most students answered that they could understand better the concepts of classes and objects using Greenfoot. They also answered that, after the experience, they were feeling more comfortable with programming and technology. As a final result, the researchers concluded that it was a very successful experience in teaching programming elementary concepts to young programmers.

On his studies, [10] also reports an experiment to improve Object-Oriented Programming learning, creating groups of students and introducing Greenfoot to them. The learning process was divided into units: on every unit a new concept was introduced and students had a new project to be developed. Each project had a wording and some resources (classes, images) so that students could develop the project using Greenfoot. As projects progressed, fewer resources were given to students; sometimes projects had only the wording problem. In the end of the process, they applied two tests to evaluate students. The results were not as good as they were expecting, but the author emphasizes that there is something very difficult to be represented on numbers of an assessment: the quality of source codes presented by students was much better than the quality of source codes presented by students years before. This happened because when students solve a problem using Greenfoot environment, they have an immediate return about success or failure and then they are motivated to implement the next program.

A research with high school students was conducted in Finland [7], which aimed to give the students: the understanding of data structures and programming basic concepts, writing and testing programs, and producing documents about their work. Authors emphasize that they used Python to introduce programming concepts and the results were very motivating: students reported success feelings when writing and reusing structured programs and when they worked with interfaces.

On the same research line, another project was conducted by [11] in which they taught object-oriented programming to CS students using Python. The language was adopted to strengthen OO concepts, and in the next semester students were presented to other OO programming languages: C++ and Java. Although they are very different languages, if compared to Python, authors reported that students did not bring difficulties in recognizing OO concepts on those last two languages.

V. OBJECTIVES

We consider that all students have their own learning potential, different skills, all they can learn, but not on the same way and the same speed. However, algorithm classes are

mistakenly taught as if every student would learn in the same way. It would be very important to provide students the possibility for each one of them to work those contents in accordance to their own learning rate, in an individualized way, using a contrutivist pedagogic model where students construct their own knowledge instead of passively absorbing it in a classroom [12]. In accordance to Constructivism theory, students are motivated to construct their knowledge rather than merely receiving and storing knowledge transmitted by the teacher.

On this work we present an experience for helping the solution of this problem with the adoption of teaching support tools for programming contents. We will present the results of two experiences we have conducted for getting better results with computer programming teaching: the first one, in 2010, was undertaken with first year students of Computer Science course using Greenfoot tool; the second one, in 2011, targeted last year high-school students using Python programming language. It is important to emphasize that our main focus on this work is introducing programming concepts for CS students, using Greenfoot and Python, but not on the tools adopted. The two experiences will be related on the next two case studies.

VI. CASE STUDY 1

In order to know better the effectiveness of Greenfoot for teaching object-oriented basic concepts, we conducted this first case study with 30 students in the first year of Computer Science at FEMA. This study was divided into four steps: identifying the students' OO knowledge, OO introductory course, Greenfoot course and assessment.

1st Step: Identification of Student's OO Knowledge

Before introducing the OO basic concepts, we applied a questionnaire to identify the students' OO knowledge level. The questionnaire form had 25 questions and, for each one, students should give an answer in a scale from 0 to 5, where 0 meant no knowledge about that topic and 5 meant deeply knowledge about that topic. About the topics, 21 of them were directly linked to object-oriented and 4 of them were about algorithm basic concepts. With that, we could extract some important information.

About the 21 topics related to object-oriented:

- 54.54% answered 0, what means that they knew absolutely nothing about those concepts.
- 28.57% answered between 1 and 2, what means that they knew very little about those concepts.
- 13.7% answered between 3 and 4, what means that they already knew those concepts.
- Only 3.17% answered 5, meaning that they knew those concepts very well.

After identifying and analyzing students' knowledge, we elaborated the strategies for the next steps.

2nd Step: Object-Oriented Introductory Course

As we concluded from the first step results, most students didn't have any knowledge about OO concepts. So that they could have a productive experience with Greenfoot, then we provided them with introductory lessons about OO. On those lessons, students were taught with OO main concepts: classes, objects, attributes, methods, polymorphism, inheritance, aggregation and composition. During the lessons, students were also asked to solve exercises for practicing the contents.

This was an important step for giving students the basic knowledge about object-oriented and they can transform their theoretical knowledge into practical ability on next step.

3rd Step: Greenfoot Course

After getting in contact with object-oriented concepts in the previous step, students were introduced to the most interesting part of this case study: Greenfoot classes and the development of a game.

In this step students had Greenfoot practical classes and were introduced to examples so that they could understand the OO concepts application. Such examples were introduced in a sequence to facilitate the learning.

The first example aimed to reinforce some OO concepts and students were also introduced to software interface, how to invoke methods from Greenfoot objects, methods return types, and methods parameters. Students were familiarized to software interface and remembered the contents of second step.

In the second example, a very important concept was practiced: inheritance. They could also work more with method parameters, learning how to edit classes' source code using Greenfoot Classes Editor.

In the third example students had more contact with the source code, increasing their knowledge. At this moment new concepts were introduced: method signature, indenting and class compilation.

In the end of all examples students needed to solve some problems, using the concepts learned. While they worked on the solution of the problems, it was remarkable students' excitement and how easily they used Greenfoot. Most students could successfully solve the purposed problems, and some of them could create new functionalities.

4th Step: Assessment

In the end of this case study, we conducted an assessment to evaluate what and how much students learned about object-oriented concepts. This assessment was not about Greenfoot, but it was about OO concepts. The grades obtained by students on this assessment process were:

- 16.67% got 2.0 to 3.9 points
- 23.33% got 4.0 to 5.9 points
- 36.67% got 6.0 to 7.9 points

- 23.33% got 8.0 to 10.0 points

- The average was 7.50 points

- The standard deviation was 2.084.

This assessment showed us that most students had more than 60% of success in learning the contents taught. Results set out the growth of students' knowledge about OO concepts.

VII. CASE STUDY 2

With the objective of verifying the contribution of Python language in algorithms and programming teaching and learning, we conducted a case study with 35 High-School students at Centro Paula Souza School.

These students were having the first classes of algorithms and programming, so they were getting into contact with those concepts for the first time in their lives. Teacher had taught these contents: variable types, conditional structure and looping structure. The teaching methodology adopted was teaching theoretical classes and presenting problems with mathematical and day-by-day wording to the students.

The same strategy adopted on case study 1 was also adopted for this case. The study was divided into four steps: identifying the students' OO knowledge, Python language course, assessment about students' capacity in solving problems and final assessment to verify students' learning.

1st Step: Identification of student's knowledge about algorithms construction

Students were asked to respond a questionnaire which aimed to identify their knowledge about algorithms contents and the use of pseudocode for problem solution. The questionnaire form had 25 questions and, for each one, students should give an answer in a scale from 0 to 5, where 0 meant no knowledge about that topic and 5 meant deeply knowledge about that topic. We extracted the following information from their answers:

- 73.70% answered 0, what means that they knew absolutely nothing about those concepts.

- 18.40% answered between 1 and 2, what means that they knew very little about those concepts.

- 6.3% answered between 3 and 4, what means that they already knew those concepts.

- Only 1.60% answered 5, meaning that they knew those concepts very well.

Starting from that scenario, we conducted the next three steps of this case study.

2nd Step: Python Language Course

The first step emphasized that most students answered they had no knowledge about algorithms construction. This was an important information for the teacher to adequate the Python material for students. On this course, the focus was: variables,

logical and relational operators, condition structures, looping structures and Python language characteristics.

3rd Step: Assessment about students' capacity in solving problems

After the second step, students had an assessment with 13 questions, aimed to evaluate how much they learned about computer programming concepts. This assessment was not exclusively about Python language but about students' capacity in solving specific problems. Students' grades were:

- 11.43% got 2.0 to 3.9 points
- 22.86% got 4.0 to 5.9 points
- 28.57% got 6.0 to 7.9 points
- 37.14% got 8.0 to 10 points
- The average was 6.51 points
- The standard deviation was 2.23.

4th Step: Final Assessment

This final assessment applied to those 35 High-School students had 20 questions about their satisfaction degree about Python course and the assessment at third step.

The data gathered from this final assessment were used to find evidences about the perception of success or failure pointed by students. Likert scale was calculated for every question in the final assessment to getting students' general satisfaction with the methodology we had adopted.

We considered Likert scale from 1 to 7 for this assessment. We considered as negative perception for answers with levels 1-3, as positive perception for answers with levels 5-7 and as neutral perception for answer with level 4.

The results obtained with data gathered from students' answers were:

- 17.1% answered in the scale 1-3, meaning a negative perception about their satisfaction;
- 14.3% answered in the scale 4, meaning a neutral perception about their satisfaction;
- 68.6% answered in the scale 5-7, meaning a positive perception about their satisfaction;
- The standard deviation was 1.706.

We got very encouraging results, as they showed an important value related to motivation and beliefs of students. Even considering that this was a subjective assessment, this scenario converged to the assessment we had on third step.

VIII. CONCLUSIONS

This work aimed to present the experiences in using two methodologies for computer programming teaching in CS introductory courses. Computer tools were used as pedagogical

basis, with the objective of providing practical activities fomenting the study assessment process.

We conducted two case studies. The first one was taken with 30 undergraduate students in the first year of Computer Science, in which we worked with object-oriented teaching and Greenfoot software. The second case study was taken with 35 High-School students, in which we worked with algorithms and programming teaching and Python language.

In the first case study we could compare students' knowledge level about Object-Oriented concepts before and after our project. It was evident in the answers gathered on first and fourth steps. In the first step we concluded that 54.54% of students had no knowledge about object-oriented concepts and the fourth step showed us that most students had more than 60% of success in learning the contents taught. Results set out the growth of students' knowledge about OO concepts. Furthermore, it is important to highlight the students behavior when using Greenfoot, they felt motivated and had fun solving the proposed problems, and these are essential factors for facilitating the learning.

In the second case study we concluded that most students (92.1%) had no knowledge for constructing algorithms. In the end of this case, we could verify that 59.71% of students had more than 60% of success in the assessment. In this case it was clear that students could construct programs only after understanding the concepts of algorithms. Python language has an important role for having a clear presentation and is coherent with the initial strategies for computer programming teaching. Due to Python having a simple syntax, if compared to other languages, it was easier to introduce programming concepts to High-School students, emphasizing programming and problem solution.

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A multinational case study on using diverse feedback types applied to introductory programming learning

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Abstract — Building written feedback, pedagogically sound, standardized and flexible enough to accommodate students who may be in different stages and learning curves is a complex and laborious task. In this paper, we describe a multinational case study involving diverse types of pedagogical feedback provided to Portuguese and Brazilian novice programming students. Programming errors, especially logical ones, can be used as a consistent metric for assessing learning. The research done looks for an innovative form to define content of several types of feedback. It also aims to create an efficient method for the discovery and mapping of students' logical programming errors. The results obtained so far using this approach are presented and analyzed.

Keywords - feedback; programming learning; logical errors; software testing; pedagogical rubric

I. INTRODUCTION

Students' difficulties in introductory programming learning are a well-known problem that motivated many researchers to propose methodologies and tools to help students [1].

Good feedback is essential to improve students' learning in Higher Education (HE) [2, 3]. They can learn more effectively if they receive quick and appropriate feedback about their actions in a short amount of time. However, creating written feedback, pedagogically sound, standardized and flexible is a complex and very time-consuming task.

When classes have many students, as it is common in introductory programming courses, feedback creation can be a huge task for teaching staff. In this context, developing methods and tools that may automate feedback creation, even partially, may be a good help for teachers' work and improve the support available for students during the course. That is the main objective of our work.

Ihantola et. al. [4] made a systematic literature review about systems for automatic assessment of programming assignments. They also discussed strategies to design good assignments from a pedagogical perspective. They concluded that not all programming exercises could be automatically assessed and also that many research projects do not offer guidance on how to overcome automatic assessment limitations.

One of the limitations of current automatic assessment tools, such as Mooshak [5] or Boss [6], is the limited quality of

automatic feedback they generate. The feedback text is fixed and little detailed. For example, in Mooshak the feedback is limited to small expressions, such as: "accept" (passed all tests), "presentation error" (mistake in input or output formatting) or "wrong answer" (failed in some tests). This is not surprising as Mooshak main objective is to support programming competitions, although it has been also used to support pedagogical activities.

There are also tools for automatic grading of programming assignments [7], but in many aspects they still require a direct inference of the teaching staff [8].

We decided to propose a semi-automatic solution that combines some types of pedagogical feedback with software testing techniques adapted to common introductory programming assignments. To define the assessment criteria consistently we used rubrics.

As we want to automatize the process as much as possible, separate steps have to be considered: logical error detection in students' assignments (programs), definition of the best feedback model to use, and adequate feedback creation and delivery to the student.

In section II we propose a method for error discovery and for students' assignment evaluation (considering common assignments in introductory programming courses). In section III we discuss several types of feedback and present a methodology for feedback creation in the context of introductory programming courses. In section IV we describe and discuss the first application of our proposals, in the context of a multinational case study that involved non-majors introductory programming courses in Portugal and Brazil.

II. DISCOVERY AND PEDAGOGICAL MAPPING OF PROGRAMMING ERRORS

To provide proper feedback to students it is necessary to detect logical errors in their assignments. Teachers know very well the logic of the assignments they suggest to students. Even without an explicit method, they can inspect students' source code and verify if it works or in which cases that doesn't happen. They intuitively use a set of test cases to verify if a solution is correct.

However, manually correcting a high number of assignments is a hard and time-consuming task. It would be

useful to have a system that helps teachers, namely analyzing students' assignments and producing the corresponding feedback. This would also allow that the testing and feedback is consistent for all assignments and for all students.

A general idea about the proposed method is presented in Fig. 1. For a particular assignment, its proponents (teaching staff normally) need to produce several pieces of information:

- The assignment description, including input examples and corresponding output (test automation needs a rigid formatting of the inputs and outputs, so it is important that students follow that formatting).
- A rubric that includes the programming aspects to verify in the students' solutions, and classification criteria to each of them. Rubrics are effective if we can enumerate exactly the qualities and the assessment criteria that the students are expected to achieve in each grading category [9].
- A correct solution for the problem.
- Set of test cases necessary to fully evaluate students' solutions and feedback sentences corresponding to the possible results of those tests (supported in the rubric defined for the particular assignment).

On their side, students have to interpret the assignment and propose a solution. Taking in consideration the test cases and the rubric defined for the assignment, the system tests each solution and produces feedback in function of the results.

In this section we focus on the method to discover and map students' logical errors.

To test a solution properly, it must be ensured that each line of code is run at least once. Therefore it is necessary to find the smallest number of test cases that guarantees this requirement. This number should be as small as possible to simplify the mapping of the set of test cases into feedback content, although some extra test cases might be pedagogically useful, for example to identify common errors novices make in that particular assignment. Mathematically, this problem can be solved using the cyclomatic complexity metric defined by McCabe [10]. This set of test cases should completely test the control flow graph (CFG) of a solution. A CFG is a representation, using graph notation, of all the paths that might be traversed through a program during its execution [10].

There are several free tools available to calculate the cyclomatic complexity of a solution. We used cyclo 2.0 [11]. It analyzes the cyclomatic complexity of ANSI C or C++ code. It calculates the minimum number of test cases necessary for a particular solution. After that it is necessary to identify those test cases and see which lines of code they cover in the solution. This can be done during code execution. We used the GCC (GNU Compiler Collection) compiler and the tools developed for it to verify the test coverage of source code (Gcov). We also used another free tool, called LCOV [12], for the dynamic visualization of the source code. It is a graphical front-end for coverage testing using Gcov. LCOV supports statement, function and branch coverage measurement.

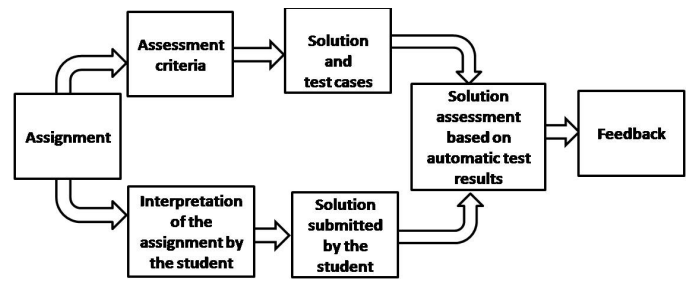


Figure 1. General working schema

The method proposed will be illustrated with a small example. Consider that the aim of an assignment is to read an integer between 100 and 999. If the sum of its digits is even, a zero should be added to the right of the number, and if the sum is odd, a 1 should be added.

In this case the cyclomatic complexity is 2 because there are only two possible linearly independent paths in the CFG of the solution. It is necessary to use a decision point, implemented in C by an if-else statement, that verifies if the sum of the digits of the number read is even or odd. It is necessary to define which are the two test cases necessary and sufficient to traverse these paths.

Looking at the decision point of the CFG, with the help of Gcov and LCOV, two inputs were chosen to test the solution: one number with an even sum of its digits and another number with an odd sum of its digits. As expected, after running the two test cases LCOV indicates 100% coverage, guaranteeing that all code lines were executed at least during one of the runs. It is possible to determine interactively which lines are executed in each test case.

Of course, having only test cases that test the expected solution is not enough, as some students' will likely submit solutions that are far from expected. So there is the need to define a set of test cases that are able to test logically equivalent solutions. A solution is logically equivalent to another if they have the same results when submitted to the same set of test cases (that tests all the program logic).

The information about each test success or failure can be used to map and simulate experimentally possible students' logical errors. Moreover, it is also desirable to create new test cases to facilitate the mapping of logical errors in students' incomplete or partially correct solutions. Also test cases can be created to identify common errors made by novices in that particular assignment (normally teaching staff has a good knowledge about this from past experiences).

The definition of test cases can be time-consuming (although Gcov and LCOV can give a good support). However, it is important to note that the time spent will allow a stronger learning support that done manually would mean much more time. Also, it is worth noting that this work is done once for assignment, but can be used many times, including in different courses and years.

III. BUILDING PEDAGOGICAL FEEDBACK

Feedback used in educational contexts is often seen as very important to improve knowledge and skill acquisition. In

addition to its influence on achievement, feedback is also seen as a significant factor in motivating learning. It is possible to find in literature a large number of research reports on feedback and its influence on learning. Many types of feedback have been proposed and different strategies for its implementation in pedagogical contexts have been suggested [2, 3, 13]. Reports are often divergent on the best type of feedback for a particular situation. It is also possible to find divergent views about what to include in feedback messages, and even in the amount of information that is more effective to reach the pedagogical objectives.

For the purpose of this study we chose three models of pedagogical feedback. Two of them are classic and very well known: formative and summative feedback, while the third is less known and used: ipsative feedback.

Formative feedback can be seen as information that is communicated to the learner to modify his/her thinking or behavior for the purpose of improving learning. Information may address the accuracy of a response to a particular problem or task and may additionally touch on particular errors or misconceptions [13].

Summative feedback is connected to summative assessment that usually is made for the purpose of assigning grades to students. So, the main aim is to find errors and judge them consistently and coherently [14]. The result of that assessment is then communicated to students in summative feedback.

Ipsative feedback is based on a comparison with the learners' previous performance and linked to long-term progress. The idea is to inform the learner about his/her performance in a specific skill developed in the long term. This type of feedback may have a higher impact on motivation, as it may stress the improvements shown by the student in a particular topic during the time. This is particularly interesting in programming learning, as students often get discouraged when they don't recognize progresses in their learning. After all it is expected that the student makes progresses and ipsative feedback may help the student to recognize them [15]. When compared with formative and summative feedback, ipsative is much less known and used, as we couldn't find any other research project that uses ipsative feedback in computer science education.

Although contextualized feedback is important to learning, it is difficult to implement in the form of an automatic pedagogically consistent assessment and feedback system [7].

In the next sections we describe the feedback creation process we propose for the context of introductory programming learning. It is based on the information about the assignment described in section II and in the student solution proposal to that assignment.

A. First stage - Creating basic pedagogical feedback

In our context, feedback content depends essentially on the programming errors made by the students and the model of pedagogical feedback in use.

As mentioned in section II, we use rubrics to consistently define the assessment criteria to be used. Rubrics should include the logical parts to verify, but also the quality criteria

for each of them (for example expressed in a qualitative scale of four levels: excellent, good, fair and poor). The number of parts to consider in an assignment and their weight in assessment depends on what is considered pedagogically important by the teachers involved. Normally, in the context of introductory programming learning, teachers are more concerned with the logical errors students make when devising a solution for a particular problem. So, in this case, rubrics will be focused (or contextualized) in the logical aspects of the proposed solutions.

The rubric criteria are associated with the test cases defined for the assignment, allowing the system to make an evaluation of which criteria were successfully met and which weren't by a particular student solution.

Our research approach supports the definition of rules connecting feedback text with combinations of test cases results. It is possible to have direct associations, for example some text that should be included in the feedback if a particular test case fails. It is also possible to have multiple associations, connecting a feedback text with a more complex situation, for example test cases 1 and 2 are successful, but test case 3 fails.

Hence, at the end of this first stage the results of test cases run on the student solution originate feedback contents that will help the student to understand the tests' results. With this information it is expected that the student reflect on the mistakes made. Hopefully this reflection may lead to learning, and, if necessary, the student will be able to improve the proposed solution.

B. Second stage – Model dependent feedback content

It is possible to enrich the feedback created in the first stage, so that it can be more useful for students. In the second stage the software test results are interpreted under the perspective of summative, formative and ipsative feedback theories [2, 3, 14]. The information given to students depends on the type of feedback the teacher feels more adequate in a particular situation.

In summative feedback it is necessary to include information about test cases where the student solution failed, and possibly also some grading information that comes from the mapping between the successful test cases and the rubric for the assignment.

The aim of adding formative information is to stimulate learning and motivation. This can be achieved including also positive aspects in the feedback, namely the test cases the solution passed successfully. Formative feedback can include also study indications, such as suggestions to read some material and indications to solve some other problem that might help the student to get insights on how to solve the current assignment.

In the ipsative feedback approach it is important to give not only feedback about the current assignment, but also some information about the student evolution in the course or the current module. Of course this past information must have been collected in previous assignments, facilitating its reuse in the current assignment.

To facilitate the understanding about the three types of feedback considered in our work, we will exemplify what could be sent to students that made a common error in the same assignment already used above: instead of calculating the sum of the digits and then check if it is even or odd, the student simply verifies if the number is even or odd. In such a case the solution would pass the test cases where both the sum of the digits and the number itself are even or odd, but it would fail otherwise.

Summative feedback would care about the test cases that failed and include the corresponding information. It would also include explicit grading information about the submitted solution. For example: “Your solution failed in all tests where the sum of digits is even and the number is odd and conversely. So your solution is not correct and was graded with 30%”.

In the same situation, formative feedback would include the result of all test cases and the corresponding information. It would also include some extra suggestions and hints for study and improvement. For example: “Your solution verifies if a number is even or odd and adds a 0 or a 1 to it. However, the assignment asked you to verify if the sum of the digits of a three-digit number is even or odd. So, your solution does not answer what was asked. Please check exercise 3 available in our course LMS, since there are some similarities to what you should have done in this exercise. Next time you should read the assignment description more carefully.”

If ipsative feedback were used, it would include information about the failed test cases and associated information. It would also include some contextual information, both about the assignment objectives, the student performance in previous assignments and other information about the student participation in the course (e.g. previous assignments not submitted, missing lab classes, results of previous assessments and others. It could be: “This assignment objective was to see if students were able to decompose a number in its digits and verify if the sum of the digits was even or odd. Your solution doesn’t solve the problem completely, since it fails in all tests where the sum of digits is even and the number is odd and conversely. This is the 3rd out of 4 assignments that you cannot solve as expected. You should commit more in the course. Remember the first test is three weeks from now. It might be a good idea if you ask some guidance from your teacher.”

Of course, it would also be possible to use mixed approaches where feedback would have characteristics from more than one type. However, it is important to keep feedback messages simple and direct, so that there are no misunderstandings from the student (the student might be tempted to skip long or complex messages).

C. Third stage – Personalized pedagogical feedback

In some cases it can be necessary to introduce some individualized information in the feedback, e.g., some remark about code quality or presentation issues. This appreciation cannot be done automatically. So, this possibility should be used exceptionally, as it may add a significant load to the teacher work.

IV. EXPERIMENTAL STUDY

A. Brief description

To make a first test to our approach and to gather information that might help us to improve it, we organized a multinational case study in the context of non-majors introductory programming courses. It includes novice students from Industrial Management Engineering of the Faculty of Sciences and Technology (FCTUC) of the University of Coimbra (UC) in Portugal and students of Civil Engineering and Food Engineering from the Institute of Informatics (INF) of the Federal University of Goiás (UFG) in Brazil. In total, these courses included 114 students (30 in Portugal and 84 in Brazil), 4 teachers and 4 monitors. In all courses the C programming language was used.

In order to compare the effects of the three feedback models considered, students’ solutions were classified using the same metric (mainly logical programming errors) and the same rubrics. Also the error discovery methods and the sets of test cases were common in all cases. Test coverage of 100% was guaranteed in the test cases used in all assignments. This was confirmed experimentally using LCOV.

The students involved in the three courses made a total of 1256 submissions that were tested using the semi-automatic method of discovery and mapping of programming errors described in the previous sections. However, for our study purposes we only considered the submissions that corresponded to a set of 10 assignments that were common to the three courses. This set was agreed with all the teachers and involved the key issues of the course syllabus (each teacher proposed other assignments only to their students). There were a total of 919 submissions to the 10 common assignments. As some students submitted a low number of solutions, we decided to consider only as participants students who submitted at least 50% of the set of common assignments, which corresponded to 795 submissions (Table I).

It was also defined that assignments would be solved in groups of two students, but only one of them would submit their solution. However, the feedback would be sent in individual e-mails to ensure that all students would have access to the same information.

In Civil Engineering and Food Engineering students were allowed to resubmit solutions after they received feedback about their first attempt. The same didn’t happen in the Industrial Management Engineering course.

TABLE I. NUMBER OF SUBMISSIONS AND TYPES OF FEEDBACK USED IN THE COMMON ASSIGNMENTS

| Feedback Model | Engineering course | | | | |
|----------------------|---------------------------|------------|-----|-----------|-----|
| | Industrial Management Eng | Civil Eng. | | Food Eng. | |
| | | 1st | 2nd | 1st | 2nd |
| Summative | 60 | - | - | - | - |
| Formative | 38 | 227 | 120 | - | - |
| Ipsative | - | - | - | 222 | 128 |
| Total of submissions | 98 | 347 | | 350 | |

Mooshak was used for automatically run the set of test cases defined for an assignment on each solution proposed for that assignment. Each test case consisted of an input to the solution and the expected output that was compared with the solution-generated output. As a result, teachers and/or monitors had access to which test cases a particular solution passed or failed. With that information and the mapping between test cases results (alone or in combination) and feedback texts, it was possible to easily compose the feedback messages to send to each student after a submission.

In the next two sections we will present the results obtained in each of the experiments.

B. First experiment - Portugal

The first experiment was done in Portugal, in the first semester of the 2011/12 academic year, with students of Industrial Management Engineering. Students were divided in three lab classes. Students from two of them received summative feedback for their solutions, while students from the third class received formative feedback.

With a few exceptions students received one assignment per week during the course. Feedback was sent to the students in a short notice (2-3 days normally).

It was decided that students' participation would be voluntary, meaning that this activity would not count for the final grading. Maybe because of this decision, only 30 out of the 90 students could be considered participants in the study (33.33%), accordingly to the rule defined.

Considering the average results of all assignments submitted, students who received formative feedback had a performance that was 26.26% higher when compared with students who received summative feedback. Of course we can question if this difference was influenced by the difference in feedback. We verified also that on average the formative feedback students submitted more assignments than their colleagues (the difference was 12,5%). Although we suspect that other variables in the learning process might have contributed to these differences, we believe that the different feedback received had also some influence. This was also supported by informal feedback during classes, making us believe that formative feedback was more appreciated than summative feedback.

C. Second experiment - Brazil

The second experiment was done in Brazil, in the second semester of the 2011/12 academic year, involving 96 students of Civil Engineering and Food Engineering, divided in 4 lab classes. As we used the same rule to define who were the participants, only 84 students (87,5% of the total) were considered participants of the study.

In this experiment we decided to use formative feedback and ipsative feedback. The former was used with Civil Engineering students and the later with Food Engineering students. In this experiment, students were allowed to make a second submission of the assignment after they had received feedback about their first attempt. Table II shows the summary of results obtained in this second experiment.

TABLE II. SUMMARY OF SECOND EXPERIMENT SUBMISSION RESULTS (BRAZIL)

| | Civil Eng. | Food Eng. |
|--|---------------------------|--------------------------|
| | <i>Formative Feedback</i> | <i>Ipsative Feedback</i> |
| Correct solution in 1 st submission | 32.92% | 20.21% |
| Partial improvements in 2 nd submission | 12.26% | 23.82% |
| Correct solution in 2 nd submission | 27.91% | 20.38% |
| No improvements in 2 nd submission | 12.86% | 13.20% |
| No 2 nd submission | 14.05% | 22.39% |
| Total | 100% | 100% |

All students that solved the assignment correctly in the first submission were not considered for the comparison of the feedback models. Comparing both submissions allowed accessing the evolution students had after receiving the feedback.

Consulting table II, it is possible to say that formative feedback had slightly better results, as there was a higher percentage of completely correct 2nd submission solutions. Also the percentage of formative feedback students who made second submissions was higher. On the contrary, it is possible to conclude that a higher percentage of students who received ipsative feedback showed partial improvements in their second submissions, without reaching the completely correct solutions.

V. CONCLUSIONS

The construction of consistent and pedagogically contextualized feedback for introductory programming students requires a methodology focusing on helping them overcome their learning difficulties.

The feedback models must be based on consistent assessment models, because otherwise feedback content can be, at best, useless and, at worst, dangerous, as it simply would not effectively measure and detect students flaws or produce useful information in pedagogical terms.

We created and experimentally tested a semi-automatic method based on software testing and rubrics for programming errors discovery and mapping in feedback texts. The results of software testing and rubrics can contain information that allows judging learning from the point of view of the correct application of the programming logic and also of good practices (comments, coding style, etc.).

This method is able to discover and pedagogically map students programming errors in information used by three different feedback models, namely formative, summative and ipsative. There are, however, some restrictions for applying any method based on automatic software testing, such as solutions with syntax errors, plagiarism, or solutions that use logic explicitly prohibited in the assignment.

In the experimental study, students who received formative feedback showed a higher percentage of completely correct solutions when compared to their colleagues.

In some cases, we observed that students who received ipsative feedback had the perception of being monitored closely, as feedback received included information about their evolution and commitment in the course. This may be positive to some students who have better performance when they feel closely monitored.

After analyzing the experimental results we can conclude that pedagogically well-constructed feedback helps students to reduce the number of logical errors in some extent. This influence depends on the model used. In general, we think feedback has a positive influence on the learning process in introductory programming courses.

It is important that feedback generation can be done without representing a significant increase in the teachers' workload. Although we already used some available tools to support the different steps in our work, our aim is to increase the automation of the full process, giving to the teachers a web-based tool that automatizes feedback generation and management as much as possible (possibly integrating some of the already used tools). This tool should allow the generation of feedback based on different models. This will be the next step in our work.

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Towards a Framework for Designing and Analyzing CS Learning Environments

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Abstract—This paper focuses on understanding and developing learning environments for computer science education. We present two models that we have successfully used in European and African contexts. The first model, Computer Science Learning Environments (CSLE), presents seven dimensions of computer science courses, which should be considered in learning environment design for computer science. The second model, Investigative Learning Environment (ILE), presents an action plan model, inspired by action research, for combining educational research and computer science teaching. In the empirical section we outline two case studies where these models were used to design and implement computer science learning environments in two different learning contexts. In the first case in University of Helsinki, Finland, we developed and studied a method of learning-by-inventing in a robotics programming course. That course was designed around problem discovery and inventing, and it employed LEGO® Mindstorms robots. In the second case in Tumaini University, Tanzania, we designed an environment for studying and improving introductory programming courses. Both models showed to be useful for designing, implementing, developing, and analyzing the courses in both learning contexts.

I. INTRODUCTION

Computer science education is a widely studied and intensely discussed topic. The literature proposes a variety of pedagogical viewpoints, practical approaches, learning theories, motivational vehicles, and other elements related to the learning situation. Recent pedagogical trends include, for example, problem-based-learning (PBL), inquiry learning (IL), and other student-centered learning practices, which are argued to increase motivation [1] and to support deep-level learning [2]. There is also contrasting evidence, speaking in the favor of more traditional, teacher-driven learning practices [3]. Evidence on cultural or contextual factors for the learning environment is also inconclusive. There is no coherent understanding on how pedagogical approaches work in different courses and in different contexts in computing education.

This paper presents a conceptual framework for classifying and analyzing learning environments in computer science. That framework consists of seven groups of variables. The model has developed as a part of an action-research ap-

proach of developing computer programming courses in two universities—one in Finland and one in Tanzania.

In the Finnish university we designed and studied *learning-by-inventing* by using LEGO® Mindstorms as a vehicle for learning. The experiment was iterated three times. In the Tanzanian university we designed and studied various pedagogical approaches to support deep-level learning and intrinsic motivation in computer programming courses. That experiment was iterated twice.

II. CS LEARNING ENVIRONMENTS: A CONCEPTUAL FRAMEWORK

A *learning environment* is a combination of teaching practices, physical surroundings, students' learning processes, and assessment. Learning environment provides scaffolding for a desired learning trajectory, which is a path that a learner takes to accomplish the learning goals [4, 61–70]. A learning environment generates destructive friction if it is too strictly or too loosely structured in relation to a student's self-regulation skills, while constructive friction emerges from a proper amount of shared control between the teacher and the student [5]. A learning environment should also activate the student's zone of proximal development (ZPD) [6].

In the context of computer science education we propose a combination of variables that should be determined in order to configure the learning environment efficiently: *tradition of computing, objectives and assessment, problem types, problem management, teaching style and social interaction, motivation and sociocultural context, and control*.

1. Tradition of Computing: Computer science consists of three intertwined traditions [7]. The theoretical tradition deals with verifiable theoretical structures, such as algorithms, data structures, and their properties. The engineering tradition aims at working implementations, products, and inventions. The scientific tradition aims at finding causalities and generalizations based on models, theories, and laws. The traditions upon which different curricula and courses are rooted bring great variation to each curriculum's problem types and to

suitable pedagogical approaches [8]. Although the traditions are deeply interwoven, most learning situations emphasize one of the traditions over the others. The traditions are often tacit within a department's ethos, and thus invisible to the teacher and/or the learners. As each tradition of computing determines techniques, theories, and working modalities in computing practice, it is a root determinant of the learning environment, and should not remain a tacit, invisible, or subliminal component of teaching.

2. Learning Objectives and Assessment: Learning objectives and their assessment usually derive from the traditions of computing. How easy it is to evaluate whether students reached the learning objectives depends on the objective. While it is relatively simple to evaluate learning of factual information or the ability to solve a first degree equation, it is certainly not straightforward to evaluate the acquisition of new learning skills or problem-solving skills, such as deep-level or active learning skills. The manifold learning objectives makes evaluation of learning environments a complex task that requires methodological and pedagogical competence. In one related study [9], it took researchers several years to be able to measure the acquisition of activating learning styles. Also, the learning environment and assessment tasks should be in proper *constructive alignment* [10, pp. 95].

3. Problem Types: A variety of problem types can be found in education. Those include, for instance, logical problems, algorithmic problems, story-problems, rule-using problems, decision-making problems, troubleshooting problems, diagnosis-solution problems, strategic performance problems, case-analysis problems, and design problems [11]. Problems are subject-relative, and context-dependent [12, pp. 76], and also problems can be classified according to their openness. In closed, or well-structured problems the starting point, solving technique, and goal state are known [13]. In open or ill-structured problems the starting point, technique, and goal can all vary from closed to open. Other classifications include the dimension between pseudo-problems, authentic problems, and ethical problems. The selection of problem types is usually related to the computing tradition and learning objectives.

4. Problem Management: Solving a problem is often only one stage in a process of solving multiple problems. Many problems raise more new problems than they solve, and thus the process of managing the solving of multiple problems is important. In computer science problem management can be closed (the teacher gives students certain problems, such as weekly theoretical exercises), or it can be done according to an industry-standard software engineering model (in software development courses of the engineering tradition), or it can be more open (a science-like research project or a design-oriented software course).

5. Motivation and Sociocultural Context: Emotions affect motivation and performance [14]. Task involvement is fostered by many emotions, and solving a challenging task often requires a range of emotions. The learning environment should promote a balance between feelings of competence and feelings of challenge [15]. Imbalance leads to a decrease in

concentration and involvement. As a rule of thumb, a too high challenge is better for concentration than a too low challenge [15]. Another theory argues that intrinsic motivation is a favorable state for learning, and it can be supported by a proper combination of autonomy, relatedness, and competence [16]. There again, emotional and motivational support requires understanding of the broader sociocultural context of the learning environment, such as power distance between teachers and students, cultural norms for classroom interaction, and individualistic versus collectivistic study habits.

6. Teaching Styles and Social Interaction: A common distinction between teaching styles is that between teacher-driven, or instructivistic teaching styles and student-centered, constructivistic teaching styles. In instructivistic teaching, the teacher is in full control and feeds students with information, while in constructivistic teaching, the teacher works more as a coach, who directs and helps students to find their own learning paths. A professional teacher can select his or her teaching style and classroom interaction types based on the selected tradition of computing, objectives and assessment, problem-, and problem management types, and context of education. Another important aspect concerning social interaction in coursework is the choice between individual work and groupwork.

7. Control: An open environment grants full control to a student, while a closed environment gives the teacher full control of the learning situation. The level of openness has triggered heated conversations between pedagogues, and it has given rise to pedagogical approaches such as PBL and IL, which stress the benefits of openness in the knowledge construction process. There again, some argue that for some learner groups, such as novice learners, too much openness is detrimental to learning [3].

The seven variables above constitute our conceptual framework for analyzing, designing, and evaluating learning environments. Theoretically speaking, teacher can configure a learning environment by freely adjusting the variables above. In practice, the configuration options depend on the skills of the teacher and the characteristics of the surrounding context. To develop new learning environments and to develop one's teaching, risk-taking, new experiments, and research is needed. Those are not always promoted by the traditional models of teaching. The following chapter presents an action-research based approach to teaching, which has, in our work, shown to be a powerful vehicle for designing and studying new learning environments.

III. INVESTIGATIVE LEARNING ENVIRONMENT

Traditional teaching consists mainly of teaching acts. But as such, teaching acts do not support research very well. Our proposed approach extends teaching to contain both teaching acts and research acts. Thus, in our approach, a number of research-oriented activities are explicitly included in teaching. Our approach includes, in a cyclical process, a background study; a literature study; a detailed plan for teaching, designing and conducting research; teaching and researching in collaboration

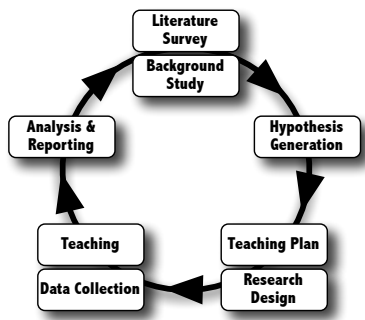


Fig. 1. Cycle of Activities in Investigative Learning Environment

with students and other staff (by observing, interviewing, and surveying); systematically combining the results; and then iterating the cycle (Fig. 1). Improving teaching through action research has been considered as a good idea by a number of studies (example: [10, pp. 284]).

Concerning teaching plan and research design, one can intertwine curriculum development principles [17], action research principles [18], and other educational and educational technology research principles [19]. The *plan* stage in action research [18, 13] is found in the first three steps in our cycle; the *act* stage is found in our teaching step; the *observe* stage is inherent in our data collection step; and the *reflect* stage is found in our analysis and reporting step. In addition, action research brings forth a number of ethical issues which need to be acknowledged [20].

In our model, teaching and researching can be done in small collaborative teams including teachers, researchers, students, and other staff. All pedagogical choices are grounded in educational theory, teaching skills and research skills are learned-while-doing, and the research parts can be conducted lightweight or more thoroughly, depending on the available resources. In the following sections we describe and analyze our experiences of investigative learning environment design in two different contexts: in a Finnish university and in a Tanzanian university.

IV. LEARNING BY INVENTING: CASE HELSINKI

The project started from amorphous thoughts and visions about a learning environment in which students would be motivated by topics and projects of their own interests, and where students could engage in their own learning without restrictions by working with various platforms, gadgets, mobile phones, game consoles, and robotics kits of their choice. An important theme was to promote deep learning and hard work through positive emotions, play, inventing, and a sense of freedom from restrictions.

We selected a very open environment by granting the learner a lot of control. We controlled the skill-level and phase of studies of students entering the course, since openness is not considered to suit novice learners well [3]. Also, solid domain-relevant skills, which the novice CS students do not yet have, are required in inventing, and in creative problem solving [21].

TABLE I
CONCEPTUAL FRAMEWORK FOR LEARNING BY INVENTING [21]

| Component | Method of Support |
|---------------------------------------|---|
| Competence | Use of creativity-enhancing methods, providing effectance-promoting feedback. |
| Autonomy | Providing choice for self-direction. |
| Relatedness | Encouraging teamwork, promoting social interaction and creative working methods. |
| Domain-relevant skills | Advanced computing skills required from all attendees. |
| Creative processes and working styles | Use of creativity-enhancing methods: brainstorming, 3+, and open-space workshops. |
| Constructionism | Use of LEGO Mindstorms robots. Each student was provided a robotics kit. |

We chose to promote all the traditions of computing (see section II). Thus, we encouraged the discovery of problems from all three computing traditions. We wanted to give the students an environment where they can practice and develop their computing skills, and we wanted to promote a new, inventive working approach for project work, and software development [21].

We did not want to specify the problem types in detail, but instead wanted to promote a problem discovery process. In the problem solving process we wanted to promote deep-level, creative problem solving where risk-taking and inventing would be preferred over risk-free textbook solutions. We also made problem management open because we did not want to promote a production-oriented working model, but instead aimed at supporting a process of inventing. To promote motivation and constructionist learning [22], we selected a flexible technical tool (LEGO®Mindstorms robotics kit) as the learning platform. On the dimension of motivation and sociocultural context we wanted to provide emotional support accordingly, especially to promote a state of intrinsic motivation and creative “flow” experiences [23].

We started by conducting a literature study (see Fig. 1), and chose the theories of creativity [23], intrinsic motivation [24], constructionism [22], and deep-level learning [25] to support the learning environment we aimed to create. Amended with the three components of intrinsic motivation—competence, autonomy, and relatedness—we ended with a total of six components for the conceptual framework, upon which the practical guidelines for the course were built (see Table I [21]).

After having developed the teaching plan and research plan we started the course, having weekly learning sessions. The learning sessions were not teaching in the traditional sense, but those sessions provided a psychologically relaxed atmosphere for discussions and idea-generation related to students’ problems. This meant sitting down together and engaging in creativity enhancing games, practices, and plays (for details, see: [21]). The data was collected using the mixed-methods approach [26].

We worked in a team of three teacher-researchers. The first iteration cycle of this action research resulted with a large set of research data and a wealth of practical information for improving the learning environment in the next iteration.

Based on the analysis (Fig. 1) we decided to add a few scaffolds for the second cycle: workshops for building robot structures, and ideas for robot designs for students who felt insecure in the open environment.

The results showed that most of the problems which students discovered in the first round of course implementation, belonged to the engineering tradition of computing. On the second round, also problems from other traditions increased. An example problem from the theoretical tradition was designing new signal processing algorithms for fixing a bad color sensor signal. An example problem from the scientific tradition was a small study for measuring the efficiency of motors and CPU under different conditions. From the engineering tradition, students introduced multiple projects with various programming problems, including game consoles, GPS devices, model cars, factories, chess-playing robots, sorting robots, ant-shooting laser robots, guarding robots, beer bottle opening robots, weather forecasting science robots, and robots communicating and being controlled by mobile phones.

The results showed that students used various types of problem management processes in their work. Some students worked in a linear, production oriented fashion, while other students adopted a more experimental approach, trying out different techniques, building prototypes, and flexibly changing their plans when necessary. Some students felt very comfortable working in this kind of open, creative environment, while others did not acquire a new active working style, but felt a need for clearer structures and guidelines.

The creative group games were received with surprise, but generally with various positive emotions [21]. Students were not used to bringing in their own problems, discussing them, and commenting and ideating on each other's problems. Breaking the usual classroom traditions might have caused some discomfort, but was generally received with joy. In learning sessions predetermined problem sets were typically discussed, students presented their solutions one at a time, and the teacher(s) then promoted and directed the discussion by using various creativity-enhancing plays and methods [21]. The final demonstration sessions were a success, with many people outside the course also joining in, including journalists.

Through the investigative learning environment we learned to support a new, inventive kinds of problem discovery, problem solving, and problem management processes related to learning computing, computer programming, and software development. We call this approach *learning-by-inventing*. The utilization of the action research process was a necessary part of the experiment. Before this activity, we did not have any knowledge or experience in arranging such courses, and the development and research of this course was an important learning experience for us as computing educators and educational researchers.

V. GUIDED ENVIRONMENT: CASE IRINGA

Our second experiment with investigative learning environments took us to a very different context: to a developing

country in East Africa. Teachers from Spain, Uganda, Tanzania, USA, and Finland have, over the past 4 years, introduced a variety of approaches for developing programming education at Tumaini University, Tanzania. The pedagogical approaches have included a traditional lectures-exercises-exams-pattern, with several attempts to employ different pedagogical extensions. Those extensions have included program visualization and animation tools, the coding-while-lecturing technique, contextual learning material and course contents, and e-learning resources as a support tool for learning [27], [28].

In 2009 we started to combine teachers' views about issues that affect the learning environment in programming courses, as well as teachers' ideas for improving teaching. That work resulted in a list of challenges related to, for example, students' educational background, hardware and software, study material, learning strategies, students' previous skills, assumptions about programming, fear of programming, time management, groupwork dynamics, and language [27]. Concerning what worked well, teachers named easy interaction in the classroom and positive experiences with e-learning materials. For suggestions for further improvements several aspects came up: addition of individualized exercises, increased amount of time to work with programming tasks, and inclusion of varying types of programming problems, such as completion of documented but unfinished example problems. Teachers also suggested increased emotional support for easing students' negative emotions towards programming [27].

After we started to have initial ideas about the challenges and possible remedies of programming education, we considered inclusion of research activities into teaching to be of top priority. By combining teachers' ideas together we came up with a five-factor model of challenges in programming in our context (Table II) [27]. The literature survey (Fig. 1) pointed out several theory-based practical ideas on how to address those challenges. We decided to add iterative action-research based activities to teaching, which would start from exploring and continue with describing, developing, and evaluating. The research and teaching activities included collaborative co-operation with teachers, researchers, students, and faculty staff.

Based on the theoretical background we made plans for providing a new kind of learning environment for basic programming courses in Iringa, Tanzania. Since the learning objectives are concerned with basic programming skills, the tradition choice (see Section II) followed mostly the engineering tradition. The learning objectives were based on a traditional CS1 course. However, in this environment learning objectives spanned beyond learning the basics of programming. Those additional learning objectives included problem-solving skills and deep-level learning skills—which have been identified as a major challenge in the whole undergraduate program—and other skills, such as groupwork dynamics, and cognitive and metacognitive learning skills. Multiple interrelated learning objectives made the design of the learning environment very challenging. Many of those learning objectives were impossible to be met within one course, but would require extensive coordination within the full curriculum.

TABLE II
FIVE-FACTOR MODEL OF CHALLENGES IN PROGRAMMING COURSES [27]

| Component | Explanation |
|---|--|
| Educational Background | Due to the multidimensional nature of the Tanzanian education system, the background skills in science topics, language, and problem solving vary a lot. |
| Learning Strategies (Deep/Surface Learning) | The mainstream learning strategy is rote memorizing and surface learning, aimed at solving well-defined, closed problems. |
| Motivational Orientations | Students risk generating extrinsic motivations when their learning strategies fail. |
| Groupwork Tendencies | Communal groupwork tradition, inherent in many African cultures, has both positive and negative effects for learning. |
| Study Environment and Habits | Language problems, copying, and plagiarizing of coursework is a common challenge. Internet, availability of computers for training, and other teaching facilities are often lacking. |

Concerning problem types we favored closed problems since most of the learners were novice learners. Also problem management was left mostly for the teacher. For quickly advancing students, we also provided more open-ended problems and small problem management tasks of building up solutions from smaller tasks. Thus, one cornerstone of the pedagogical approach was the provision of large amount of contextual multi-level exercises starting from extremely simple, but providing enough challenge for advancing students, too.

In terms of *teaching styles and social interaction* in classroom sessions we designed several roles for the teacher. As a rule of thumb, every learning session contained an instructive part, which introduced some general theme and then proceeded with a method we call *coding-while-lecturing* (similar to think-aloud modeling, e.g. [10, pp. 144]), where the teacher wrote programs while interacting with the class. The teacher and students discussed and debugged the program, taking multiple viewpoints into account. That method aimed at making explicit the implicit problem solving processes required for writing programs, and at helping students to unlearn their rote-memorizing learning styles, and thus, to support deep-level learning [28].

For western teachers, the social interaction in the class posed some cultural challenges. Students were not used to questioning a teacher's authority, which sometimes limited classroom interaction. To overcome these kinds of communication barriers, students were constantly encouraged to ask questions and to discuss the topics from multiple viewpoints.

In the dimension of motivation and sociocultural context it became evident that understanding the cultural context posed challenges for western teachers. While emotional support is needed in universities worldwide, the means of supporting it may vary a lot between sociocultural contexts. For example, in Tanzania expressing emotional support seemed to require a closer and more personal contact than it does in Finland. The intricacies of this aspect included a social code of manners and politeness, with elaborate greetings concerning matters of family, life, and health. The power distance between a teacher and student seemed to remain high, which sometimes seemed

unnatural from outsiders' perspective. Our affective support was based on the three components of intrinsic motivation: autonomy, competence, and relatedness [16]. We aimed for a relaxed, trusting, close, and safe interaction and environment, though it is hard to evaluate how those worked out.

Students at Tumaini University are mostly used to closed learning environments, and during classroom sessions we sometimes utilized methods of open learning environments by utilizing PBL-style activities, and by granting the learners more autonomy. Thus, we promoted the feelings of autonomy by shifting control between the learner and the teacher.

In this environment, a traditional mode of teaching does not work well because the learning environment is poorly understood. Hence, we employed the investigative learning environment design approach (see Section III) and worked in a team of three teacher-researchers, working in multiple and changing roles in the learning environment. We shifted roles between teachers, researchers, observers, and interviewers. The first iteration of this research was investigated by group interviews and survey studies accordingly [27], [28].

The first iteration (2010–2011) with the initial teaching plan (see Fig. 1) and case-study research design yielded a lot of practical guidelines and important understanding about the challenges of learning in this context of education [27]. Still, although a number of students made impressive developmental leaps during those activities, the overall learning outcomes remained unsatisfactory. Rather than answers, the analysis of the first iteration resulted with a number of open hypotheses for further research. The most important question that arose concerned students' work when they practice on their own time. Probably the most important learning environment for learning—one's work on one's own time, especially doing homework—would need careful inspection. The home environment is, however, typically highly unguided, and unguided learning has, in educational psychology, been considered negative for novice learners [3]. Pedagogical approaches for promoting guidance in programming have been successfully used in other contexts [29].

In the second iteration we aimed at firstly testing the impact of guided learning sessions on the learning outcomes, and secondly, at studying students' problem solving processes during homework practice more thoroughly. To do the first, we changed the research design into an experimental research setup. We kept all the previous pedagogical approaches constant, but added guided exercise sessions as a pedagogical intervention. We conducted a pretest-posttest experimental research setup, recorded observations utilizing a thinking-aloud-protocol [30], and conducted a survey study (for detailed results, see [31]). While the outcomes in the classroom looked very promising, there was no statistically significant difference between the control group and experimental group in the learning outcomes (see [31]). The difference between qualitative results and quantitative learning outcomes led us to consider additional hypotheses: for example, maybe we test the students' learning wrong. If we want the students to learn-by-doing, perhaps we should test-by-doing also [31].

VI. CONCLUSIONS AND DISCUSSION

Our two example cases extended teaching activities with research activities. The educational contexts were very different from each other, the other being a top-100 university in a hi-tech society, and the other being a new educational program in a small private university in a developing country. In both cases we wanted to extend current computing education by promoting deep-level learning and problem solving through a number of pedagogical tools and vehicles and through iterative development activities inspired by action research.

A learning environment is a complex construction of multiple factors. This research was based on our initial draft of a conceptual framework for classifying and analyzing learning environments of computer science (see Section II). Although the two learning environments had notable differences, both of them could be defined with our model.

Our proposed model of investigative learning environment, following the action research tradition, has several gains in computing education. Teaching in a collaborative team brings multiple viewpoints and ideas to action, and the planning sessions force the staff to articulate their reasoning behind the pedagogical routines. This discourse can be aided with a framework that focuses on the cornerstones of a learning environment. In this study we found the framework presented in Section II useful in both of our educational contexts.

By bringing rigorous research into teaching we reminded that teaching is not only an art but also an activity where teachers should be able to justify their selections by reasoning and intellectual traditions. We have found action research activities to fit well in both developing and developed country contexts. Investigative learning environment design can be conducted lightweight or in a comprehensive manner, depending on the available resources.

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A Scratch-based CS0 Course for At-risk Computer Science Majors

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Abstract—This paper presents the results of a CS0 course based on the Scratch programming language that was designed to improve the retention of at-risk computer science majors. At the authors' university, prior to the introduction of the CS0 course, students who selected the computer science major but entered the university with weak mathematics preparation from high school left the major at a high rate. The Scratch-based CS0 course was developed to keep the students who had a desire to major in computer science engaged in the department, as well as prepare them for success in future computer science courses. This paper discusses the formal study that was conducted on the CS0 course offerings in Fall 2009 and Fall 2010, which reached about 120 students total, and over 60 in the target group of freshman CS majors with low mathematics placement scores. The study examined the course's effectiveness at improving the retention, performance and attitudes of these at-risk majors.

Keywords—CS0; retention; Scratch

I. INTRODUCTION

This paper presents the results of a CS0 course based on the Scratch programming language that was designed to improve the retention of at-risk computer science majors. At the authors' university, prior to the introduction of the CS0 course, students who selected the computer science major but entered the university with weak mathematics preparation from high school left the major at a high rate. These students left the major for several reasons, such as the following: if the students were not allowed to take CS1 until they had completed one or two semesters of mathematics, they were likely to leave the major because they were not taking any computer science (CS) courses; if they were allowed to take CS1 in their first semester at the university, then they had a high failure rate, and thus also tended to change majors. The Scratch-based CS0 course was developed to keep the students who had a desire to major in computer science engaged in the department, as well as prepare them for success in CS1 and CS2.

The course is a hands-on oriented introduction to programming, covering core programming concepts including sequence, iteration, selection, variables and arrays. The Scratch language and development environment, created at MIT, allows students to focus on programming concepts without the distraction of syntax errors. It also allows the students to create much more creative and interesting projects, like games and animations, than might be possible for

beginning students in languages like C++ and Java. The Scratch language also allows for early introduction of more advanced programming concepts, such as event-driven programming and concurrency.

The CS0 course was piloted in January 2009. This paper discusses the formal study that was conducted on the course offerings in Fall 2009 and Fall 2010, which reached about 120 students total, and over 60 in the target group of freshman CS majors with low mathematics placement scores. The study examined the course's effectiveness at improving the retention, performance and attitudes of these at-risk majors. Results of the study indicate that students of the target group who programmed using Scratch had a high degree of perceived self-efficacy with respect to their programming abilities, both in Scratch and later, in C++. Furthermore, the target group's performance in CS1 was better than that of freshman CS majors who were not considered at-risk, and their performance in CS2 was equivalent to that of all other CS majors. Finally, retention of the target group improved significantly over historical rates for at-risk majors, and also exceeded the rates for majors not considered at-risk.

The rest of the paper is organized as follows: Section II explains the details of the motivation for the new course. Section III provides some background and discussion of related work. Section IV gives some details about the course itself. Section V discusses the results of the study, and section VI concludes with a discussion of the meaning of the results and some directions for further work

II. MOTIVATION

The CS0 course was created as an intervention to improve retention. In the years leading up to the course's creation, the authors had noted that the attrition of computer science students with weak mathematics backgrounds was excessively high. The definition of a weak mathematics background for this study is placement in elementary or intermediate algebra upon entering the university. Students whose placement test scores indicate that their level of mathematics understanding is at the college algebra or college algebra and trigonometry level are considered to have acceptable mathematics proficiency. Students who place into calculus may take an honors section of CS1, and these students are not considered in any of the statistics presented here.

In the years 2005-2007, 38 students who were declared CS majors placed into elementary or intermediate algebra. Of these students, only 13 went on to take the CS2 course, and of those, only 5, or 13%, passed on the first attempt. This is in contrast to 39% of the CS majors with acceptable math proficiency. In Fall 2008, there were 18 freshman CS majors with weak mathematics backgrounds who took CS1. Four semesters later, in Spring 2010, only 3 of those students (17%) were still active CS majors and had passed CS2.

Obviously, failure of the core CS courses is a good reason to leave the major, and almost none of the students with weak mathematics backgrounds were being retained. To solve this problem, the CS0 intervention addressed two objectives: to improve the success rates of students in the core CS courses (CS1 and CS2), and to improve the attitudes of the students towards computer science and programming (the normal content of CS1 and CS2) in particular.

The new course was offered using an existing course, CSC169 Fundamentals of Computer Science, which was intended for non-majors. Some students take it as a free elective, but it is required for certain majors, including the natural sciences, mathematics, and some education tracks. Those departments agreed to the new content, so about half the students in the new CS0 course are non-majors. However, unlike some of the efforts with Scratch described in the next section, this course is not intended for recruitment, and neither does it succeed in recruiting students from other majors. Most of the non-majors take the course in their junior or senior years. However, one student did change his major to CS, and a few others expressed interest in a CS minor, as a result of taking the course.

III. BACKGROUND

A. Related Work

In the past decade, several approaches have been proposed by researchers to reduce attrition through the development of visual programming tools. The objective of these tools is to provide some level of abstraction with respect to the syntax of the programming language and to provide media-enriched programming environments that support computational thinking and creativity to gain the interest of students who have little prior experience. Examples of these languages and environments are Alice [3] and Greenfoot [8].

Several studies have been conducted on the effectiveness of media-rich languages in attracting and retaining students in the CS major. Most notable is the study conducted by Cooper, Dann and Moskal [2, 12] on the use of Alice as a programming language for CS0 courses. Guzdial [6, 7] has also successfully incorporated several media-rich computational courses using Python as the programming language into the curriculum at the Georgia Institute of Technology.

Recently, Malan and Leitner [10] and Wolz [18] used yet another media-rich language that was originally designed for use with K-12 students, Scratch, during the first week of their introductory computer science courses. Malan and Leitner were the first to perform a preliminary study on the use of Scratch as a precursor to Java in a course that was offered at

the Harvard Summer School. At the end of the course, they surveyed the students with respect to the impact that Scratch had on their experience programming in Java and found that 76% rated the effect as positive, 8% rated the effect as negative, and 16% indicated that there was no effect [10]. Wolz at The College of New Jersey also used Scratch at the beginning of a CS1/CS2 course before transitioning into Java [18].

The positive results of Malan and Leitner influenced several researchers to experiment with Scratch as an introductory programming language for the first few weeks of a programming course. In the second semester of 2007, Kereki at ORT Uruguay University initiated a study to determine the effect of using Scratch for three weeks in a CS1 course as the initial programming environment before transitioning into either Java or Visual Basic [9]. Although Kereki saw no significant differences in grades, she reports that students' description of their learning process and programming experiences differed between the target group, who programmed in Scratch first and then went on to use the main programming language of the course, and the control group, who did not program in Scratch. Those who started with Scratch used words such as "interesting" and "easy" to describe their learning process and programming experiences whereas the control group described them as "difficult" and "not easy" [9].

Malan and Leitner's work also influenced another team at the University of California - Berkeley [4, 5] to develop a CS0 course in Fall 2009. In this course, students were taught computational thinking. Programming assignments were implemented using Scratch and in a new programming language based on Scratch, Snap! (formerly known as BYOB (Build Your Own Blocks)), that was developed at UC Berkeley [1]. In Snap!, additional functionality, including procedures and multi-dimensional arrays, was incorporated into the Scratch environment. Therefore, using Snap!, more advanced programming topics such as recursion could be introduced. Berkeley's new CS0 course also covered diverse computer science topics such as the social implications of computing and video games.

Unlike the CS0 course that was developed at Norfolk State University, only about half of the CS0 course at UC Berkeley was focused on programming [5]. Additionally, the two CS0 courses have different objectives. The objective of the CS0 course at Norfolk State University is to retain freshman computer science majors, while the CS0 course at the UC Berkeley has a recruitment objective.

The idea of developing new courses to better orient at-risk students, women or all students to computer science or to programming before they start the traditional CS1/CS2 programming series is not a new concept. There have recently been some approaches that use multimedia. For example, in a study that was conducted at the University of Illinois at Chicago [17], a CS0.5 course was created using the Python media materials developed by Guzdial at the Georgia Institute of Technology [7]. According to [17], Sloan and Troy were able to increase retention by 21%. They also indicated that the number of students who rated themselves as having good

programming skills increased by 61% by the end of the course. Cooper and Dann created an Alice-based course that aimed to improve the performance and retention of at-risk students [2]. Their findings indicated that targeted students' retention rates were raised dramatically [12].

B. Scratch

Scratch is a media-rich programming language and environment developed by the Lifelong Kindergarten group at the MIT Media Lab, which was officially launched in May 2007 [11, 13, 16]. In addition to helping students develop or enhance their problem-solving skills, Scratch provides an environment conducive to learning about problem decomposition and the design process. The following are the major design goals and features of Scratch: a simple and intuitive snap-together block style that prevents syntax errors, media-richness, the support of common programming constructs, a *failsoft* programming environment, and the large online community of Scratch programmers that provide an enormous repository of programming examples [11]. A sample Scratch program, developed by a student in the CS0 course, which implements a game, is shown in Fig. 1.

Although Scratch is not object-oriented, it supports the notion of objects through its sprites and the scripts associated with the sprites. Thus, a student is exposed to objects in a natural manner. Additionally, Scratch provides an environment which makes it easy for students to express their creativity while programming.

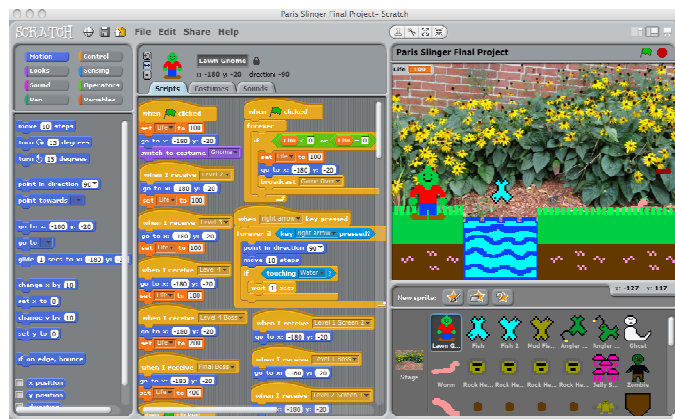


Figure 1. Sample of the Scratch Programming Environment

Although the designers of Scratch do not encourage the use of Scratch at the upper high school level or at the college level, the programming environment supports programming concepts like variables and arrays, which are not typically used by the primary target group for Scratch, children aged 8 - 16. In fact, statistics available on the Scratch website show that variables are used in less than 25% and arrays are used in less than 2% of all Scratch projects shared on the website [16]. Variables and arrays, along with more advanced features in Scratch, such as concurrency and event-driven programming, combined with the simplicity of the programming environment, make Scratch a very suitable choice for freshman college students with no prior programming experience.

IV. THE CS0 COURSE

Beginning in Fall 2009, the CS0 course was offered to students who placed into lower-level mathematics courses. Before Fall 2009, these students had been allowed to take CS1 directly. Currently, all students that do not have the mathematics prerequisite for CS1 cannot take CS1. Thus, students who do not have the mathematics prerequisite are encouraged to take CS0 by their academic advisors and 100% of them elect to do so, even though it is not a required course. In the second year of the course offering, a few students whose mathematics levels were at the level of proficiency elected to take the CS0 on the advice of other students who had found the course enjoyable and/or valuable.

Details of the course content have been published in [14]. The CS0 course is structured like most introductory programming courses, consisting of lab work and some lectures on general topics, such as program design, variables, and 2D graphics. Most lectures introduce a concept and demonstrate it with examples. Each concept is reinforced with a hands-on lab exercise, an in-class review of the lab, and then a homework exercise that includes the new concept as well as concepts previously covered.

Lab exercises focus on one concept by having the students solve problems (e.g. evaluate Boolean expressions), create individual Scratch scripts to perform specific tasks, or modify existing projects by adding new features or revising the techniques used in the project. Homework assignments usually require that a full Scratch project be developed. Sometimes the students are permitted to choose their own project topic as long as it fulfills certain criteria; in other cases, the project to be built is fully specified.

The focus of this course is the core programming concepts up to and including arrays. Students grasp the ideas of sequence, iteration and selection quite easily. Scratch currently has no procedure construct, but it will be available in Scratch 2.0 (expected 2012). Scratch has the broadcast mechanism, where signals can be broadcast to initiate actions. Students also grasp this concept quite easily, as well as the simple sound and animation concepts.

However, the concept of a variable, which is introduced around midterm, is difficult for some students, and the concept of arrays, introduced in the last month of class, is difficult for most students. This is despite Scratch's very visual and intuitive interface for both programming constructs, and numerous class exercises on reading code and tracking the contents of variables and arrays. The authors' personal experience with other introductory programming courses suggests that this issue occurs regardless of the language used.

Students are assigned exercises and homework that is geared toward mastering the concepts of variables and arrays. The final exam has two parts – programming and written. The programming exam requires the use of variables, but not arrays. The written exam contains questions that address both these concepts. Many of the students' final projects contain variables, but almost none of their projects contain lists. The authors believe that this initial introduction to variables and arrays, although most of the students only partially master

them in CS0, makes the concepts more familiar when they are introduced in CS1 (in C++).

V. RESULTS

In Fall 2009, 35 freshman CS majors took CS0 and 42 freshman CS majors took CS1. In Fall 2010, 29 freshman CS majors took CS0 and just 15 freshman CS majors took CS1. These differences are based simply on the changing number and level of students entering the university from year to year. In Fall 2009, the instructor for the CS0 was one of the authors of this paper, so she was highly invested in the success of the project. In 2010, a different instructor, unconnected to the project, taught one of the CS0 sections, using exactly the same materials and structure. There was no difference between any of the results for that section and the other section.

The students who took CS0 in Fall 2009 and Fall 2010 are considered the target groups of this study. The students who took CS1 during their first freshman semester in 2009 and 2010 are the control groups. Only freshman CS majors were considered in both the target and control groups, even though students from other majors take both the CS0 and the CS1 courses.

A. Student Attitudes

As reported in [15], the data for the Fall 2009 students showed that the target group's self-perceived programming proficiency improved continuously throughout CS0 and up to the end of CS1. Additionally, a focus group was conducted with the 2009 target group in Fall 2010 to determine their impressions of the CS0 course while they were taking CS2. Students were asked to respond to the following question:

"In what ways has learning how to program in Scratch helped you in your programming classes?"

Some unedited anecdotal data in response to the above question is presented below:

- "Using loops, it helps in C++"
- "Helps to learn how to trouble shoot problems"
- "Gave us a programming mindset, doing things step-by-step"
- "Good foundation to start with"
- "Teaches you how to plan instead of just jumping into it"
- "Steps and logic are similar in Scratch and C++"

In Fall 2010, some problems with the survey mechanism occurred and, although the results were similar, not enough data were collected to be statistically significant.

B. Performance in Future Programming Courses

The performance of the target group in future programming courses was compared against the performance of the control group. The results are shown in Table I. It should be noted that the low pass rate for freshman CS majors in CS1 in Fall 2009 was consistent with the overall pass rate for all students in CS1, and was similar across different instructors. The instructors who taught CS1 in the spring were the same ones who taught it in the fall.

TABLE I. CS1 PASS RATES

| CS1 Pass Rate | Academic year: 2009-2010 | Academic year: 2010-2011 | Overall |
|-----------------------------|-----------------------------|-----------------------------|---------|
| Target group (CS0 & CS1) | 74% (17/23) | 67% (14/21) | 70% |
| Control group (CS1 only) | 39% (15/38) | 60% (9/15) | 45% |

Due to students from both groups retaking CS1 and CS2, it was not easy to isolate the control group for CS2; therefore, in looking at performance in CS2, only students from the target group who took CS2 on schedule were considered. The pass rate in CS2, collected in Fall 2010 for the Fall 2009 target group, and in Fall 2011 for the 2010 target group, was exactly the same as the pass rate for the course as a whole. Only CS majors take CS2, so this shows that the target group is performing at the same level as all other students when they reach CS2.

C. Retention

In considering retention, the Fall 2009 target group was compared with the Fall 2008 students who placed at the same level in mathematics (similarly 'at-risk' students). The 2008 students took CS1 in their first semester (there was no CS0 intervention). The one-year retention rate is defined as the number of students who are still actively taking classes and still CS majors in the fall of the following year. The Fall 2010 target group's similar retention rate indicates that the increase gained by the initial introduction of the CS0 course is consistent. The rates are shown in Table II.

TABLE II. ONE-YEAR RETENTION RATE

| | One year retention rate | |
|----------------------------|-------------------------|---------|
| Fall 2008 at-risk students | 33% | (6/18) |
| Fall 2009 target group | 57% | (20/35) |
| Fall 2010 target group | 59% | (17/29) |

A long-term retention rate for the Fall 2009 target group as compared to the 2009 control group was also collected, representing the number of students who started in Fall 2009 and were still active CS majors six semesters later in Spring 2012. Of the 35 students in the 2009 target group, 14 (40%) remained active in 2012, and of the 42 students in the 2009 control group, 13 (31%) remained active in 2012. The long-term rates show that the CS0 intervention produced retention rates for at-risk students that are slightly better than those for students who were not at-risk.

D. Other results

Anecdotal data indicates that the CS0 course, and Scratch, is enjoyable for non-majors as well as CS majors. Generally non-majors get the highest grades in the class, but they are usually junior and senior science or mathematics majors, so it is not surprising, due to the maturity level of these students. Invariably, non-major female students get the top grades in the class, and seem to enjoy the class more than their male counterparts, but this is not the case among the CS majors. In fact, there is no indication that the CS0 course has any special effect on women CS majors, of whom there are very few.

VI. CONCLUSION

The Scratch-based CS0 course as an intervention to improve the retention of at-risk CS majors has been successful by meeting the objectives of the study through improving the students' attitudes towards programming in general and their perceptions of their own abilities with respect to the programming process, as well as improving the students' success in future programming courses. With Scratch, students always get some level of success in the programming process; they are never faced with a screen full of syntax errors. They are able to see the outcome of their programs visually and learn how to modify their programs to get the desired behavior. The CS0 course provides the students with rewarding programming experiences, such as presenting their final projects to their classmates who provide positive feedback about their programming abilities. Additionally, students are provided with an extra semester to learn about algorithm development and core programming constructs such as control structures, variables and arrays. The authors believe that it is a combination of all these factors that have allowed the targeted 'at-risk' students to exceed the performance of the students who were not at-risk.

The authors expect that further improvements in the overall success of the target group will occur after the release of Scratch 2.0, which contains the concept of a procedure with arguments. They are considering expanding the group of students directed into CS1 to include the students who place into college algebra, and only have students who place into college algebra and trigonometry take CS1 directly. An extra semester spent in CS0 is preferable to an extra semester retaking CS1 or CS2. A further improvement being considered is to make a smooth transition between CS0 and CS1, using the last few weeks of CS0 and the first few weeks of CS1.

The materials for this course are available at <https://sites.google.com/site/upccssite/>.

ACKNOWLEDGMENT

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Evaluation of the Learning Effectiveness of Game-based and Hands-on Gear Train Laboratories

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Abstract - Recently, academic institutions have started to explore the potential of commercially available multi-player computer game engines for the development of virtual environments for instructional purposes. This trend is motivated by the fact that many students are highly accustomed to and knowledgeable about playing electronic and computer games. Computer games share a number of potential characteristics with effective instructional tools and therefore have a great potential for positively affecting learning. Achieving a sense of immersion by the students and interactive collaboration among them are two of the main goals being pursued in exploring new types of educational laboratories as alternatives or complements to traditional hands-on experiments.

A scripted scenario for a game-based gear train laboratory exercise was implemented in 'ME 358 Mechanisms and Machine Dynamics', a junior-level course for mechanical engineering majors at Stevens Institute of Technology (SIT). This paper discusses the learning assessment conducted in that implementation. The results are presented for two assessment studies comparing versions of game-based gear train experiments to workbook-based gear train experiments with a 'hands-on' laboratory experience. The results suggest that the students learned the concepts addressed by the laboratory content better in the game-based condition and that they had a realistic understanding and appreciation of the practical advantages of game-based gear train experiments over more traditional learning experiences. In addition, a questionnaire was administered to the students and then analyzed in order to obtain further insights into the students' opinions about and attitudes toward the game-based laboratory approach.

Index Terms - Game-based laboratory, Gear design, Virtual experiment, Assessment, Game engine.

INTRODUCTION

Today's students habitually use digital electronic technology for communication, entertainment and education on their own, and often they have a more positive attitude toward games and simulations than they have toward traditional instruction [1]. Several studies [2,3] concluded

that computer/video games are characterized by rules, goals, objectives, outcomes, feedback, conflict, competition, challenge, opposition, interaction and representation of the story. These capabilities will lead computer games to become recommended practice and preferred tools for solving problems. They are proving to be effective as learning devices for people of all ages [4]. As a result of the widespread availability and popularity of gaming technology [5], computer games have drawn significant attention in a number of businesses to help users/workers in developing skills through hands-on navigation of simulated scenarios in virtual environments. By now, they have been adopted for use in many fields, including education, medicine, architecture, city planning, disaster response and military training [6,7]. The report of the Summit on Educational Games released by the Federation of American Scientists [8] indicated that computer games and simulations can serve as powerful 'hands-on' tools for teaching practical and technical skills, from automotive repair to heart surgery. It is for these reasons that computer games have strong potential for providing the basis of powerful learning environments.

As computer processing speeds continue to increase, computer hard drives grow in capacity and available network bandwidth expands, computer games continue to become more sophisticated and complex [9]. Upon examination of modern computer game architectures and their features that are essential to build an interactive collaborative laboratory environment [10,11], Figure 1 illustrates the core components of a generic game and its engine, which can be divided into three distinct layers:

- **System Layer:** This layer represents the hardware of both the computer and the network. Modern computer games are usually structured as client-server applications. The client machine communicates with a centralized game server via data packets in order to evaluate the moves made by the users within the game. This layer defines the low-level performance of a game engine, determining the quality of graphics, the quality of sound and the network capabilities.
- **Engine Layer:** This layer consists of the software that abstracts the lower layer and implements functionalities such as the artificial intelligence (AI) of the characters,

the physics of the environment, etc. For example, the physics engine uses advanced mathematical models for calculating rigid body motions of arbitrarily shaped and articulated objects (e.g. vehicles, machines, etc.). The graphics engine displays and manages the data related to graphical content and visual effects. All audible content such as sound effects, ambient noise and music is handled by the audio engine. Artificial intelligence, provided by the AI engine, is needed for controlling non-player characters (NPCs). The AI engine deals with giving emotions to the NPCs, path finding, decision making, scripting and the finite state machine. The term NPC is used in computer role-playing games to describe entities not under the direct control of the players. The NPC behavior in computer games is usually scripted and automatically triggered by certain actions or dialogue with the player characters.

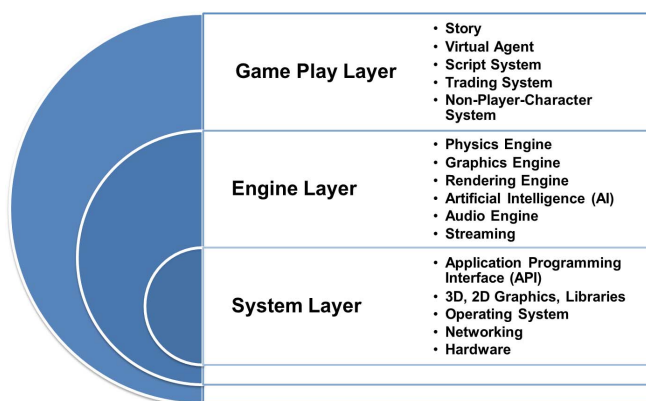


FIGURE 1
COMPUTER GAME TECHNOLOGY CORE

- **Game Play Layer:** In this layer, all of the game rules are defined. It is about creating the game play and defining how it works before the software developers put any substantial time or effort into decorating the game environment. It also includes the actions that the players can take. For example, almost every game has some sort of a story, the ‘embedded’ story (created by the designer) and the ‘emergent’ story (created by the players). This layer depends on the complexity of the game and integrates challenges into a larger task or a problem. Also, progress in a game is rewarded with positive feedback and rewards. There are three categories of rules: setup (things the players do once at the beginning of the game), progression of play (what happens during the game) and resolution (what conditions cause the game to end and how an outcome is determined based on the game state). In accordance with the goals of engineering education, all these rules can be educational.

Several observations can be derived from the above examination. Computer games can provide familiar and engaging interactions and increase the appeal of an

educational experience [12 , 13]. They have many characteristics of problem solving activities, for instance the construction of a problem context, multiple paths to a specific goal, learning by doing, discovery learning and guided discovery, task-based learning, role playing, etc. Therefore, computer games and problem-based learning are experiential, collaborative, active and learner-centric approaches [14, 15]. Taking advantage of the favorable characteristics of computer games [16], existing multiplayer computer game engines [17] can be utilized as a means for creating educational tools that have the potential for enabling students to learn in an engaging manner.

COMPUTER GAMES AS AN EDUCATIONAL TOOL

By utilizing one of the commercial game engines with its vast set of built-in functions as the framework for creating an interactive virtual laboratory environment, the continued advances in gaming technology are leveraged and the system development efforts can thus be focused more on implementing effective pedagogies. Recently, a virtual laboratory environment has been created for the laboratory component of a junior-level undergraduate mechanical engineering course on mechanisms and machine dynamics at SIT as shown in Figure 2.

Detailed Level



FIGURE 2
MODELING OF A REALISTIC VISUALIZATION OF A PHYSICAL
LABORATORY SPACE

This immersive interactive laboratory environment is based on ‘Source’ [18], a commercial multi-player computer game engine that is widely distributed and commonly used to develop massively multiplayer online role playing games. It provides all the functions needed to develop a virtual laboratory environment. Furthermore, it has extensive

support included in the form of the associated Software Development Kit (SDK) [19], e.g. the ‘Hammer’ editor and the game engine’s source code. All physics simulations are handled by the ‘Havok’ physics engine [20], which allows for realistic interactions between the objects in the virtual world. The experimental equipment was implemented using custom models, and the custom model primitives were made by third-party 3-D modeling software such as 3ds Max or SolidWorks. These custom models were extremely useful in implementing the virtual laboratory, as scripts can be written to define their behavior. So far, two predefined scenarios for laboratory exercises have been scripted and implemented [21]. They both allow teams of students to assemble an experimental setup within the game environment and subsequently carry out an experimental procedure using this setup.

GOALS OF THE PRESENT PROJECT

The goals of this project are to evaluate the educational effectiveness of a game-based gear train experiment relative to a workbook-based gear train experiment with a ‘hands-on’ experience within the context of a course on mechanisms and machine dynamics. This course involves three 50-minute lectures and one 2-hour laboratory per week for a total of three academic credits. It is designed to provide mechanical engineering students with the background and necessary tools for the kinematic analysis and synthesis of mechanisms and machines as well as the skills required for considering the role of dynamics in the design of machines. Our assessment of the educational effectiveness includes learning outcomes, student ratings of satisfaction, effectiveness and teamwork across the two different laboratory formats.

GEAR TRAIN LABORATORY

During the course of this laboratory exercise, the students study some basic elements of power transmission. The transmission (also called gear train) consists of several mating gear pairs. It represents a vital system used in many tools/machines to transfer mechanical energy and to change the type and direction of motion, increase/reduce the output rotational speed(s) relative to the input speed and reduce/increase the output torque(s) relative to the input torque. This laboratory exercise is intended to give the students an understanding of the overall function of a gear train system. The experimental capabilities of this laboratory system include:

- Introduction to gear trains, transmission ratios, speeds, etc.
- Assembly of a variety of gear train arrangements that include spur gears, helical gears, worm gears, bevel gears, rack and pinions and compound gear trains
- Demonstration of the working principles of gear train systems
- Calculation and experimental observation of the angular velocity ratios of gear trains

- Experimental determination of the torque ratios in gear trains
- Calculation of the gear train system efficiency

Two specific laboratory experiments were designed for this evaluation: a workbook-based planetary gear train experiment with a hands-on experience and a game-based simple gear train experiment. In each laboratory session, the students were divided into teams of three members each. Each laboratory session consisted of four phases. First, the students were asked to complete a pre-experiment test designed to gauge their prior knowledge of the gear train system. Following completion of the pre-experiment test, the hands-on or game-based experiment phase began with a brief introduction. The workbook-based planetary gear train experiment with a hands-on experience was conducted at a particular time and place and required face-to-face interaction. During the game-based experiment, the students moved their respective characters (avatars) through the virtual laboratory and interacted with other characters to achieve various goals. The teaching assistant (TA) observed how the students interacted with the game interface, how much difficulty they had in assembling the gear train and in performing various calculations, and how long they took to finish the different steps. After the hands-on or game-based experiment, the students were asked to complete a post-experiment test with the same number and format of questions as on the pre-experiment test to measure their learning outcomes. At the end of each session, the students’ feedback about the laboratory’s usability was solicited.

GAME-BASED GEAR TRAIN LABORATORY SCENARIO

The scripted scenario for the game-based experiment was implemented in the Fall 2011 semester in ‘ME 358 Mechanisms and Machine Dynamics’, to perform several experiments related to the fundamental law of gearing and the fundamental concepts of planetary motions of gears [22]. This virtual environment offers experiments dealing with simple, compound, reverted and planetary gear trains. Each experiment was designed to teach the students how the gear ratio of a gear train alters the output speed and torque of a machine. The apparatus in the virtual gear train laboratory consists of spur gears, helical gears, bevel gears, base, axle shafts and holders as shown in Figure 3. In addition, several spacers and washers are included to allow alignment of the gears and to ensure tight meshing.

Setting and Procedure

The study took place in three separate rooms. The groups consisted of three students who were each placed in one of the three rooms. Before conducting the game-based experiment, the students were provided with an experiment scenario in the form of a tutorial in order to introduce them to the capabilities of the laboratory environment and to inform them about how to log into the experiment webpage, how to customize their game avatars (i.e. gender, outfit, physical appearance, etc.), how to distribute the work load amongst the team members, how to select and use the built-

in features of the laboratory system and how to get feedback from the instructor. Note that the developers and a TA were present during the laboratory sessions as well. While most of the laboratory sessions for the student groups lasted approximately half an hour, some students who had additional questions and needed extra help with the tutorial stayed longer for further assistance. After introducing them to the general concept of the game-based laboratory environment and to the specific experimental setup, the students first had to sign in on the attendance sheet, familiarize themselves with the laboratory manual and then enter the virtual laboratory environment for performing the selected experiment.

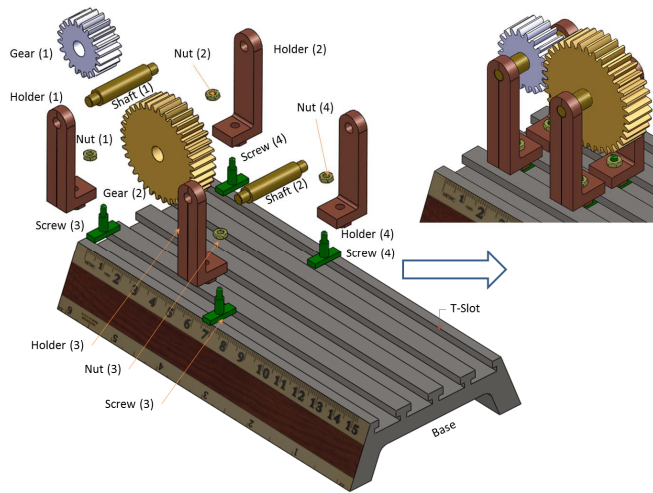


FIGURE 3
SIMPLE GEAR TRAIN EXPERIMENT ASSEMBLY

Usability of the Game-based Gear Design Laboratory

After the brief introduction at the beginning of the laboratory session, the game-based laboratory system [23] administers a simple pre-experiment test to the students to gauge their knowledge of the gearing system and the fundamental concepts of planetary motions of gears (see Figure 4). Then, the laboratory system offers input options related to the experiment, the students select a particular input configuration (gears, shafts, holders, base, etc.) and proceed to performing the experimental procedure. After the experimental results (gear ratio, angular speeds, torques, etc.) have been displayed, the students may repeat the experiment with a different set of input parameters if they wish, thus enabling them to compare the results of the different configurations with each other. At the end of the virtual experiment, the system administers a post-experiment test to the students. Finally, the system provides the students with a questionnaire, offering an opportunity to give feedback regarding the game-based laboratory environment in general, its control and navigation, ease of use, the students' learning and feel of immersion, and other aspects. This user feedback is considered very important for future improvements in the existing virtual laboratory environment.

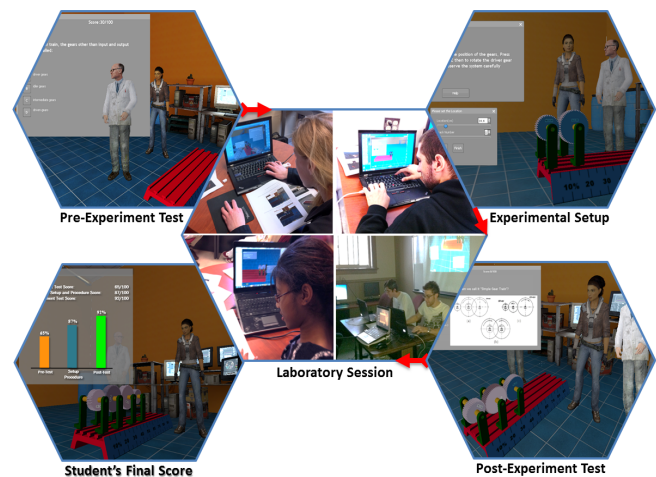


FIGURE 4
GAME-BASED GEAR DESIGN LABORATORY SCENARIO

PRE- AND POST-EXPERIMENT KNOWLEDGE TEST

The pre- and post-experiment knowledge tests used exactly the same format. Each test consisted of ten multiple-choice questions. Table 1 describes the content of the pre- and post-experimental test questions for the simple gear train laboratory. The purpose of the pre- and post-experiment knowledge tests was to determine whether or not the game-based gear design laboratory had helped the students to improve their understanding and knowledge of the concepts taught in the lecture component of the course and to see whether they had improved in the areas where they had problems in the pre-experiment test. The results of the pre-experiment test highlighted the areas where the students had the most difficulties and also informed the instructor about the subject areas where they needed additional or remedial instruction.

TABLE 1
SIMPLE GEAR TRAIN PRE- AND POST-EXPERIMENT TEST QUESTIONS

| No. | Pre-Experiment Test | Post-Experiment Test |
|-----|--|--|
| 1 | Gear train arrangements | Distinction between different gear trains |
| 2 | Motion transfer between two meshing gears | Purpose of simple gear trains |
| 3 | Examination of simple gear train output speed | Gear ratio in simple gear trains |
| 4 | Train value | |
| 5 | Identification of an idler gear in a simple gear train | Function of an idler gear in a simple gear train |
| 6 | Effect of an idler gear on the gear ratio | |
| 7 | Effect of an idler gear on the rotational direction | |
| 8 | Effect of the number of idler gears on the rotational direction and output speed | |
| 9 | Problem-solving | |
| 10 | Real applications of simple gear trains | Limitations of simple gear trains |

STUDENT EVALUATION QUESTIONNAIRE

The purpose of the questionnaire was to obtain student evaluations of the game-based gear design laboratory and to identify issues for further investigation in future work. The questionnaire consisted of two main parts. The first part concerned the evaluation of the laboratory experience regarding the laboratory's educational effectiveness, student satisfaction and team communication. The second part contained four additional questions about the gear assembly and an additional opportunity for students to comment on other aspects.

EVALUATION RESULTS

Student Evaluation Questionnaire: In the first set of questions, the students had to evaluate the educational effectiveness of the simulation-based laboratory experience. Specifically, the students were asked to rate, on a five-point scale (from 1 = 'strongly disagree' to 5 = 'strongly agree'), how effective they thought the laboratory exercise had been in 'teaching specific concepts relevant to the laboratory topic', 'increasing the general knowledge of the field', and 'providing skills that will make one a better engineer'. Another group of questions addressed student satisfaction (again rated on a 5-point scale) with the following specific aspects of the laboratory: overall satisfaction, feeling of immersion, ease of use, total time required, clarity of instructions, ability to control assembly, ability to set parameters and ease of collecting data. Descriptive statistics for the respondents who completed the questionnaire (N=22) are given in Table 2.

TABLE 2
DESCRIPTIVE STATISTICS ON EFFECTIVENESS AND SATISFACTION RATINGS

| Question | | M | s.d. |
|--------------------|-------------------------------|------|------|
| Effective in: | Teaching specific concepts | 3.82 | 1.01 |
| | Increasing knowledge of field | 3.55 | 0.86 |
| | Better skills as engineer | 3.45 | 1.01 |
| Satisfaction with: | Overall satisfaction | 3.95 | 0.72 |
| | Feeling of immersion | 4.09 | 0.81 |
| | Ease of use | 3.50 | 1.06 |
| | Total time required | 3.59 | 1.14 |
| | Clarity of instructions | 3.77 | 0.81 |
| | Ability to control assembly | 3.50 | 1.14 |
| | Ability to set parameters | 3.77 | 0.75 |
| | Ease of collecting data | 3.91 | 0.97 |

The results in Table 2 show that the effectiveness and satisfaction ratings of the simulated laboratory experience were generally quite high. For effectiveness, the students judged the virtual laboratory best at teaching laboratory-related concepts and somewhat less effective at providing general knowledge and skills needed by engineers. Satisfaction was highest with the feeling of immersion and overall satisfaction as well as with the ease of collecting data. The students were least satisfied with the ability to

control the physical assembly of the gears and the overall ease of use.

Four questions addressed the nature of the immersion experience, i.e. to what extent the simulated laboratory really promoted a feeling of 'being there'. These questions, answered using a 5-point scale, were: 'During gear assembly and data collection, to what extent did you: ... feel engaged in/absorbed by the experiment?' (M = 3.41, s.d. = 0.85), '... feel you had active control over the experiment?' (M = 3.45, s.d. = 1.01), '... feel you could choose freely what you wanted to see?' (M = 3.76, s.d. = 1.09), '... experience a sense of 'being there' inside the environment you saw/heard?' (M = 3.55, s.d. = 0.96). Again, the answers were generally positive (i.e., above the scale midpoint) but the pattern suggests that the visual aspects of the simulation were more compelling than the physical-control aspects.

The teams seemed to function well in the simulated laboratory environment. Three questions that dealt with team cooperation and effectiveness elicited very positive agreement ratings (where 1 = agree not at all, and 5 = agree completely): 'You and your team mates communicated effectively' (M = 3.73, s.d. = 0.98), 'You and your team mates worked cooperatively on this lab' (M = 4.14, s.d. = 0.83), 'You could depend on your team mates for help' (M = 4.36, s.d. = 0.49).

Another section of the questionnaire asked the students to indicate information sources that helped augment their learning, choosing from the textbook, conversation with the instructor, online resources, conversation with the TA, conversation with teammates, and conversation with other students. Generally, the social sources of information were most often mentioned as augmenting laboratory learning: 68% of the students cited conversations with the instructor and 59% conversations with team mates and other students. Also frequently mentioned were the TA (55%) and the textbook (50%). Only 18% of students cited online resources as being helpful.

Learning outcomes: As described above, the students took both pre- and post-tests of their laboratory-related knowledge, for both the simulation-based simple gear laboratory and the workbook-based planetary gear train laboratory with a 'hands-on' experience. Descriptive statistics summarizing performance on the pre- and post-knowledge tests (both measured on a 10-point scale) are shown in Table 3. The students did well on the tests, though less so on the planetary gear post-test.

TABLE 3
DESCRIPTIVE STATISTICS ON LEARNING OUTCOMES.

| Knowledge Tests | M | s.d. | N |
|------------------------------------|------|------|----|
| Pre-test - VR simple gear lab | 7.52 | 1.26 | 25 |
| Post-test - VR simple gear lab | 7.40 | 0.91 | 25 |
| Pre-test - workbook planetary lab | 7.28 | 1.31 | 25 |
| Post-test - workbook planetary lab | 6.40 | 1.00 | 25 |

However, direct comparisons of the mean performance on these four tests should be interpreted cautiously. In particular, the post-tests were purposefully made more difficult than the pre-tests so that they would be more appropriate course experiences. Thus, the decline in scores from pretest to posttest presumably means that the post-tests were more difficult and not that student understanding declined. In contrast, attempts were made to equate the two pre-tests (for the simple and planetary gear train experiments) for difficulty, and the near-equality of the mean values ($M = 7.52$ versus $M = 7.28$) seems to confirm success in this equating. Similar attempts to equate difficulty for the two post-tests were also made; thus, the difference in post-test mean values for the two laboratory formats may be interpreted (cautiously) as showing an advantage for the VR game-based laboratory.

The observed differences in knowledge test mean values were confirmed in a repeated-measures ANOVA, which revealed a significant main effect for laboratory format due to higher scores in the VR game-based condition, $F(1,24) = 9.55$, $p = 0.005$, and a marginally significant laboratory format \times time interaction, $F(1,24) = 3.610$, $p = 0.087$. The direction of the results is consistent with the idea that VR simulation-based laboratories are equivalent to or better than the workbook-based laboratory in promoting the learning of course concepts.

However, the confounding of laboratory content (simple vs. planetary gears) with laboratory format makes assessment and comparison of learning effects difficult. More carefully controlled evaluations of the effectiveness in teaching course concepts of simulation-based laboratories would be desirable in future studies. Specifically, such studies should unconfound content and laboratory format and better control test difficulty.

CONCLUSIONS

A virtual laboratory environment was used to implement and pilot laboratory exercises on both simple and planetary gear train systems. It was found that game-based laboratories can excite and motivate students, foster experimental, design, problem-solving and analysis skills, allow real-time feedback and remedial instruction based on the integrated learning assessment, promote student collaboration, and facilitate 24-7 laboratory access. Thus, virtual laboratories can help students to achieve many of the learning goals for educational laboratories listed by the Accreditation Board for Engineering and Technology (ABET) in 2005. However, more rigorous assessment of the learning effectiveness of game-based laboratories will require large-scale studies that control for laboratory content and test difficulty. We plan for such studies in future work.

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What Are We Teaching In Cyber Competitions?

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Abstract— *Student competitions are widespread across all academic disciplines, and are often touted as a means to motivate and educate students. Competitions may be internal within a single class or course, or vie school against school as regional, national, or international competitions and exist at all levels including 9-12 grades. These competitions have different formats and focuses such as vulnerability assessments, forensic challenges, offensive, and defensive competitions (or a combination of these). Some competitions require simple scripts and are considered ideal for script kitties while others require in-depth understanding of computer security and networking techniques to successfully compete in the competition. While the number of competitions and students participating in them have increased, it is unclear whether the stated academic goals of the competition are being met. In some cases, it appears that the focus of the student and institutional effort is more on the competition itself than on learning underlying concepts and developing skills. At our institution, students participate in several cyber-competitions, some of which we have initiated. The purpose of this paper is to survey existing cyber-competitions to understand the purpose of the competition, review underlying stated educational goals, and explore how the competition meets these goals. We compare the role of cyber competitions with the role of other computer-related competitions such as robotics, programming, unmanned aerial vehicles, and artificial intelligence comparing and contrasting the educational impact of the competitions on the participants.*

Keywords: Cyber, Competitions, Security Education

I. INTRODUCTION

In the past few years, competitions have become more and more a part of Cyber Security educational programs. Organizations are creating new competitions focusing on offensive, defensive, and computer forensics exercises. At our institution, we have created a student cyber competition team that we support by providing funds to travel to competitions as well as excused absences from classes and other required school events to prepare and attend formal competitions. When one of our classes needed a way to assess how well students can identify and correct vulnerabilities in a computer system, we created our own competition and opened it to a number of universities in our geographical area. It has even become popular with local high school students as an opportunity to develop computer security skills. Our competition was created with a strong mission statement, clear

goals, and identified educational outcomes directly supporting classes taught in our curriculum. This competition caused us to wonder what goals and outcomes were being addressed by other cyber competitions. This focus on what we are teaching in cyber competitions is the impetus for this paper.

II. BACKGROUND

Competitions have long been used as a motivational mechanism for students across a wide variety of academic disciplines and age groups. Spelling bees, science fairs, science Olympiads, writing contests, discipline-specific competitions, and quiz bowls are but some of the many competitions that have been created to attempt to enhance student learning and development.

Historically, student competitions were used to identify talent and develop gifted students for advanced study. Some of the earliest examples of competitions in academia came from Russia who started the academic Olympics in 1934 [1]. These competitions focused on mathematics and were used as a means to identify talent for further development. Students scoring well in the competitions were given automatic admission into top universities. Competitions grew throughout Europe with Germany having the most elaborate nationwide system of competitions with over 100,000 students participating annually in more than 20 federal competitions across many disciplines [1]. In the United States, interest in academic competitions increased significantly after the Russians launched Sputnik and President Eisenhower's science advisor, Edwin Teller, urged the use of competitions to get students interested in technical fields at an early age (www.osti.gov/accomplishments/teller.html).

Today, academic competitions are prolific throughout the educational process. Individual, team, inter-classroom, local, regional, national, and international competitions can be found in almost every discipline at all grade levels. Many studies have been conducted to attempt to evaluate the impact of competitions with both advocates and critics pointing to results supporting their positions.

Proponents of competitions in academia point to the additional motivation for self-learning and peer-learning provided by the natural competitiveness of many students. Competitions are

typically well-structured events with clearly-defined goals. Individuals or teams compete within the competition framework for some extrinsic award or recognition. Proponents claim such competitions encourage participants to excel on a mental level much the way they do on a physical level in competitive sports. In an evaluation of 44 student competitions for engineering and technology students, Wankat [2] discovered that student advisors were unanimous in their opinion that the contests provided a good learning experience, and students learned more by participating in the competition. Wankat [2] also drew a correlation between success in the competition and alignment of the competition with an institution's curriculum.

Another positive aspect of competitions is that they can direct career choices and provide participants with a broader view of possible life choices motivating further education. In a discipline-specific study, Bishop found 39% of competition participants claimed their participation influenced their choice of college major [3].

Team competitions that engender a cooperative learning environment within a team are more effective than individual competitions [4]. In an analysis of 46 studies on cooperative versus competitive competitions, Qin showed cooperative learning significantly outperformed a competitive approach. Effective teams generate a sense of belonging to individual participants, encourage peer mentorship, and provide the cohesiveness of a common goal. Hammer [5] noted the additional benefit gained from using peer-assessed competitions as opposed to expert judging.

Critics of competitions point to misplaced participant motivations, a focus on winning versus learning, negative impacts on self-concept, and self and peer pressure to perform resulting in negative learning experiences. In evaluating motivations for student participation in science fairs, Abernathy and Vineyard [6] found the majority participated through teacher coercion, as a requirement, or because of credit given. In a study of student motivation for participation in quiz bowls, Dalton found that reasons such as being able to claim participation on college applications far outweighed student interest or desire to learn [7]. External motivations for participation are not in and of themselves a detriment. In an evaluation of over 30 years of science fair participant surveys, Bellipanni [8] found the vast majority (96.2%) rated the value of participation as high.

Another criticism of competitions is the potential negative impact they have on student self-concept. Students who perceive themselves as less-able than their peers and perform worse than their counterparts in competitions have their low self-image reinforced and can become discouraged and frustrated [9]. Cheng proposes an "equal opportunity tactic" to allow students of similar ability to compete with each other and reduce the perception of underachieving students.

Gay et al [10] suggest several negative messages that can result from grading based on individual competitions including:

1. Learning is an activity that is to be pursued individually.
2. What is to be learned is determined solely by the teacher.
3. Learning consists of memorization and translation on what authorities agree is true.
4. The measure of how well one has learned can be determined by examining one's scores on objective tests in comparison to one's peers.
5. School learning has nothing to do with real life.

If the emphasis is on winning and the extrinsic reward is great enough, competition can be viewed as mutually exclusive goal attainment. That is, the success of one requires the failure of another. The article also points out that competition can foster cheating.

III. EXISTING COMPETITIONS

One of the earliest identified academic competitions is the science fair competition sponsored by the Society for Science and the Public. Beginning in 1950, and expanding to an international competition in 1958 by bringing in Canadian, Japanese and German students, this competition has set the standard for many others to follow (<http://www.societyforscience.org/iseef/about>). The science fair offers a vision of "promot[ing] the understanding and appreciation of science and the vital role it plays in human advancement: to inform, educate, and inspire." Focusing on high school aged students, this competition offers a strong set of rules which emphasizes the design of the research project ensuring that it not only meets rigorous standards but also matches up students with mentors (high school faculty or even college faculty members) to ensure a strict set of criteria is followed. Human research requires a formal Independent Research Board approval and strict criteria is provided to students as part of the registration process. Judging of the competition is well designed and consistent across competitions clearly outlined in writing.

Another well-known and defined competition is the Scripts Spelling Bee. The national spelling bee, a uniquely American experience, has been run since the 1920's and is set on a series of well-defined rules for both contestants and judges. The spelling bee has a strict mission focusing students on the study of "help[ing] students improve their spelling, increase their vocabularies, learn concepts, and develop correct English usage that will help them all their lives." (<http://www.spellingbee.com/about-the-bee>).

Both the science fair and the spelling bee are well defined competitions which have clear missions, goals and clear educational outcomes.

As the popularity of competitions continued to grow, competitions have been created which include such themes as Robotics, Computer Programming, and Artificial Intelligence. Technology subjects lend themselves to multiple team-based competitions which are often sponsored by well-known organizations such as the Institute of Electrical and Electronics Engineers (IEEE) and the Association for Computing Machinery (ACM). Some of these competitions are well designed and are defined with formal missions and structure. An analysis of well-known technical competitions at the high school and collegiate levels, in an attempt to understand what drove the individual competitions, is outlined in Table 1.

| Robotics Competitions | | | | |
|-----------------------|--------------------------------|-------------|------------------------------|---|
| Name | Well Defined Mission Statement | Clear Goals | Defined Educational Outcomes | Reference |
| FIRST LEGO League | X | X | X | http://www.usfirst.org/roboticsprograms/fl |
| IEEE Robot Challenge | None | None | None Identified | http://robotchallenge.com/ |
| Battlebot IQ | X | X | X | http://www.botsiq.org/manage.aboutbbiq.php |
| Gear Robotics | X | X | None Identified | http://www.gearrobotics.org/jm/index.php?option=com_content&view=article&id=44&Itemid=56 |

| Programming Competitions | | | | |
|--|--------------------------------|------|------------------------------|---|
| Name | Well Defined Mission Statement | Goal | Defined Educational Outcomes | Reference |
| ACM International Collegiate Programming Contest | X | X | None Identified | http://icpc.baylor.edu/welcome.icpc |
| Windward CodeWars | None | None | None Identified | http://www.windward.net/code_war.php |

| AI Competitions | | | | |
|------------------------------|--------------------------------|------|------------------------------|---|
| Name | Well Defined Mission Statement | Goal | Defined Educational Outcomes | Reference |
| MIT Battlecode | None | None | None Identified | http://www.battlecode.org |
| Botball Educational Robotics | X | X | None Identified | http://icpc.baylor.edu/welcome.icpc |

Table 1 - Non-Cyber High School and Collegiate Technology Competitions

Each of the identified competitions was analyzed based on three criteria: a well-defined mission statement, clear goals outlining the competition, and clearly defined educational outcomes or expectations. In addition to the science fair and the spelling bee, eight competitions were identified. Out of these eight, five had well defined mission statements and clear goals. Only two (the First Lego League and the BattlebotIQ) had well defined educational outcomes.

IV. CYBER COMPETITIONS

To fully discuss cyber competitions, we must define the word cyber. For the purpose of this paper, we refer to cyber as a reference to both networked infrastructure components

(computers, routers, hubs, switches, and firewalls) as well as the assets which go with it (critical data for a given organization) [11]. In the case of cyber competitions, any competition which focuses on the above definition was identified. Cyber Competitions are focused on three specific areas: computer forensics, capture the flag (offensive) competitions, or cyber security (defensive) competitions. All three were included in this analysis.

A review of the literature as well as competition web pages found a total of fourteen formal competitions open to the public and one formal competition (CDX) which was not open to the public but available only to US military organizations. An overview of these competitions is outlined in Table 2: High School and Collegiate Cyber Competitions along with a notation as to whether clear goals, well defined mission statements, and clear education outcomes associated with the competition were located on the competition's web site or in the advertised literature.

Of note from this analysis is that only one of the cyber competitions had clear educational outcomes identified and associated in the competition description. This is true even though six of the competitions (NYU Poly, US Cyber Patriot, Pacific Rim CCDC, UCB CTF, San Diego Mayor's Cyber Cup and CDX) were all focused on high school or college student participants. The CyberPatriot competition provided materials for use in preparing teams to participate in the event. This could be due to the fact that CyberPatriot is attempting to recruit members from high schools, a population that is not commonly thought of when developing cyber competitions. In fact, out of the fifteen formal competitions and four information competitions reviewed, only two (CyberPatriot and the San Diego Mayor's Cyber Cup) were focused on high school students while others focused on either college undergraduates, graduate school students, or industry experts. Understanding its population, the CyberPatriot developers realize that high school teachers may not have a background in cyber security and compensate for this by providing formal training modules as well as coordinating an industry-based mentor to work with each team during the training process. This compensation requires the competition to identify associated educational outcomes as well as clear competition goals to ensure that participants develop skills needed to succeed.

| Name | Well Defined Mission Statement | Clear Goals | Defined Educational Outcomes | Reference |
|---|--------------------------------|-------------|---|---|
| DC3 Challenge | None | X | None | http://www.dc3.mil/challenge/2011/play/index.php |
| CyberQuests | X | | None | https://uscc.cyberquests.org |
| SANS Net Wars | X | X | None | http://www.sans.org/cyber-ranges/networks/overview.php |
| US Cyber Challenge | X | None | None | https://www.nbise.org/our-work |
| NYU Poly CSAW Cyber Security Competition | None | None | None | http://www.poly.edu/csaw2011/about |
| CyberPatriot | X | X | Training Materials with Learning Outcomes | http://www.uscyberpatriot.org/about/Pages/default.aspx |
| N-CCDC | X | X | None | http://www.nationalccdc.org/index.php?option=com_content&view=article&id=48&Itemid=54 |
| USCB International Capture the Flag | X | X | None | http://ictf.cs.ucsb.edu |
| Pacific Rim Regional Collegiate Cyber Defense Competition | None | X | None | http://ciac.ischool.washington.edu/?page_id=234 |
| Codegate: YUK | None | None | None | No Discussion of Mission or Goals |
| Cyberlympics | X | X | None | http://www.cyberlympics.org/Home/AboutUs.aspx |
| OWASP Secure the Flag Competition Project | X | X | None | https://www.owasp.org/index.php/OWASP_Secure_the_Flag_Competition_Project |
| CyberSecurity Challenge UK | X | X | None | https://cybersecuritychallenge.org.uk/about.php |
| San Diego Mayor's Cyber Cup | X | X | None | http://securingourexcity.org/blog/wp-content/uploads/2012/01/SDMCC_Flyer_LF.pdf |
| Cyber Defense Exercise (CDX) | None | None | None | N/A (Limited public information from the originators) |

Table 2- High School and Collegiate Cyber Competitions

V. CONCLUSIONS: WHAT ARE WE TEACHING WITH OUR CYBER COMPETITIONS?

Over the years, in the non-technical realm (Science Fairs, Spelling Bees, etc.), competitions developed clear mission statements and goals as well as educational outcomes. Most technical competitions, however, do not seem to be as well focused. Looking specifically at cyber competitions, there are even fewer organizations which identify their own competition mission and goals much less specify associated educational outcomes. In fact, in our analysis there was only one competition (specifically focused on high school students) that has educational outcomes identified on their web pages and those outcomes come from the fact that the program provides

an educational piece to help teachers and mentors to prepare the students for the competition.

A lack of identified educational outcomes leads to the question of what purpose cyber competitions are trying to attain. Is the goal to motivate students to learn by focusing them on the opportunity to 'win' against other schools or even against other teams within the same school? Without clear educational outcomes associated with the project, how are students expected to prepare for a competition? Some even suggest that schools should focus on creating a curriculum to support competition [12] or even identifying learning objectives through competition [13] instead of developing competitions to support existing learning objectives. While supporting the concepts identified by Wankat [2] that a strong alignment of competition with an institution's curriculum is a sign of a winning institution, the fact that competitions are being used to drive curriculum suggests that overarching educational outcomes are not being sufficiently identified prior to developing and implementing formal cyber competitions.

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Work in Progress: Evaluating the Use of Mobile Game Development in Introductory CS Courses

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Abstract—Computer games have been accepted as an engaging and motivating tool in the CS curriculum. However, designing and implementing a playable game is challenging and is best done in advanced courses. Games for mobile devices offer the advantage of being simpler and, thus, easier to program for lower-level students. By exposing these students to a wide range of advanced topics, we can demonstrate to them that CS can be much more than coding. Here, we discuss our evaluation of a set of learning modules for introductory CS courses that use mobile game development as a motivational learning context.

Keywords—Games, mobile computing, introductory courses, motivation, engagement

I. INTRODUCTION

Computer games have been successfully applied to improve recruitment and retention in Computer Science (CS) courses and degree programs [10]. They have been shown to be a successful learning tool by leveraging students' enthusiasm towards computer games and their social relevance. Designing and implementing a playable game is a very challenging task, especially for lower-level students. Thus, this is best done in advanced CS courses where students already have sufficient experience in software development and exposure to other CS topics. Games for mobile devices, on the other hand, are simpler by nature and are thus easier to program [6]. This makes it more feasible for lower-level students to develop playable games as part of their classroom experience [4]. Mobile applications are often easy for students to relate to since mobile technology plays an increasingly important role in the lives of today's students. Thus, leveraging mobile game development as a motivational learning context has strong potential to improve student success in introductory CS courses and increase student motivation to stay in the major [8].

Creating engaging and feature-rich games requires a skillful integration of a wide range of techniques from many areas of CS; thus, computer games can be used at different points in the CS curriculum including in introductory courses. Using mobile devices as a learning context in these courses aims to provide a simple and elegant means to motivate students and communicate the diversity and power of many advanced CS areas in a manner that engages students in experiential education [9]. Moreover, research also shows that participatory learning methods such as those used in mobile game development can level the playing field for different types of students [1]. Research literature and our own experience

demonstrate that most CS students seem to be very interested in computer game development, and introducing students to this topic early in the curriculum could serve as a good tool to increase student retention [1]. More broadly, current research literature indicates that students perform better when they find their course material relevant and motivating [2].

II. DEVELOPMENT OF LEARNING MODULES

Supported by an NSF TUES/CCLI grant, we are working on a comprehensive set of eight learning modules consisting of laboratory projects and accompanying instructional materials for introductory CS courses taught using Java. Each learning module serves as a platform to introduce students to an advanced CS topic, such as algorithms, artificial intelligence, computer networking, computer security, computer systems, database management, human-computer interaction, or software engineering, as well as to practice a fundamental topic, such as arrays or inheritance. By demonstrating these and other non-programming and diverse aspects of the discipline to the students early, this approach may help dissolve a widely popular misconception that "CS is all about coding" [1].

Each learning module consists of a small laboratory project suitable for CS I and beyond. Each project focuses on a single mobile game, introduces one advanced topic, and reinforces one core concept. In addition to the project, deliverables for each module include a set of instructional and supplementary materials. These include an instructor's manual that provides a sample syllabus to go with each project and guidelines for the adoption and adaptation of the curricular material. Instructional materials consist of lecture notes, illustrations, references, and sample solutions, as well as supporting materials such as project source code and documentation.

III. EVALUATION OF OUR APPROACH

We tested a few of the developed modules at Central Connecticut State University (CCSU) and Rose-Hulman Institute of Technology (RHIT) with a total of 161 students. In testing the modules highlighted above, we employed three assessment strategies: 1) student course grades and course completion, 2) the Classroom Survey of Student Engagement (CLASSE) administered at the end of the term, and 3) the Motivated Strategies for Learning Questionnaire (MSLQ) administered at the beginning and end of the term. The modules were used relatively late in the courses, during the last few weeks of the term.

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During the first year of the project, 161 students enrolled across eight sections of introductory CS courses at CCSU and RHIT, although the total number of students who completed each assessment varied. A total of 84 students were enrolled in a test section in which one or more curricular modules using mobile game development were used to convey basic concepts, and 77 students were enrolled in paired control sections of the same course. Not all students completed the courses, however; nor did all of those students who completed the courses participate in both administrations of MSLQ and the one administration of CLASSE. At both CCSU and RHIT, the courses were open to students of any major, as long as they met the courses' prerequisites.

According to the interim report [7], results from the first year of the assessment of the project yielded findings in various areas of interest. We highlight a few of these areas.

A. Student Persistence

Persistence rates appear independent of administration of mobile game development curricular modules but were significantly different between the two institutions, with students at CCSU persisting at lower rates. The differences between universities in persistence rates very likely reflect the selectivity of the institutions, composition of the class population, and academic inputs of students taking the courses, with students at the less selective CCSU exhibiting lower persistence rates and lower levels of academic performances.

B. Course grades

Student course grades were independent of the use of the curricular modules. This suggests that the mobile game development modules as administered at both institutions did not affect student performance on the assessments used by these instructors.

C. Student engagement with course

Findings about student engagement in the course present a mixed bag of results that suggest limited positive effects of using the mobile game development modules in increased note taking, making connections across courses, and for the students at CCSU, whose academic preparation for college was not as strong as those at RHIT, perceptions of course difficulty decreased. Use of the mobile game development modules with the better prepared RHIT students, however, exhibited some negative effects in the area of instructor comfort and communication as well as student interest in the material. It is possible that these negative findings were a result of students who expected a more traditional classroom experience with these concepts or that the curricular modules did not fit seamlessly into the rest of the course taught at RHIT.

D. Student motivation

Generally, motivation among students in CCSU computer science classes declined, but this decline was less pronounced in test sections than control sections. By contrast, RHIT student motivation stayed level or increased slightly over the course of the term for both the test group and the control group, with motivation gains among the control group slightly outpacing those in the test group.

IV. SUMMARY AND FUTURE WORK

Evaluation results indicate that in each of the areas discussed above, the test groups did no worse than the control groups. As a matter of fact, students in the test groups were more engaged with the course in which the modules were presented and their motivation did not decline as much as the control groups. We will continue to refine the modules and adjust the points in the courses in which we use them. Allowing students more time to work with the modules and to apply what they learn to other topics may produce more positive results.

This project has a lot of potential. We believe that using mobile game development projects in introductory CS curricula will promote teaching and learning, help improve student experience in the critical introductory CS courses when student attrition is at its highest, and ultimately will help train outstanding computer scientists. We are currently in the process of making changes and finalizing the modules to address the concerns raised as a result of ongoing project assessment. We shared one of the modules with instructors at the 2011 ACM Special Interest Group on Computer Science Education (SIGCSE 2011) symposium and at several Consortium for Computing Sciences in Colleges (CCSC) conferences [5] and it was very well received. We are also working toward developing a web portal where we can share this and other modules with the wider community.

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Work in Progress: Teaching Game Design and Robotics Together:

A Natural Marriage of Computing and Engineering Design in a First-Year Engineering Course

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Abstract—The increased dependence on computer programming in engineering has made it essential for engineering students to learn about programming throughout their undergraduate education. In the same vein, computing students benefit when given an opportunity to learn more about engineering design and systematic thinking. This paper discusses how one college embedded computing and engineering into a combined first-year introductory course. The course fuses computing and engineering using game design and robotics as an offering for both cohorts of students to work together in a multidisciplinary environment. Over the course of the semester, students learn introductory computing and engineering design concepts by designing games and robots using informatics tools to solve design challenges. Interdisciplinary teams consisting of computing and engineering students work together to prototype a game design idea and then bring that idea to life using robots as part of their final project.

Keywords – game design, robotics, project-based learning, problem solving, common engineering core, computing for engineers

I. INTRODUCTION

Understanding of and an ability to program has become an essential skill for engineers to learn since the creation of the computer. The increased reliance on computing to address engineering needs has rapidly increased the number of programming-based courses required to receive an engineering degree. A parallel need also exists for computing students to understand the principles of engineering as it relates to design, problem solving, and applied learning [1]. The ability to think in a design-centered way and approach problems systematically are skills that assist engineering and computing students in problem solving. The intended goal of these two learning objectives suggests a mutual give and take that lends itself ideally to a multidisciplinary approach. Yet, common offerings to address the learning of these skills have taken on a “siloe” or separate disciplinary structure where engineering and computing students learn these skills separately [2]. This has several pitfalls; the most severe being that underclassmen lack the maturity or the far-sightedness to understand why they have to learn the basics of other disciplines if it is not their intended major [3, 4].

The following work-in-progress discusses the creation of a

fused multidisciplinary computing and engineering course, similar to that of Xu *et al.* [5], that relies heavily on the principles of game design [6] and LEGO® Mindstorms® robotics [7, 8]. The course was designed and taught by a computing and engineering faculty team – one instructor from each discipline. Students in both engineering and computing enrolled in the course together during their first-year to create a multidisciplinary experience.

II. COURSE DESIGN

In 2009, the computing department merged with the engineering department allowing for an opportunity to fuse each disciplines separate introductory courses. Teams of computing and engineering faculty began offering these fused introductory classes. The fused computing and engineering course is taught as part of a required first-year project spine.

Anecdotally, the faculty found that the courses were not preparing students well enough for the subsequent second-year courses in both engineering and computing, especially in computing. The courses were technically fused, but in practice became essentially two courses taught during one insufficient time block.

A new approach was piloted during the Spring 2012 semester to explore how a combination of game design and robotics would impact the computing-engineering fusion. The course was designed to utilize the strengths of the department, to make use of the flexibility of both media to address computing and engineering content, and to learn how the benefits of learning robotics and game design separately could be applied to one another.

As shown in Figure 1, students started out by learning the principles of programming using a drag and drop tool (GameMaker™) to design games. They then transitioned into another drag and drop tool (ROBOLAB™) to learn the principles of engineering design. The two skills were then combined via a final project. The final project placed the emphasis on game design to prototype the solution for an engineering design problem (i.e. iterate, test and refine the solution). Robotics was then applied to finish the real-world

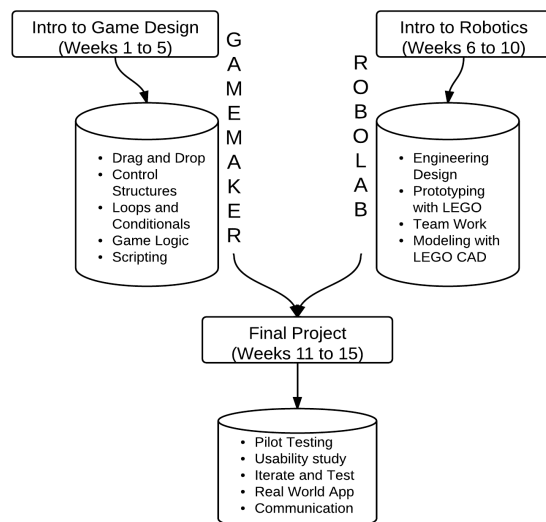


Figure 1. Design of a 15 week fused course

implementation of the solution. Multiple projects for each of the first two sections were used to ensure students had opportunities to display their competency and to work in many different groups. A flipped classroom approach (reverse teaching-homework paradigm) was also used to save class time for hands-on assignments and troubleshooting [9-11]. The overall curriculum design aimed to extract the benefits of gaming and robotics in harmony with one another in a way that showcases the importance of learning both computing and engineering design fundamentals.

III. COURSES ASSESSMENT

During the Spring 2012 semester, one of four sections consisting of twenty-one students, used the combined game design and robotics curriculum. The cohort of students consisted of eleven declared computing students and ten declared engineering students. The course was assessed throughout the semester using student reflections to determine the effectiveness of this approach. Students provided feedback on the content and identified the “muddiest point”, i.e. what was most confusing, each week (source of quotes seen below).

A. Game Design

Game design was received well by the students. The drag and drop style programming of GameMaker made it straightforward and easy for students to learn through the online video tutorials. The majority of students found “*GameMaker [to] definitely [be] an interesting learning experience.*” The flipped classroom approach made it easy for the instructors to help students learn the basic skills necessary to program in GameMaker. Individual and group assignments were then completed in class in an environment that allowed students to consult one another. Students generally “*...enjoyed working on assignments in class in collaboration with other students.*”

The most common “muddiest point” was the conversion from drag and drop to written script. The instructors agreed

that all of the students, particularly the computing students, needed practice with written code, including an ability to identify what a drag and drop function would look like if written. This proved to be a difficult transition for many of the students with the limited time given to learn the skill.

B. Robotics

The easy assembly and familiarity with the LEGO products made it easy for students to design and construct their ideas. Students found the robotics section to “*Overall [be] a pretty enlightening experience*” that gave students “*... a great concept on how to be an engineer.*”

The programming was a natural extension of the game design section. ROBOLAB is also a drag and drop program that runs within LabVIEW™ Software; the chosen programming language used in the second-year engineering project courses.

As opposed to the game design section, the robotics section utilized teams of students to complete a series of tasks. The explicit team projects were enjoyed by all of the students.

C. Final Project

The biggest challenge of the game design—robotics curriculum was determining how to combine the two media into a natural final project. While both utilize a drag and drop approach to programming, the two programs do not naturally interact with one another. To temper the compatibility issue, it was decided that students would design a two-player game. First, the students would draw up multiple ideas for their game in written form. Second, the students would create a video game version of the game using GameMaker. The video game would act as a simulation of a physical game. Finally, the teams were tasked with creating a physical version of the video game using robotics.

IV. CONCLUSIONS & FUTURE WORK

Our preliminary results suggest the use of game design and robotics as natural media to include in a fused computing and engineering introductory course. The skills required to complete game design and robotic activities complement and enhance each other. The two media are also viewed as fun to the first-year students.

Future assessment of this course will involve an in depth analysis of how this approach impacts student learning. A comparison will be made between traditional offerings and the fused course. Additional quantitative analysis of computing and engineering design self-efficacy, anxiety, and the perceived values associated with a computing-engineering fused course will expand our understanding of this new approach. Research will also identify how best to use a flipped model classroom by iteratively changing the curriculum to improve proficiency with programming.

ACKNOWLEDGMENT

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Work in Progress: Who Answered First? – A Trivia Game utilizing Timed Electronic Classroom Response Systems

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Abstract—Currently, classroom response systems (CRS) are being integrated into an increasing number of university courses. One of the least pursued usages of CRS is the ability to capture speed of student responses. Many of these systems produce a dynamic comma-separated value (CSV) file that presents all of this information in a database that can then be tapped for various uses. The system described in this paper combines the i>Clicker CRS, Mathworks MATLAB, and Microsoft PowerPoint to create an interactive trivia game for use in the classroom. The current implementation is used as an exam review in two first-year fundamentals of engineering courses at the university level.

Keywords—classroom technology, clickers, trivia, classroom games, classroom response systems, classroom applications.

I. INTRODUCTION

The quiz show Jeopardy!® is one example of a timed response trivia game. The greatest challenge in implementing such a trivia game in the classroom is the ability to measure who “buzzes in” first. Generally, only two dichotomous methods have been utilized: hand- raising and remote timed response systems. Both of these methods sacrifice some aspect of the quality of experience. Hand-raising, although cost effective, is an imperfect system and cannot be scaled well to a classroom-sized group. Hand-raising often involves time spent arguing about who has raised their hand first and causes instructors or TAs to make somewhat arbitrary decisions based on what they saw at the time. On the other hand, remote timed response systems are expensive, situation specific, likely difficult to set up, and not scalable.

The system described in this paper offers an alternative method utilizing already widely operating CRS. Specifically, this system combines Mathworks MATLAB [1], Microsoft PowerPoint [2], and the i>Clicker system [3] to create an interactive trivia game for use in the classroom. The current implementation is used as an exam review in two first-year fundamentals of engineering courses at the university level. To the authors’ knowledge, there are no other published works on interactive quiz-style systems using CRS.

The development and implementation of this interactive game includes three major steps. The first step was the development of the software interface between the i>Clicker database and the programming environment, MATLAB. The

second step was the development of fully-functional PowerPoint slides that provide parallel operation between the slides and the MATLAB program. The third step was conducting a case study involving a first year engineering course at the university level with approximately 60 students using this system as an exam review session. Finally, future developments are presented with the goal of attaining a smoother, more user-friendly system which will be adaptable to many different classroom situations. This work is significant because it shows an inexpensive and scalable timed electronic CRS for use in an academic setting.

II. SOFTWARE

A. MATLAB/i>Clicker Interface – Quicker Clicker

A MATLAB program, Quicker Clicker, was developed to display the name of the student who clicked in first in response to an i>Clicker question asked by the instructor. The i>Clicker system is set up to record student responses in a comma-separated value (CSV) file. After asking a question with the i>Clicker software, the file is immediately updated with information on the question, including the students response and the time of their first click. The program works by polling the CSV file and running whenever the file is updated. The file is searched and the student’s name is displayed in a large yet unobtrusive format on the screen. At this point, the instructor can call on the student to answer the current question. The student’s name drops off the screen after about five seconds, allowing for subsequent responses.

B. PowerPoint Slides

A PowerPoint Jeopardy-style system was developed in order to efficiently ask questions and allow seamless interaction between slides. Each round begins with a display board with six categories and five squares per category with increasing point values. When a student or team selects the category and point value desired, the instructor can click on the square and the question will appear. The question is then asked by the instructor and the Quicker Clicker program is activated. Once the question is answered, the instructor can click the back button and return to the display board.

The slides are set up in such a way that an instructor can change category titles and individual questions, with the

functionality remaining intact. This allows for this software to be expandable to any class with any type of questions.

III. FIRST-YEAR ENGINEERING CASE STUDY

This system has been developed for use in a first year engineering course at the university level with approximately 60 students using this system as an exam review session. Over the past three years, the software has been developed and improved based on trials in this setting.

The course is already broken-up into teams of four students, and these teams are used for the game scoring. Students use their i>Clickers to click in for each question and control of the board goes to the team that most recently recorded a correct answer. The game can either progress until all questions on the board are answered or the game can be timed. In a 90 minute class session, two full rounds and a final round can be run, which gives students access to 61 questions. Generally instructors can also provide insight after a student response to each question.

There are many benefits that have been noted based on these trial sessions. First, student engagement in the review process is much higher than a standard review class period due to the competitive nature of the game. Second, the questions are set up in a very organized manner covering all of the topics students need to review, which allows students to go back after the class and review effectively. Third, students can choose to participate actively or passively based on their learning preferences. Some students try and click in for every question whereas others decide they would rather pay attention to the questions and answers and they do not click in. Fourth, the process to students appears seamless and non-intrusive, thus allowing them to focus completely on the questions and reviewing.

IV. NEXT STEPS

Although the software currently works as written, there are a few areas that are being improved to make for a more manageable, scalable system. Ultimately, the package will be released online for general academic use. The following is a list of improvements in development:

- *Question elimination* – The current system relies on the instructor and students to remember which questions have been answered. A beta version of a MATLAB implementation of question elimination is currently in use, but is still not very user friendly. The goal is to make a system that either dynamically updates the PowerPoint slide as questions are selected or automatically records these clicks in the MATLAB program.

- *Team responses* – The current system only allows for individual student names to appear as a response for fasted click. An improvement would allow for the instructor to choose between individual and team operation.
- *Automated scoring* – The current system does not integrate scoring and this is currently done by the instructor or teaching assistant. This manual process is very time intensive and does not allow for students to have a consistent, quickly updated score available. The improved system will automatically record and display scores based on who has clicked in and an instructor's click on "right" or "wrong" after the question is answered.
- *Automatic roster updates* – The current system requires the instructor to modify the remote identification file to put in full student names. The improved system will cross-link the names from other files already created, so that the instructor does not need to do any preprocessing before running the session.
- *Automated Timer* – Currently the instructor needs to be careful to time the game appropriately. The improved system will include a timing system in order to make sure that the game will end by the end of class.
- *Enhanced MATLAB/i>Clicker Interface* – Currently the interface neglects many technical issues with wireless communication and may not accurately select the quickest clicker in all cases. The improved system will look at a more fair and accurate method to obtain the quickest clicker.
- *Help request mode* – A feature is planned that will allow the system to be utilized as a team request for help. Identifying which team requested help first during work sessions in an active classroom environment can be challenging. In our experience it is often the closest team requesting help which receives it first. In "Help Request Mode," teams would click in when they have a question and the team number would be displayed on the screen. Instructors would then have a time based order to follow in which to give aid to the different student teams.

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A study on the influence of rich versus traditional classroom response system (CRS) questions on concept retention

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Abstract—Clickers in classrooms have been shown to increase student engagement. With the emergence of touch-based smart devices, such as iPhones and iPads, there is a move towards migrating the functionality offered by the clickers to these advanced response systems. Apart from being a convenient alternative, do these advanced touch-based devices offer anything new with respect to student learning? For a start, beyond the traditional multiple-choice and true/false responses, these advanced clickers provide several new question modalities that the traditional button-based clickers do not offer. It can be hypothesized that the rich interactions offered by touch-based devices can enhance student engagement even further than the traditional clickers currently do and contribute towards improvements in student learning. To explore this hypothesis, a study was designed to investigate the difference in concept retention among students who use the traditional versus rich classroom response systems (CRS). The study was conducted using a custom-designed iPhone app during an engineering lecture. While no significant difference in retention was evident, several insights were gained in favor of the rich interactions offered by the new CRS. This work highlights the distinct features that make advanced clickers conducive to student engagement and guides future developments in such next generation classroom technologies.

Keywords—component; clickers; iPhone; iPod; iPad; classroom response system; CRS; rapid feedback; student feedback; smartphones

I. INTRODUCTION

Research has indicated that classroom response systems (CRS) make classrooms more engaging for students [1]–[7]. For instance, extensive work with traditional clickers has demonstrated improved student participation [6],[8],[9], interaction [10]–[13], engagement [14][15], retention [16] and sometimes even grades [1],[17]–[19]. Such studies make CRS very attractive for our classrooms. However the current CRS technology exhibits limitations in terms of the types of interactions offered. Typically when using commonly available button-based devices, only multiple-choice answers (A, B, C or D) or true/false answers (e.g., A for True or B for False) are available as response alternatives. Figure 1(a) provides an image of a traditional clicker that is currently available as one

of the least expensive CRS option. Also depicted in Fig. 1(a) is a touch-based smart device by Apple, iPod Touch that can at minimum provide response options similar to the traditional clickers.

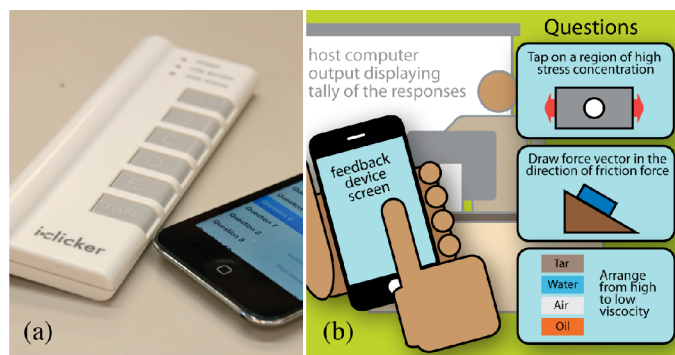


Figure 1. (a) A photo of a traditional i>Clicker response device, currently a widely used clicker system, along side Apple's iPod Touch unit. (b) An illustration depicting possible rich interactions via a touch-based platform.

A touch-based system, however, can dramatically expand the available forms of interactions considering it is not limited to the four buttons (or more) that are available on the traditional clicker. Though the examples provided are specific to engineering, the illustration in Fig. 1(b) demonstrates the potentially new and improved interactions available via a touch-based platform. Instructors will be able to solicit responses by asking every student in the class to, for instance, tap on the region of an image where the correct answer exists, draw the response with their fingers, and sort items in an ascending or descending order. Previously, such deep interactions were limited to instructors individually asking a student for response. Considering the touch-enabled devices such as iPod Touch and iPhone are ubiquitous, these rich question types can be easily adapted to develop an advanced CRS platform.

While we can anticipate rich questions providing deeper engagement with the questions, it is yet to be seen if the rich questions improve learning. Specifically, do rich questions

enhance concept retention because of their ability to better engage compared to traditional questions using a classroom response system? The study described here attempts to investigate this research question using a custom-designed app that runs on an iOS device (iPod Touch, iPhone or an iPad). This paper describes the details of the preliminary study and how concept retention was tested. Even though the study did not provide conclusive result, the outcomes are promising for future investigations into advanced CRS; which will inevitably become part of future classrooms.

II. DESCRIPTION OF THE TECHNOLOGY

CRS typically involve two critical response stages: the *student response* stage where students respond to pre-designed questions and the *instructor feedback* stage where the instructor reviews and discusses the student responses. The customized touch-based CRS was developed as a two-component system:

- **ClikMe.** An iPhone/iPod app called ClikMe was developed by engineering students at Rowan. ClikMe allowed a) remote downloading of question packs prepared by the instructors, b) displaying the questions for student interaction, and c) students to send their responses to a remote location for analysis.
- **Server.** The server was designed to accept student responses from the various iPhone and iPod Touch devices over the campus WiFi network. The responses would then be aggregated and analyzed for correctness. The server also provides simple analyzed output of the student responses.

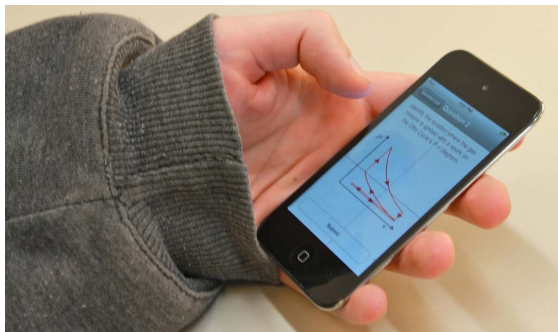


Figure 2. A photo of ClikMe app running on an iPod Touch. Student interacting with Region of Interest question.

ClikMe offered the following question modes: a) Multiple-choice - select from a list of choices, b) True/False - select whether the statement is true or false, c) Short Answer - provide a short response to the statement, d) Sorting - arrange in ascending or descending order, e) Region of Interest - identify a region on the image, f) Drawing - draw an arrow over the image provided. All question types were able to embed an image to provide a more visual experience. The question packs were remotely downloaded from a cloud storage location (dropbox.com) to the iOS devices. The responses were sent to a designated web-server for subsequent analysis. At this stage of the app development, the *student response* stage of CRS was fully functional however the

instructor feedback was only partially complete. For instructor feedback to take place the server required the ability to analyze the data and visually present the results. Therefore, the student responses were aggregated but their responses were not instantly available for analysis by the instructor. Also, for the preliminary study, the drawing question was not included due to the incomplete nature of the server component. However, the rest of the question-types were included in the study. Figure 2 provides a photo of a student interacting with ClikMe's Region of Interest question.

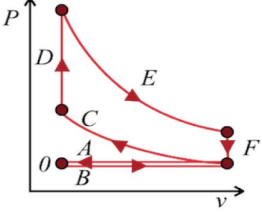
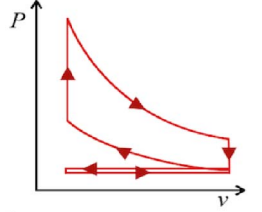
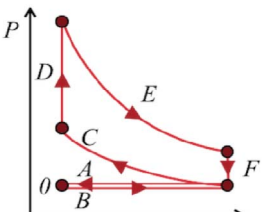
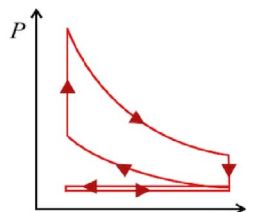
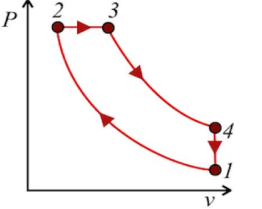
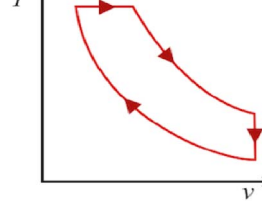
III. METHODOLOGY

An undergraduate Thermodynamics course was selected for the study. Internal combustion (IC) engine cycles topic was chosen as a lecture-topic for the ClikMe CRS session. Both rich and traditional questions were prepared beforehand and the study was conducted at the end of a lecture on Otto and Diesel cycles. Half of the students in the class received iOS devices loaded with traditional questions ('control') while the second half received devices loaded with rich questions ('treatment'). The students were randomly assigned to receive traditional or rich devices. ClikMe was used to present both rich and traditional mode questions to the participants. Traditional clickers (the button-based devices) were avoided to limit any unintentional biases between the rich and traditional responders (eliminating the 'coolness' factor of using iPods). The only difference between the rich and traditional question responders was the question mode - the traditional responders were limited to multiple-choice and true/false question types. The study proceeded in two stages: the clicker test (treatment stage) and the concept retention test (assessment stage). For the clicker test, a touch-based CRS session was conducted at the end of a lecture. The concept retention test was administered during the next class period (4 days later and over the weekend) to assess the influence of rich or traditional question types on concept retention.

A. Clicker Test

Six equivalent questions were prepared for rich and traditional responders. Each question was designed such that it fit the respective definitions of rich versus traditional question types. The list of questions for both question types is provided in Table I. As an example, the first question (Q1) tests the same concept however the traditional format asks the student to select a single step that follows the BDC location of the piston, while the rich question-type asks to arrange the three steps in order. It is anticipated that the rich question responder is forced to understand the relationship between each of the steps compared to understanding the sequence with respect to BDC alone when considering traditional question type. As another example, the second question asks students to indicate where the gas mixture is ignited on the plot, providing six choices for the traditional question format. Here the rich question format affords numerous potential responses, including the end points for the steps. Again, the rich responder is forced to consider a multitude of choices and select a single response. It is this more open-ended process, that provides an avenue for deeper engagement and thus retention of concepts being tested.

TABLE I. CLICKER TEST QUESTIONS DIVIDED INTO TRADITIONAL AND RICH QUESTION TYPES.

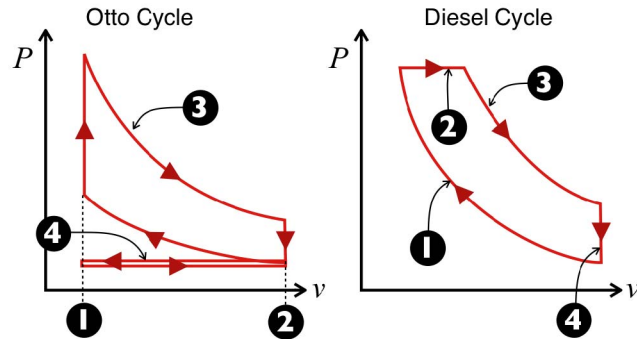
| Traditional | Rich |
|--|---|
| Multiple-choice 1. Which step of the Otto Cycle follows the piston at the Bottom Dead Center (BDC)? A. Piston at the Top Dead Center B. Isentropic Compression C. Isentropic Expansion D. None of the above | Sorting 1. Arrange the Otto Cycle steps in sequential order starting with the piston at the Bottom Dead Center (BDC). 1. Isentropic Expansion 2. Piston at the Top Dead Center 3. Isentropic Compression |
| Multiple-choice 2. Identify the location where the gas mixture is ignited with a spark on the Otto Cycle's P-v diagram.  | Region of Interest 2. Identify the location where the gas mixture is ignited with a spark on the Otto Cycle's P-v diagram.  |
| True/False 3. Thermal Efficiency of the Otto Cycle is a direct function of the compression ratio. Spark knock is observed when the recommended limit for compression ratio is exceeded. | Short Answer 3. Thermal Efficiency of the Otto Cycle is a direct function of the compression ratio. What phenomenon is observed with exceeding recommended compression ratio for an Otto Cycle? |
| Multiple-choice 4. Indicate where the combustion products are exhausted in the Otto Cycle P-v diagram.  | Region of Interest 4. Indicate where the combustion products are exhausted in the Otto Cycle P-v diagram.  |
| Multiple-choice 5. The difference between an Otto Cycle and a Diesel Cycle, respectively is A. Constant volume versus constant pressure heat addition B. Spark versus compression ignition C. Lower compression ratio versus higher compression ratios D. All of the above | Short Answer 5. A major difference between an Otto Cycle and a Diesel Cycle is ... |
| True/False 6. The step 1-2 is unique to a Diesel Cycle compared to an Otto Cycle.  | Region of Interest 6. The following step is unique to Diesel compared to Otto Cycle.  |

For the clicker test, the class was equally divided into rich and traditional participants, who were randomly assigned question types. The questions were revealed sequentially and students answered each question simultaneously before moving to the next. Once all the responses were registered, the instructor briefly explained the concept without differentiating between rich or traditional question explanations.

B. Concept Retention Test

Following the clicker test, the next class session involved a paper-based quiz to assess the retention of the IC engine concepts covered in the previous week. Individual students were tracked using their ID numbers (which were subsequently eliminated once the two intervention results were evaluated). The three concept questions were common for both the rich and traditional responders students and are summarized in Table II.

TABLE II. CONCEPT RETENTION TEST QUESTIONS.

| |
|--|
| True or False. 1. Engine knock or auto-ignition is a problem common in a Diesel Cycle. |
| Short Answer. 2. List (one or more) ways in which the Otto and Diesel cycles differ? |
| Short Answer 3. Label the diagrams (to the right) according to the numbers provided.  |

IV. RESULTS

A total of 28 students participated in the study using a variety of devices: iPod Touch, iPad, iPhone and iPhone simulators on an iMac (N=28). All the responses were simultaneously collected over WiFi on a local server. The clicker responses were analyzed for correctness and the students tagged with an ID for the follow-up concept retention tests. Once administered, the concept retention tests were manually evaluated and assigned to the respective students with their clicker performance. The grader was blind to the rich or traditional assignment. Figure 3 provides a comparison of the final results. The plot provides the average scores for the two interventions (the clicker test and the concept retention test) separated into rich and traditional student responders.

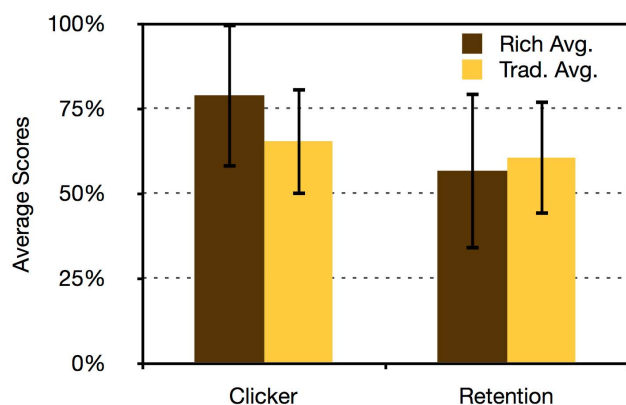


Figure 3. Average scores for the clicker test and the concept retention test for rich and traditional question responders. The error bars represent one standard deviation in the test scores.

Figure 3 shows that the students with the rich question types performed better on average than the students with traditional question types during the clicker test stage. For the concept retention test, there was a noticeable drop in the average scores for rich responders with performance at 50-60%. Interestingly, there was no discernible difference between the average scores for the rich and traditional question responders, especially considering the large error bars. In other words, the study yielded no observable influence of question type during CRS session on concept retention. However, to make such a conclusions would be premature considering the small sample size and several other factors that can obscure the causality.

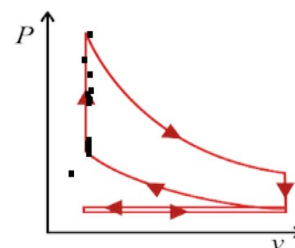
V. DISCUSSION

The described study is one of its kind using touch-based portable devices to explore new question modalities for student engagement. Even though, laptops and tablet PC's have been used to expand the CRS medium [20],[21], their bulky form factor and high costs are considerable limitations for mass implementation. The transition to such 'post-PC' devices is a more natural evolution of CRS technology. Therefore, the demonstration of an advanced CRS on an iOS platform is an equally important endeavor from the educational technology standpoint, as is the research question to investigate the influence of question types on student learning. The combination of these efforts are necessary to build a robust next generation CRS.

An added benefit of using the advanced CRS, which could not be captured with the described concept retention study, became clear while analyzing the student responses. Considering the rich question types are more open-ended and do not present pre-defined misconception to the students, the CRS session created an opportunity for instructors to discover unanticipated misconceptions. This is in contrast to the construction of multiple-choice and true/false question types where misconceptions are designed from instructor's perspective. For instance, question two (Q2) for the rich responders asked students to indicate where the gas mixture is ignited. The correct answer lies towards the bottom of the left-

most vertical rise in pressure. As seen on the server-analyzed output of rich Q2 in Fig. 4, several students indicated their response as an area close to the top of the pressure increase. This option was noticeably unavailable in the traditional question format and would prompt further discussion as an incorrect choice after employing a rich questioning mode. This example demonstrates additional benefits beyond engagement

Q2. Identify the location where the gas mixture is ignited with a spark on the Otto Cycle's P-v diagram.



offered by an advanced CRS.

Figure 4. Server analyzed response showing student submissions to the rich Question 2 during the clicker session. Black dots indicate student inputs.

The inconclusive nature of the results can be attributed to the preliminary nature of the study. As identified earlier, the CRS platform was incomplete with respect to the *Instructor Feedback* stage. It is entirely possible the differences in question types manifest themselves during the question review by prompting instructors to elaborate on all the incorrect responses and misconceptions rather than at the *Student Response* stage where the deeper engagement was anticipated. Since this stage was replaced with a more general discussion of the correct answer after the CRS session, it is conceivable no influence on concept retention was registered. It is also unclear what yielded the overall better performance with the rich question types during the clicker test over traditional question types. One can hypothesize that the intentional ambiguity introduced with multiple-choice alternatives when constructing the traditional question could have made some questions particularly more difficult. Nevertheless, this was an unexpected outcome of the study that requires further investigation to make sure no biases were introduced during question preparation and construction.

Current efforts are underway to develop a more rigorous research study involving all the features of the advanced CRS platform once complete. The following is a list of potential study aspects that will be addressed to strengthen the methodology.

- Involve a third party with expertise on the topic concepts to verify equivalency in questions among rich and traditional question types.
- A number of lecturers and a variety of topics need to be considered.
- A more open-ended concept retention test holds a better chance to amplify the differences in retention, as

opposed to some of the multiple-choice and true/false question types used [22],[23].

- The study needs to involve varying sample size with both large and small class sizes.
- An additional control group can be incorporated to highlight the benefits of using clickers in general: those who did not participate in a clicker study.
- Involve a crossover approach where rich and traditional students switch for a second round of the CRS session.
- Include the drawing question-type for further differentiation between rich and traditional.

VI. STUDENT FEEDBACK

In order to gain a student perspective regarding the touch-based CRS, the participants were solicited for their feedback at the end of the clicker session. The students used the same advanced CRS devices to provide responses to the survey questions. The first two questions were multiple-choice questions while the last two were open-comment questions. Table III provides the list of question and the corresponding summary of results for the multiple-choice questions. No differentiation between the rich and the traditional question responders was made. The students had an opportunity to provide additional open-ended feedback during the concept retention test.

TABLE III. STUDENT FEEDBACK QUESTIONS AND RESPONSE RESULTS TO THE MULTIPLE-CHOICE QUESTIONS

| Questions | Response Alternatives | Results |
|---|---|-------------------------|
| 1. How useful was the response experience | a. Hindered learning b. Not useful c. Somewhat useful d. Greatly helpful | 3% 11% 65% 21% |
| 2. What were the questions like? | a. Unfair b. Difficult c. Appropriate d. Ideal | 0% 0% 79% 21% |
| 3. Comment on the responses to the questions above. | (open-ended) | |
| 4. What did you like most or least about the response experience? | (open-ended) | |

Considering every student provided responses to the survey questions (100% response rate), the study gathered invaluable feedback from the student on the methodology and the technology. The results from Table III indicate 100% of the students felt the questions were appropriate and the majority of the students (>85%) perceived the response experience as useful. Among the most encouraging feedback was the overwhelming support for the advanced CRS through the open-ended questions. The statements below are a few that highlight these sentiments.

- “This was fun! And it helped me realize what I need to study after having a lecture and then a “quiz”.”
- “Good for increased class participation and understanding material.”

- “The questions were appropriate and they are useful for reinforcing major concepts.”
- “I thought it has the potential to be an effective education product...”
- “The visuals (example: Q3 on this questionnaire) are an especially good mental check of concepts learned in class. Visuals = Good!”
- “The questions were very ideal in determining whether you knew the material and I liked the variety of questions. I liked the graph questions the most because they really challenged how well you knew the material.”
- “I have been told that it is best to review material within an hour after you learn it. This helps prove that as long as the smart technology is used at the end of the class as a review it will likely stick in a student's mind better. I would have likely forgotten these answers otherwise.”

A. Student Feedback Conclusions

Overall, the students provided useful feedback on the study and the ClikMe app. A majority of the negative feedback was associated with the incomplete nature of the platform and not necessarily the concept. The feedback is summarized below into themes to provide a general sentiment shared by the students on specific aspects of these efforts.

The Technology. Several students commented how typing long sentences was challenging, especially when providing feedback. This is understandable considering not all the students were familiar with the specific devices they were using. The short answer question was designed to limit the length of input from students for this reason. A number students felt there should be an indication of whether their answer was submitted or not and that the app should proceed to the next screen once submission was complete. As noted, these were mostly interface concerns and that can be easily addressed.

The Questions. A number of students acknowledged the novelty and uniqueness of the “graphical” or “coordinate-based questions”. Of course, the region of interest questions were specific to the rich responders but the comments clearly demonstrated the advantage of such advanced clickers and their ability to visualize questions. None of the traditional question responders commented on the question types other than sharing their appreciation for the visual nature of the multiple choice questions.

The CRS exercise. There was a general consensus that this was a very helpful exercise. Whether the students felt this was a good mental check for their understanding or that they thought it helped everyone participate, the student viewed the app as a positive influence in a lecture. Other students commented more generally on how the app was a good idea or that the exercise was simply “fun,” suggesting potential for better engagement. These were all positive indications, in

addition to the fact that over 80% of the students felt the experience positively influenced their topic knowledge.

VII. CONCLUSION

The emergence of touch-based smart portable devices have invigorated the development of social and professional apps that are readily available for deployment where laptops previously proved impractical to carry. It is foreseeable that these devices will make a transformational impact in the classrooms where a single device offers multiple functionalities. This work was designed to highlight how such a technology can influence student learning. Specifically, does the more natural mode of interaction afforded by a touch-based CRS improve student learning. While the results were inconclusive, the feedback and outcomes suggest a strong need for further research using advanced CRS. The students especially appreciate the highly visual aspects of interactions offered. Suggesting an advanced CRS can, in turn, engage a wider spectrum of learning styles. Therefore, from a broader sense, these efforts are aimed at inspiring the next generation of classroom technologies that will directly benefit the students.

ACKNOWLEDGMENT

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Work in Progress: Examination of Student Experiences in Immersive vs. Traditional Group Projects

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Abstract—Group projects are essential for graduate level programs. This paper presents a study on student experiences from immersive and traditional online group projects. The study revealed that student engagement in group projects is a distinguishable construct worth to be studied further. Review of conducted research on student engagement revealed also that there is a need of a reliable and valid measure of student engagement in group projects.

Keywords: *student engagement; immersive group projects; virtual worlds; reliability and internal consistency of test scores.*

I. INTRODUCTION AND BACKGROUND

Graduate programs have to emphasize on group projects, as they bring social, psychological, and learning benefits to students; and because team-work is increasingly essential in the new era of globalization and information technology (IT). So, the question is not: Should we have graduate level group projects? The question is rather: How should we optimize students' learning experiences from group projects, as well as the projects' outcomes?

Since Spring 2010, immersive group projects have been conducted at the Information Technology Systems (ITS) department at the University of Maryland University College (UMUC) in parallel with traditional online group projects. The approach is applied to the most challenging core IT course, ITEC620 Information Technology Infrastructure, which each semester has 4 face-to-face and 20 online sections. Students from several sections, taught by the same professor, are able to choose to work on an immersive or on a traditional group project with the same required deliverables: project outline and schedule, project status, peer evaluations, project presentation, presentations' evaluations, and time-sheets. The immersive group project experiences are based on virtual team-building and research activities, enabled by the futures of a virtual world. Students conduct avatar-based meetings and presentations, and participate in virtual learning tours, simulation games, and scavenger hunts [1, 2]. The focus is on enhancing course objectives through utilization of free educational resources in Second Life.

II. PURPOSE OF THE STUDY

The purpose of the presented study was to analyze student experiences from immersive and traditional online group projects, focusing on the following objectives: (1) Identify a distinguishable construct, worth to be studied further via a focused on group projects, reliable, valid, multi-dimensional

measure. (2) Review conducted research on identified construct and the availability of corresponding measurement instruments.

III. DATA

All students from seven ITEC 620 sections, taught by the same professor in 2010 and 2011, were invited to participate. Data was gathered from 107 students: 33 of which worked on an immersive group project and 74 – on a traditional group project. The participants' demographics highlights are as follows. More students with expert technical level worked on immersive projects (33% vs. 3%); but, also more newbies worked on immersive projects (6% vs. 3%). More not-working students (12% vs. 3 %) and none part-time working students were involved in immersive projects. Almost same percentages by gender worked on both kinds of projects (30% vs. 27% female; 70% vs. 73% male). More students of age over 35 worked on the immersive group projects (60 vs. 47%).

IV. METHOD

A multiple-item instrument with Likert-type scaling [10] (Table I) was developed to examine student experiences in the two types of group projects. Calculated Cronbach's α coefficients of reliability (all above 0.9) and Pearson's r correlation coefficients (all positive, average 0.5 [4]) indicate a high degree of reliability and internal consistency of the administered measurement instrument.

TABLE I. STUDY'S MULTIPLE-ITEM INSTRUMENT.

Please answer the following questions about your experiences from the Group Project. Rate each of them on the following scale:

1 = Definitely Not, 2 = No, 3 = Maybe, 4 = Yes, 5 = Definitely Yes

The group project helped me:

Q1: Develop my communication/presentation skills

Q2: Develop my technical skills

Q3: Develop my team-building skills

Q4: Develop my leadership skills

Q5: Understand better course material

The group project activities:

Q6: Challenged me academically

Q7: Developed my critical thinking and problem solving

Q8: Provoked my curiosity and sense of discovery

Q9: Were engaging and fun experience

Q10: I would like to have similar in other classes

A. Main Results

Analysis of survey's results shows that: Students working on both kinds of projects equally agreed that project activities helped them develop team-building skills (80% for traditional vs. 79% – for immersive projects). Students working on the immersive group projects were much more engaged and had fun experience (**100%** vs. 58%). The project activities helped them more to develop their communication/ presentation skills (73% vs. 69%), and technical skills (79% vs. 65%). They also would like to a much larger degree to have similar projects in other classes (82% vs. 50%). Students working on traditional online group projects were slightly more academically challenged (77% vs. 70%). The project activities helped them more to understand the course material (78% vs. 64%) and to develop their critical thinking and problem solving skills (85% vs. 79%), as well as leadership skills (68% vs. 58%).

B. Intriguing Correlations

The strong correlations ($r > 0.7$) of the survey results are as follows. For immersive projects: "Technical skills" & "Team-building skills", "Engaging and fun experience" & "Provoke curiosity and sense of discovery". For traditional projects: None. For both kinds of projects: "Academically challenging" & "Develop critical thinking and problem solving", "Communication/presentation skills" & "Technical skills", "Communication/presentation" & "Team-building skills", "Leadership skills" & "Team-building skills", "Would like similar in other classes" & "Engaging and fun experience".

Further examination of correlations reveals that students working on immersive projects would like to have similar projects in other classes mainly because of the engaging and fun experience, which is strongly correlated to provoking curiosity and sense of discovery.

Some intriguing facts based on correlations' examinations are as follows. For immersive projects: "Time spent on research" does not correlate to "Academically challenging" (0.024), but negatively correlates to "Team-building skills" (-0.371), "Leadership skills" (-0.316) and "Engaging and fun experience" (-0.306). "Time spent on presentations" correlates negatively to student "Technical level". "Time spent on all research, collaboration, and presentations" correlates negatively to "Develop critical thinking and problem solving" (-0.436) and "Engaging and fun experience" (-0.312). For traditional projects: "Time spent on research, collaboration, and presentations" correlates to "Would like similar in other classes" (0.302). Interestingly, 44% of students, who worked on traditional projects, had the technology to work on immersive projects; and 34% of them did not even check if they had the technology.

C. Distinguishable Construct

The study identified student engagement in group projects (100% for traditional vs. 58% – for immersive projects) as a distinguishable construct that deserves further reliable, valid, and detailed examination.

A. Measuring Student Engagement

"Student engagement is generally considered to be among the better predictors of learning" [3] and research on this construct date to the mid-1980s [14]. Search on student engagement research revealed there are higher education studies that assess student engagement at institutional and program level. For example: the Higher Education Research Institute (HERI) [6]; the National Survey of Student Engagement (NSSE) [13]; the Community College Survey of Student Engagement (CCSSE) [5]. There are also studies that assess student engagement at course level and specifically in online courses. For example: Handelsman et al. developed a reliable and valid measure of in class college student engagement [8]; Molinari & Huonker developed an instrument to diagnose student engagement in business school classes [12]; Robinson & Hullinger, researched student engagement in online classes [15]. However, no reliable and valid measure of student engagement in group projects was identified.

B. Developing a New Measure

Research on constructs that are relative to attitudes, emotions, and opinions involve the use of Likert-type scales. To quantify a not directly measurable construct such as "engagement", a summated ratings scale should be developed. The scale should have multiple items – each measuring something with a quantitative measurement continuum, having no right answer, and being a statement that can be rated [16]. To capture the many potential dimensions of "student engagement in group projects", an inductive approach should be applied. Focusing on student engagement definitions, students and faculty should be asked to describe what engaged in group projects students *do*, *feel*, and *think*. The responses should be used to generate items that reflect the construct and to develop a preliminary scale with potentially indicative of engagement behaviors and attitudes. The preliminary scale should be further discussed and refined by a focus group.

C. Explanatory Factor Analysis and Reliability Estimates

A study on the scale's initial data reliability and validity should be conducted in accordance with established psychometric principles for use in survey research [9]. Initial item reduction should be performed through exploratory factor analysis and examination of reliability estimates [11]. The validity of the measure should be further verified through a study on the relationship between the scale factors and, for example, students' self-reported engagement, endorsement of self-theories, and goal orientation [7].

VII. CONCLUSION

This paper presents an examination of student experiences in group projects, focusing on immersive and traditional online group projects. Main findings of the research are that students' engagement in group projects is a distinguishable construct, worth to be studied further and that there is a need of a reliable and valid measure of student engagement in group projects. The paper discusses further steps for developing a new measure of student engagement in group projects and refining its scale.

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Collaborative Learning Frameworks to Promote a Positive Learning Culture

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Abstract — Engineers are often required to make critical judgments involving decisions that extend beyond traditional discipline boundaries. This requires professional engineers to undertake ongoing learning. Much of this learning is informal, learnt on the job from peers. Hence, to prepare students for professional practice they require opportunities to experience, practise, reflect and improve their ability to work in collaborative learning environments.

While few would argue the benefits of collaborative learning these benefits are not automatic. Thoughtful design including scaffolding to motivate desired approaches and behavior is required. In this paper we report the results of several studies investigating the components of successful collaborative learning activities. We found that assessment scaffolding directed at promoting a culture of learning rather than a focus on passing a series of assessments was effective in engaging students, that formative activities allowed students to focus on learning and that learning from collaborative activities improved if the activities included variation for learning and a confirmation task. Using the results of these studies we developed two frameworks characterizing the elements of collaborative learning activities. In this paper we report investigating the capacity of these frameworks to develop an effective and integrated learning experience for students.

Keywords—collaborative learning; learning oriented assessment; formative; summative; assessment scaffolding.

I. INTRODUCTION

Stump et al [1] report criticism of traditional engineering educational strategies such as lecture, laboratories and homework because of their inadequacy in preparing students to engage in the collaborative partnerships that are expected of practicing engineers [2]. Others have reported that these traditional teaching methods often promote passive learning and compartmentalize the curriculum and run the risk of being ineffective in preparing students for the roles expected by industry [3-6]. Workplace learning is often collaborative [7]. Hence, to prepare students for professional practice they require opportunities to experience, practise, reflect and improve their ability to work in collaborative learning environments. Dana [7] reports that compared to traditional competitive or individualistic learning environments, benefits of collaborative tasks such as small group or team based learning include higher student achievement, greater use of

higher level reasoning and critical thinking skills, more positive attitudes toward the subject matter and satisfaction with the class, and better interpersonal relationships among students and between students and instructor. Furthermore, others including Prince, Springer et al and Bowen report collaborative learning's potential to positively influence students' achievement, persistence, and attitudes about learning [3, 8, 9].

In an educational context, collaboration is generally described as an approach involving joint intellectual efforts between students, or between students and the instructor [10]. While few would argue the benefits of collaborative learning these benefits are not automatic. Kirschner et al [11] suggest that group learning could be more effective than individual learning if the complexity of the material to be learnt is high. Based on cognitive load theory the collective working-memory effect predicts sharing the load of processing complex material among group participants enables more effective processing and easier comprehension of the material to be learned. Groups in effect form a distributed working memory which had greater capacity than the working memory of an individual. However, one must be careful to avoid the issue of “collective ability” reported by Willey and Gardner [12, 13]. They found that some students as part of a collaborative team were strong contributors who appeared to understand the subject learning outcomes. However, they could only demonstrate this understanding in a collaborative environment. Individually, without the support of their peers, gaps in their understanding became evident.

Thus planning a successful collaborative learning activity is a nontrivial task. Thoughtful design including scaffolding to motivate desired approaches and behavior is required. In this paper we report the results of several studies investigating the components of successful collaborative learning activities. We found that assessment scaffolding directed at promoting a culture of learning rather than a focus on passing a series of assessments was effective in engaging students, that formative activities allowed students to focus on learning and that learning from collaborative activities improved if the activities included variation for learning and a confirmation task. Using the results of these studies we developed two frameworks characterizing the elements of collaborative learning activities. In this paper we report investigating the capacity of these frameworks to develop an effective and integrated learning experience for students.

II. RESEARCH STUDIES

For several years the authors have been researching the impact of learning oriented collaborative activities on students' learning [12-15]. These activities have been both formative and summative but in each case were specifically designed to provide opportunities to learn.

In these studies, we found that:

- When activities are summative students, with some justification, tend to strategically focus on how to achieve the best mark.
- Formative collaborative activities provide a low-risk environment [16] allowing students to push their learning boundaries, make mistakes, identify gaps in their learning and have these addressed by their peers and if necessary the teaching academic.
- To assist students to make the most of the opportunities provided by formative learning activities their design should include scaffolding to promote a learning focus as opposed to a task-focused disposition in students. For example, we constantly remind students that "mistakes compress learning" and to benefit most from formative activities they should be pushing their learning boundaries until they make mistakes and / or discover what they do not know [17]. Furthermore, the formative activities should be one of the best opportunities for students to assess and receive feedback on their learning in preparation for their eventual summative assessment.
- Collaborative activities should include several cycles with increasing complexity
- Collaborative activities should include variation for learning to check understanding [18].
- Collaborative activities should be followed by an individual confirmation task allowing students to confirm their learning to address the issue of "collective ability"[12, 13].
- When activities are open-ended (have more than one answer), context dependant and have no specific endpoint for example a design problem, students learning is difficult unless it is supported by a

discourse and feedback that allows students to discover the strengths and weaknesses of their thinking.

III. FRAMEWORKS

The results of these studies informed the development of the following two frameworks to assist in the design of effective collaborative learning activities.

A. Framework 1: Collaborative Learning Activity Cycle

This framework was designed to assist in the development of collaborative learning opportunities. The first step in every collaborative learning cycle should be an individual activity that allows participants to identify gaps in their learning/ understanding. Often these individual activities are undertaken out of class. Fink reports that "*The key to getting students to do the necessary work and reading before class seems to lie in devising the right kind of in-class activities. Students need to know that the reading done beforehand will be absolutely necessary to do the in-class work and that the in-class work is an important and valuable kind of work*"[19]. The individual activity is followed by a collaborative task where participants have their learning gaps addressed by their peers while completing the activity collaboratively. Groups are then brought back together and an instructor clarifies any outstanding issues. In order to discern a difference, one must have experienced a variation from their previous experience [20]. Consequently, variation is needed for discernment, which is an important step in learning [18]. Hence, to verify understanding the instructor should subsequently vary an aspect of the activity changing the outcome and have students complete this first individually then collaboratively to check their understanding. Finally, a confirmation task that applies the learning in a new context and/or a more complex situation should be undertaken individually to confirm understanding after which the cycle is repeated.

We also recommend that a review be undertaken after any summative activity including a final exam. While completing summative activities students are often able to identify gaps in their learning through finding they were not able to answer a question or demonstrate a skill. The authors hold reviews where students can come and look at their papers, discuss their presentation, etc. These are not an opportunity for a remark but purely for students to continue learning by addressing any learning gaps identified during the summative activity.

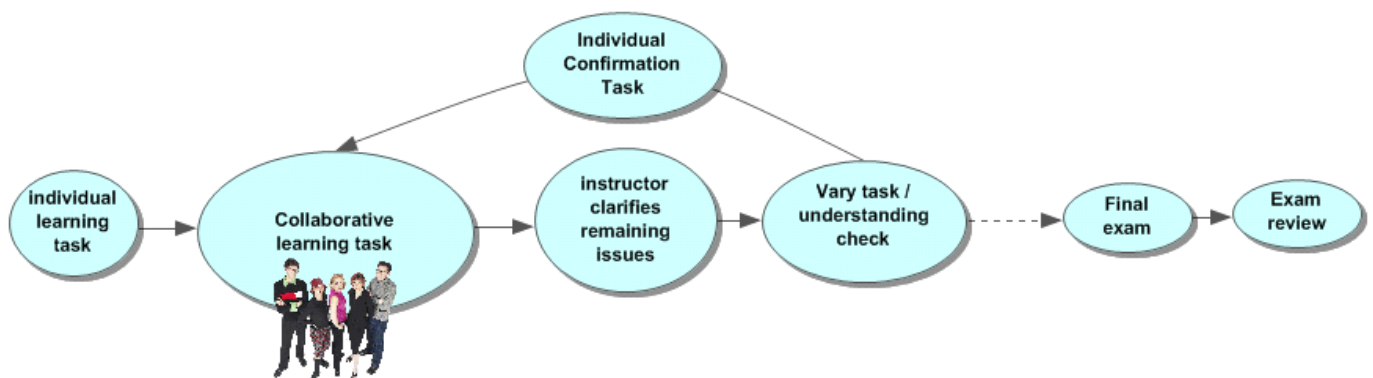


Figure 1. Collaborative Learning Activity Cycle Framework

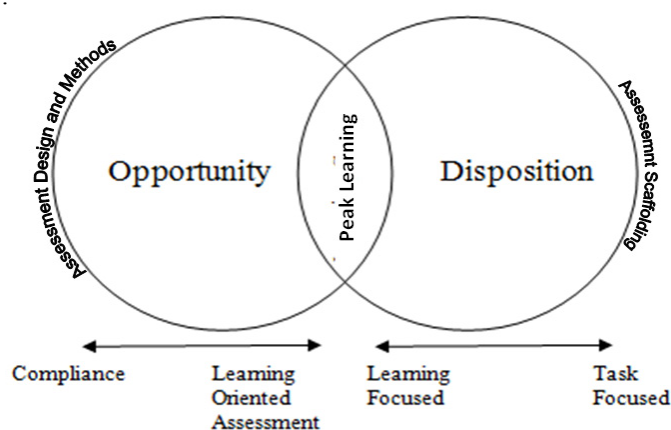


Figure 2. Opportunity and Disposition Framework

B. Framework 2: Opportunity and Disposition Framework

In this framework we suggest that learning is maximized when an assessment activity provides a well-designed learning opportunity and participants (students) approach the activity with a learning focus. Carless [21] describes learning oriented assessment as assessment designed to meet both certification and learning purposes. He characterizes learning oriented assessment as having three major components:

1. Assessment tasks as learning tasks
2. Students involvement in the assessment process (self and peer assessment) and
3. Feedback as feed forward

In the case of formative activities the certification purpose could be considered an evaluation purpose. That is, certification implies meeting the requirements of the third-party whereas evaluation can solely be for the purpose of the students evaluating their learning and identifying any gaps and/or areas that need to be addressed. Through discussions with academics examining their assessment tasks we identified a tendency to include compliance measures to encourage students to engage with these tasks. For example academic comments included, “*if I didn't give the students marks then no one would complete the exercise*” and “*if I didn't have a quiz each week students wouldn't come to the lecture*”.

Furthermore, as discussed by Sadler [22] we regularly found instances of instructors giving marks for activities that were not related to learning outcome achievement. Even when they were, they were often below the level required to demonstrate satisfactory achievement for the subject. For example:

- attendance (not participation) at tutorials
- revision of pre-requisite material
- frequency of contributions to a discussion forum (without regard to the quality of these contributions)
- quizzes containing simple questions that assessed material at a level lower than required to satisfactorily meet the course learning outcomes

- spelling and grammar
- participating in an activity for example self and peer assessment or peer-review (without regard to the quality of their contributions)

From our research we theorize that the effectiveness of assessment opportunities is often undermined by the addition of compliance measures [22]. Through structured discussions with students we found evidence that compliance measures may result in over assessing or at least over stressing conscientious students who strive to obtain the maximum grade in all activities. They sometimes describe their semester learning experience as going from “*assessment to assessment*”, “*revising material I already know to prepare for assessments*” (summative) and being so focused on so many summative assessments that there is “*no time to really learn*” by engaging deeply with the material. While poorer students conceded such measures did force them to at least participate more with such activities, we suggest that often this engagement may only be at a surface level.

We would argue that instructors should focus on developing a good learning opportunity and then design scaffolding aimed at moving students towards approaching the activity with a learning focus. Scaffolding measures could be described as being persuasive rather than punitive in that there is no summative penalty for non-compliance. Subsequently we recommend that for all assessment activities (both summative and formative) academics should explain to students:

- 1) why they designed the assessment activity the way they did.
- 2) what learning opportunities the activity provides the students
- 3) how students can evaluate their learning from the activity
- 4) how it is going to impact on their reality (enable them to see the world differently)

C. Integrating the two frameworks into a single collaborative learning activity.

The following is an example of how these two frameworks could be integrated in designing a collaborative learning activity:

- 1) **Opportunity** undertake a formative activity/assessment individually (often out of class) keeping in mind Finks [19] recommendation reported earlier in this paper.
Scaffolding Students are instructed to use the exercise as a means of identifying gaps in their understanding /learning.
- 2) **Opportunity** Students work in groups to repeat the activity/assessment collaboratively.
Scaffolding Groups are reminded to not only answer the question but to particularly focus on helping team member's address their learning gaps and through their discourse identify new ones.
- 3) **Opportunity** Course instructor leads a discussion to resolve any outstanding issues.

Scaffolding Explain to students that this is their opportunity to address any outstanding questions.

- 4) **Opportunity** The instructor varies an aspect of the problem (introducing variation) and asks students to reattempt the problem first individually and then collaboratively to evaluate their understanding.

Scaffolding Explain to students that this is their opportunity to check their understanding

- 5) **Opportunity** Students are given a new problem in a different context (and often slightly more complex) to attempt individually to confirm their understanding and identify any learning gaps.

Scaffolding Explain to students that this is their opportunity to confirm their understanding and check that they have addressed their previously identified learning gaps and / or identify new gaps in their learning.

Steps 2 to 5 are repeated. That is, in each subsequent cycle the confirmation task in step 5 became the individual task (that was originally completed in step 1).

IV. METHOD

The subject Design Fundamentals taught in English for the University of Technology, Sydney in Hong Kong was chosen as the vehicle to investigate the effectiveness of the two collaborative learning frameworks. Students had previously had difficulty with the subject material that required them to apply critical thinking and judgment. The activities designed using the frameworks are as follows:

A. Out of Class Preparation

Students were asked to complete pre-readings for each

subject topic. To both guide their reading and help them evaluate their understanding against the subject learning outcomes students were also provided an opportunity to complete a series of online formative multiple choice questions (out of class preparation). The software tool SPARK^{PLUS} [23] allows students to log on and compare their answers with their peers. That is, students are able to compare their answer (indicated by the yellow (lightest) bar in the histogram Fig 3) to the range and frequency of answers provided by their peers. Furthermore, students are able to click on the slider to view the reasons de-identified peers gave for each answer choice. Fig 3 shows that for question 2 this student chose answer D, one of their peers chose answer B, while the rest and by far the majority chose answer E. The sub window shows the reasons given by peers for those who chose answer B. The instructor deliberately chose not to provide the correct answer to the questions before the lecture sessions to encourage students to reflect when comparing their answers and reasons with those provided by their peers. In contrast to instructor feedback that often provides closure discouraging reflection, (as students accept the instructors opinion) students must use judgment in interpreting feedback provided by peers.

Before each topic was presented in class students were asked to discuss what they already knew from their pre-readings. After a general discussion and answering any questions the instructor proceeded with presenting the topic lecture. The fact that students had already completed pre-reading and partially evaluated their learning by both attempting and viewing their peers' answers to the multiple-choice questions meant that the instructor could move quickly through the fundamentals in each topic allowing the majority of time to be focused on the higher-level learning outcomes.



Figure 3. SPARK^{PLUS} results screen. The histogram shows the range of answered provided by students in the class (the logged on student's answer is identified by the yellow histogram bar). The sub window shows the reasons given by students who chose answer B. Similarly, these answers can be displayed for any individual choice (A, B, C, D or E) or for all answers simultaneously.

Furthermore, as the instructor had viewed the summary histograms reporting the range and frequency of answers to the multiple-choice questions prior to each topic they were able to identify aspects of each topic that were less understood and subsequently place more emphasis on these aspects during the lecture.

B. In Class Collaborative Learning

After each topic was presented students undertook a series of in-class formative assessments first individually and then collaboratively. These assessments took the form of a series of problems (at least 3) that increased in complexity until they were typically harder than students would encounter in their final examination. The process combined the two frameworks in line with the opportunity/scaffolding process described in Section 2 Part C summarized below.

Students first undertook each problem individually then formed into groups to repeat the exercises collaboratively. The course instructor then led a discussion to resolve any outstanding issues, then varied an aspect of the problem and asked students to reattempt the problem first individually and then collaboratively to evaluate their understanding. Finally, students were given a new more complex problem in a different context to attempt individually to confirm their understanding and identify any remaining knowledge gaps.

This process was repeated at least three times for each topic. Each stage was accompanied by associated scaffolding including the instructor explaining the assessment design (by articulating the 4 points described in Section 2 Part C) to focus students on using the collaborative activities to first identify and then resolve gaps in their understanding/learning.

These activities were evaluated using a combination of survey instruments, focus group, observations and video analysis.

V. RESULTS / DISCUSSION

All students (n =16) in the class agree to be part of this research under the condition of the usual ethical practices. Each student kept a learning diary, completed two survey instruments and participated in a focus group.

A. Pre-work Activities

In regard to the pre-work activities students reported that it helped them to get more out of the lectures as they already had some understanding of the subject material. Some students expressed a reluctance to reflect and consider the explanations provided by other students to their pre-work multiple-choice answers. In particular, they were uncomfortable when they could not decide on the correct answer and would have preferred to be told by the instructor. We expect this discomfort to dissipate as we gain more experience with running these type of activities and provide better scaffolding to support students in their endeavors. As stated earlier in this paper, in our experience if an instructor prematurely provides the correct answer to the questions than this provides a form of

closure and students tend to commit the answer to memory without reflecting on or challenging their understanding.

Overall students were positive about the opportunity the pre-work provided as demonstrated by the following free response comment:

“more easy to remember the material learned than with traditional reading learning”(sic)

B. Individual in Class Activity

In regard to the in-class individual activities students reported that it helped them identify their learning gaps and gave them the opportunity to independently reflect on their learning/understanding before commencing the group activity as articulated in the following free response comments:

“I can think myself about the whole picture first before getting into a group discussion or idea”

It was good *“to know my degree of understanding during the individual part then addressing my gaps with my team”*

C. Collaborative Activities

Many students reported that the discussions in the collaborative activities were not only useful in addressing the learning gaps identified in the individual activity *“my group members helped me fill my knowledge gaps”* but typically uncovered even more and often higher-level gaps in their learning. In the individual activities on average student's identified 2.3 gaps in their learning, while in the collaborative activities this increase to an additional 4.8 (Table 1).

They described the collaborative activities as making it *“easier to learn the content through discussion”*, that they could *“share our idea of how to solve the problem”* and *“get to know the opinions of others”* and they *“improved our problem-solving methods”(sic)*.

Students commented that the process assisted them to identify and understand what they did not know allowing them to more clearly articulate what they wanted feedback on to assist their learning.

Students also reported that the collaborative activities improve their confidence in what they had learnt commenting that: *“I can confirm my answer, increase my confidence”* it was good *“to understand what you got wrong”* and the *“group discussions gave me confidence that I could pass”*

One unanticipated result is that students commented that the collaborative activities gave them the opportunity to *“communicate in our primary language Chinese to explain ... ideas”*. This assisted greatly with overcoming the comprehension problems associated with not being instructed in your primary language.

TABLE 1: NUMBER OF LEARNING GAPS IDENTIFIED BY STUDENTS IN THEIR LEARNING JOURNALS

| Learning Gaps Identified | Average | Minimum | Maximum |
|--------------------------|---------|---------|---------|
| Individual Activities | 2.3 | 0 | 7 |
| Collaborative Activities | 4.8 | 1 | 13 |

While students were overwhelmingly positive about the format of the collaborative activities they did highlight some areas of concern including:

“sometimes you can be lazy and don't do anything” making “no contribution to the group”

and feeling apprehensive when we had “different answers in a group and no one person is sure what the correct answer is until the lecturer explains the answer in class”

D. Instructor Impact

The presented frameworks have assisted both the authors and other academics in developing collaborative learning activities. Breaking the activities down into a number of steps with specific impacts and outcomes enables one to focus on designing the opportunity, scaffolding and evaluation for each individual element, providing efficiencies for the instructor and when combined an effective and integrated learning experience for students. Furthermore, the frameworks provide a language for instructors to discuss, reflect and evaluate their design of and students their learning within collaborative activities.

The authors and a number of other projects have subsequently applied these frameworks to designing other collaborative learning activities including tutor and / or marker benchmarking [24], the development of academic standards [25] and improving research peer review [26].

VI. CONCLUSION / RECOMMENDATIONS

We found that the frameworks presented in this paper provided both efficiencies for the instructor and an effective and integrated learning experience for students. Furthermore, we recommend that all assessment activities include scaffolding directed at promoting a culture of learning in students, include variation for learning and a confirmation task. In addition, we encourage all instructors to explain to their students why they designed their assessment activity the way they did, what learning opportunities the activity provides them, how they can evaluate their learning from the activity and how it is going to impact on their reality (enable them to see the world differently).

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Work in Progress: Choose Your Own Homework

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Abstract—We are developing online interactive materials that allow students to adapt their text and homework to their own needs and interests. For example, students may specify topic areas of interest and then selected mathematics homework word problems are adapted to those areas. Using proper data management, their work can be hand-graded with feedback for the students and allowances for students to correct and resubmit their work after initial feedback in less time than is taken in grading traditional assignments. Such tools can support individualizing instruction even in large lecture classes.

Keywords—*component; differentiated instruction; online homework; open-ended problems*

I. INTRODUCTION

At Kansas State University, we are currently in our sixth year of running a version of college algebra called “Studio College Algebra,” which focuses on connecting real world phenomena to concepts taught during lecture (see [1] for a discussion of the specifics of this class). We have started building and maintaining an online “Choose Your Own Homework” (CYOH) system, in which students have the opportunity to learn about and apply college algebra concepts to various problems in a context of their interest, emphasizing categories such as student major, Hollywood, and entertainment. The system has a built in 2-step grading/feedback component in which students have the opportunity to modify their solutions based on grader comments (grading done by a human). This project aligns well with the objectives of differentiated instruction, mainly by giving students the option to customize their own assignment while addressing their interests simultaneously. The ultimate goal is to create a system with a large library of CYOH online assignments, serving as a permanent, stand-alone (textbook-independent) tool that can be incorporated into any college algebra curriculum.

II. THE MOTIVATION FOR CYOH: DIFFERENTIATED INSTRUCTION

The need for a student-centered curriculum in which students are given the chance to learn and demonstrate their knowledge lies at the heart of differentiated instruction. This instructional approach has been a key focus area in the movement to improve student learning and retention. This method of curriculum design recognizes that individual students are unique, possessing different learning styles,

interests, background knowledge and preparedness when coming into a new course. Flexibility in the approach and design of curriculum materials is a suggested method of accommodating this variance in the classroom. See [2] and [3] for more discussion of differentiated instruction.

III. DESIGN OF ASSIGNMENTS

With the CYOH system, the student chooses the context of each problem. A typical assignment is developed in the following manner. First, we begin with a particular topic of interest that all students need to master. We then select contexts in which we can explore the concept. Two examples of CYOH assignments already in place within the Studio College Algebra course at Kansas State University, for instance, cover the topics of power/exponential models and quadratic models.

The design of these initial versions of CYOH were based on

- the need for accommodating a large number of students;
- using real, relevant, and current data, and
- providing a variety of contexts

Future assignments will be modified to include questions based on contexts and settings relevant to student interests and undergraduate college life. These areas include sports, music, and various social issues. Within each context, we search through a variety of sources for real world data, and create downloadable spreadsheets containing the information we find. Examples of data sets that we have used in past assignments include the number of students taking AP tests each year, the number of apps available in Apple’s App store, and the weekly box office receipts for the movie Inception.

For each CYOH assignment, students work online, and are presented with a problem and 4 radio buttons, each corresponding to a different context. Students are welcome to click through all 4 buttons and decide which question they like. Students then download associated data/spreadsheets and carry out a mini-exploration/investigation. Typical investigations include finding a model that describes the data and deciding whether the model is appropriate, along with

using the model to predict future outcomes. Students may work on the selected problem and save their work at any time, and they may edit saved work until the deadline. Responses in the CYOH framework are allowed to be lengthy, frequently having a written component. Students may type out all their work and include written explanations (which is often necessary in application based problems, especially when asked to ‘interpret’ or ‘analyze’ an answer). See Fig. 1 for an example of how the system looks to the student.

IV. GRADING FEATURES

These new assignments are not graded automatically, but by a human. After students submit their answers for the first deadline, our departmental graders for the course are presented with a set of responses for one problem and one context on the assignments. Rather than grading several assignments one at a time, the graders are assigned to a specific problem/context. The graders are also presented with the correct answers for their question. The graders mark the number of points earned on each problem, along with providing certain comments, such as ‘error in units’ or ‘calculation error.’ The first round of grading is completed in two days, and students may log into the assignment to view their feedback. The student is shown the grader responses, and given one chance to correct their answers. Once the student submits corrected answers, the graders go to work once more, this time finalizing scores. Because grading online avoids the paper chase of collecting and returning paper homework and reading scribbled student answers, and because organizing the grading by problem is more efficient than having each grader grade all the problems for a particular section, grading the assignments twice in the new system is much quicker than grading them once in the traditional fashion. Thus this system allows additional opportunities to the students at a reduced cost in terms of grader time.

Section 5.4
Exp and Log Trend Data spreadsheet

4. After downloading the Exp and Log Trend Data spreadsheet, click on the tab at the bottom of the worksheet that corresponds to the type of problem you wish to complete (Agriculture, Hollywood, Life Expectancy, or Apps). Make sure the radio button you clicked corresponds with the spreadsheet you choose to work with.

Select the type of problem you would like to answer.

- ☐ Agriculture
- ☐ Hollywood
- ☐ Life Expectancy
- ☒ There's an App for that

Apple introduced the iTunes App store in July 2008. Since then the number of apps available has increased. The Apps worksheet has the number of active Apps available by month for the first two years of the App store. Graph the data on an x-y scatter plot.

(a) Using what you learned in studio, add an EXPONENTIAL trendline with the equation and the R^2 value displayed on the graph. What is the exponential equation that best models the data?

(b) Using your model, predict the number of apps available in June 2011. Is this value reasonable?

(c) Create a second trendline, this time a POWER function. Make sure to display the equation and the R^2 value on the graph. Enter the equation in the space provided. Does the exponential or the power function appear to be a better model of the data. Refer to the techniques in the studio to decide on which model, exponential or power, is better.

(a)

(b)

(c)

Figure 1

V. STUDENT REACTIONS

Initial student reaction to the assignments was mixed. The initial implementation only allowed for a single submission, as we had not yet discovered the increased efficiency in grading would support repeat submissions. Since the standard online assignments, which were computer graded, allowed for multiple submissions, students felt that any online assignment should allow for that. Changing the grading protocol to include an option to revise the answers has improved the student reaction.

A second issue was adapting problems to engage student interests. Only about a quarter of the students reported that they selected problems based on their interests the first time the system was used. Most students indicated they looked through the problems to find the one that looked easiest, with others just picking whatever was the first problem listed. After interviewing students, we decided we had erred in picking contexts based primarily upon common student majors. Many freshmen students do not yet have sufficient experience or engagement in their majors for that to be the most effective way of addressing their interests. After discussing ideas for engaging student interests with our office of New Student Services, we added contexts such as entertainment and technology and that increased the number of students selecting topics that they found personally engaging.

VI. FURTHER WORK

Now that we have refined our techniques so that they are succeeding in engaging student interests, we are expanding our approach in three ways. First, we are developing more assignments and contexts so that we have materials for a full semester and not just for selected assignments. Second, we are including ways for the grader to provide feedback beyond a score. Analyzing answers submitted in previous semesters has allowed us to identify about a half-dozen typical errors for each problem. We now allow graders to select from a short list of comments to help students identify their mistake. Note that the last choice in the list is always, “Non-standard error – get human help.” Finally, we are starting to experiment with use of techniques such as support vector machines to build a model for automated grading of the free response questions based on the database we have accumulated of student responses and grades they received.

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When Students Choose Competencies: Insights from the Competency-specific Engineering Portfolio Studio

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Abstract— Recent work in engineering education has made it clear that for students to be prepared to function effectively as engineers, they will need to acquire a diverse set of competencies by the time they graduate. In this research, we explored students' experiences with an innovative pedagogy—a competency-specific, engineering-preparedness portfolio studio—as a means to support students in being prepared with respect to specific competencies. In this work, we showed that when given the opportunity to choose, students select a range of competencies for quite sophisticated reasons. Furthermore, when in this studio environment for multiple experiences, students engaged in deeper reflection and meaning making about prior experiences. Finally, through this environment students supported one another through formal and informal peer learning.

Keywords- competency, portfolio, studio

I. INTRODUCTION AND BACKGROUND LITERATURE

Current work in engineering education has emphasized the link between students' engineering preparedness and the fact that they must acquire a diverse set of competencies by the time they graduate. What is less clear is exactly which competencies are most important and how to support competency development. Consider that while there is overlap in the competencies identified in the Engineer of 2020 report [1] and those embedded in the ABET accreditation criteria [2], the competencies represented in these two sources, as well as the competencies represented in other sources [3-7] are not the same. Such disparate calls in needed competencies for engineering students suggest that one challenge is how to grapple with which competencies are most significant.

Understanding what competencies students are attaining, supporting them in attaining the competencies and gathering evidence of competency attainment are also challenges. In an intriguing piece of research, Walther and his colleagues [5] demonstrated the complexities of this space through their exploration of the notion of accidental competencies including what they are, how students acquire them and how to elicit them from students. Others focus on efforts to support competency development such as the purposeful integration of on-campus and workplace environments [6], and more generally the alignment of engineering curriculum with practice (e.g., [5]-[7]).

In this research, we are exploring student experiences with an innovative pedagogy—preparedness portfolios and portfolio

studios [8]—as a means to grapple with these challenges. The core of the pedagogy involves asking students to create a professional portfolio in which they make an argument about their preparedness to engage in engineering practice. The studio environment provides a supportive social environment for working on the portfolio. In five sessions, students in the studio share and provide feedback to one another on their portfolios. For example, in the second session participants share and provide feedback on initial drafts of their portfolio statements, while in the fourth session, students share and provide feedback on the first draft of their overall portfolios.

In prior research studies, we have linked student experience with this pedagogical activity to important educational issues such as professional identity development, goal setting and monitoring, epistemological awareness, and self-efficacy (see [8] for a summary). In addition, in our work with students, we have consistently heard about the benefits of the peer learning aspect of the studio—the learning opportunities that occur because of peer review activities and general opportunities for students to learn about and from each other.

For this research, we are interested in a variation of this pedagogy in which students create a competency-specific preparedness portfolio—an argument about their preparedness to engage in a competency in a manner relevant to engineering. So, for example, in a communication-specific, engineering-preparedness portfolio, a student would make an argument about his or her preparedness to engage in the type of communication relevant to engineering. In addition, we are interested in an implementation of such an idea that involves students *selecting* the competency that they will focus on in their portfolios, which results in a studio where multiple competencies are being addressed across students.

At this point, we have offered two competency-based portfolio studios, with fourteen students in one studio and seven in the second. While some students chose to work on relatively traditional competencies (e.g., communication), other students made more non-traditional choices (e.g., leadership, adaptability). Because of the nature of the larger project of which this work is a situated within, this portfolio was not the first portfolio studio for the students to participate in—all students had completed a prior portfolio studio in which they created a "core" engineering preparedness portfolio (see methods for portfolio descriptions). For some of the students, the "core" portfolio studio was the only other studio experience

that they had had; still other students had had an additional portfolio studio in which they focused on building a course-specific preparedness portfolio. Clearly, it is possible that their prior experience with building a preparedness portfolio in a studio is significant.

In this research, we sought to use analysis of the students' portfolios and their experiences in the studio as a means to explore the general challenges raised above. To this end, we captured the students' reactions to the experience (via surveys and an exit interview with each student) and collected the student portfolios. In our paper, we use these data sources to address the following questions:

1. Which competencies did students choose and why?
2. What were students' reactions to the experience of choosing and defending a competency?
3. How did the fact that this portfolio studio came as a second or third studio experience factor into the students' experiences?
4. What role did peer learning play in students' experience?

In the sections below, we focus on answering these research questions and then discussing how the answers link back to the overall issues of helping students develop competencies and grappling with which competencies are most significant.

II. METHODS

In this study, we investigated students' experiences with the competency-specific preparedness portfolio intervention. Over the course of two separate ten-week academic quarters, junior and senior engineering students ($n = 21$) from a range of engineering disciplines participated in a studio that consisted of five two hour sessions per quarter. Specifically, we analyzed the data to address the questions cited above.

In this section, we describe the portfolio intervention and environment, participants, and data collection and analysis.

A. Intervention – Portfolio construction in a studio setting

In a social environment, engineering undergraduate students who had completed previous preparedness portfolios (i.e., a core engineering preparedness portfolio and possibly a course-based engineering preparedness portfolio) constructed a competency-specific engineering preparedness portfolio. Fourteen students had constructed only a core portfolio; seven students had developed both a core portfolio and course-based portfolio.

The focus of each of these portfolios was to make an argument about one's preparedness for future activity. Across the portfolios, the emphasis of the content and/or the source of the evidence differed. In a core portfolio, students create an argument about their preparedness for engineering (i.e., across the broad array of competencies necessary for engineering) and support their preparedness argument using evidence gathered from their life experiences. In the course-based portfolio, students make arguments about engineering in general but draw evidence from a single course. In the competency-specific

preparedness portfolio that is the focus of this paper, students created an argument about their preparedness for a specific competency within engineering (e.g., communication, leadership, or programming) and then supported their preparedness argument using evidence gathered broadly.

The competency portfolio process was the same as developing a core or course-based portfolio. In the studio environment, students constructed the competency portfolio. The studio took place in five, two-hour sessions over the course of a ten-week academic quarter. The studio environment was characterized by a great deal of student interaction in the sessions, as students worked alongside their peers to develop their individual portfolios. The students were guided by a facilitator through activities (e.g., peer review, usability testing, think aloud) that were intended to scaffold the process of developing portfolio content.

B. Participants – Engineering undergraduates

With human subject's approval, we invited engineering undergraduate juniors and seniors who had completed prior portfolios (i.e., core and/or course-based) to develop a competency portfolio. In spring 2010, 14 students (5 men and 9 women) developed a competency portfolio; in fall 2011, 7 students (4 men and 3 women) completed a competency portfolio. Students received compensation for their participation in the study.

These students, from a research extensive institution, represented nine out of ten academic departments, specifically Aeronautics and Aerospace, BioEngineering, Chemical Engineering, Civil & Environment Engineering, Computer Science & Engineering, Electrical Engineering, Human Centered Design & Engineering, Industrial & Systems Engineering, Material Science & Engineering. Some of these students were also double majoring; second major departments included Spanish, Business, Math & Natural Sciences, and Digital Arts & Experimental Media.

C. Data collection – Survey and interviews

In order to understand students' experiences, we surveyed and interviewed them at the completion of portfolio development. The survey and interview consisted of a range of questions. Both opened with questions designed to elicit information about the students' experiences generally (e.g., take-aways, surprises, challenges). Both instruments also included more targeted questions, such as questions designed to address life-long learning and questions specific to the type of portfolio being designed.

The current data analysis focused on parts of the survey and interview that elicited answers to the research questions: which competencies did they choose and why, their overall reaction to the experience of choosing and defending a competency; how the fact that this portfolio studio came as a second or third studio experience factored into the students' experiences; and the role of peer learning in their experience.

D. Data analysis – Constant comparison, deductive coding

For this study, the post-surveys and interviews served as the primary data source. While the portfolio content was not

directly analyzed, it helped to confirm findings (i.e., validating findings from the post-surveys and interviews).

Using a deductive exploratory approach [9], the second author conducted a constant comparison thematic approach to the data [9]. First, the data was read to identify potential emerging themes and confirm the potential of the research questions. Once these areas had been identified, the data was filtered for survey and interview questions that directly addressed these areas or would be potentially fruitful areas in regards to these themes. Third, the second author conducted a constant comparison [9] of this data in order to understand the findings. Finally, the first author provided confirmation in these results by providing spot checking and confirmation of the emerging results. The results below represent these 20 students along the lines of precise qualitative language (i.e., some, few, and all).

III. RESULTS

In this section we provide results around the four questions: what students chose and why, students’ reactions to developing a competency portfolio; students’ opinions about developing a second or third portfolio; and students’ experiences in peer learning. The themes discussed below represent the students’ experiences building a competency portfolio in a studio setting.

A. What students chose and why

When asked to develop a competency portfolio and given the freedom to choose the competency, students chose a range of competencies for a variety of reasons. Table 1 represents students’ chosen competencies and their reason(s) for choosing the specific competency.

As indicated in the table, the most frequently chosen competency, selected by seven students, was communication (including technical communication). This choice represented the most direct connection to the ABET learning outcomes. Among the other competencies chosen, leadership played a role in five portfolios, research in two portfolios, and adaptability in two portfolios. The remaining portfolios featured competencies that were emphasized by only one student. While some of these remaining competencies were relatively standard within the engineering education community (e.g., community, design), other competency choices were more idiosyncratic (e.g., audio tech art/design and opportunity advantage optimization). These latter choices reflect a certain amount of creativity on the part of the students.

Students' reasons for choosing the competencies also varied. While some students chose a competency based on whether they had enough artifacts, other students had more nuanced reasons. Consider the following explanations from the students:

“I chose the leadership and management, and I chose that one 'cause I felt that I probably had the most like artifacts, experiences, to support it.” (004F)

“Um, I chose design because I feel like that's one of the most important things in engineering, because whenever you do projects, or big projects, you have to -- like it's not

just laid out for you, like, you know, like a freshman class where they just” (016M)

“[I chose experimental design] because I thought it encompassed a lot of what a chemical engineer needs to know how to do to be an effective chemical engineer, so to design an experiment, ...so like in regard to choosing artifacts, I had some available under the topic of designing experiments.” (056M)

“Oh, I choose leadership and management skill, because I knew that I had in my...in the future, I want to pursue my career in management, so I thought this would be a good way to actually find out what I've been doing.” (003F)

“I chose adaptability for a challenge because I had not ever considered this quality and think it's very beneficial in the field of engineering, but it's an aspect that's often overlooked.”...(001F)

“The reason I chose that [opportunity advantage optimization], like you said, was being unique, but I also felt like that was a huge personal way that I think and operate, whether it's in the engineering world or whether it's in classroom form, that's something that actually like I'm good at and something I use, and it defines like how I'm able to achieve different things, and the one skill that sets me apart from other people. That's what I really wanted to emphasize.” (073M)

TABLE 1. RANGE OF COMPETENCIES AND REASON FOR CHOOSING ASSOCIATED COMPETENCY.

| Student | Competency | Reason |
|---------|------------------------------------|-------------------------------|
| 002M | Leadership | Competent leader |
| 003F | Leadership & Management | Future, strong experiences |
| 004F | Leadership & Management | More experiences |
| 009F | Tech. Comm. & Leadership | Enjoys public speaking |
| 074M | Leadership | Growth |
| 007F | Communication | Importance |
| 008F | Communication | Importance |
| 011F | Communication | Broad |
| 031F | Communication | More experience |
| 033F | Communication | Related to future aspirations |
| 086M | Tech. Comm. | Unique, more experience |
| 103F | Communication | Importance, broad |
| 010M | Independent Researcher | Useful for interviews, broad |
| 038F | Research | More experiences |
| 056M | Experimental Design | Importance, more experience |
| 001F | Adaptability | Challenge, engr. relevance |
| 113F | Adaptability | Importance |
| 005M | Programming | n/a |
| 016M | Design | Importance |
| 030M | Audio Tech Art/Design | n/a |
| 073M | Opportunity advantage optimization | Unique |

*n/a: students did not provide reason.

B. Students' reaction to developing a competency portfolio

All students had a positive reaction to developing a competency portfolio. Several students reported generally learning about the definition of a competency. For example, one student (086M), when asked about his chief take-aways from the experience, described learning about competencies as “enlightening”:

Well, I guess the main one was especially just finding what a competency actually was, because for the—I don't know, I think it was the first session where we actually did spend a lot of time going over the definition of a competency, and so that was really enlightening.

More specifically, these students' reactions included enthusiasm for learning about competencies generally and about various competencies that are “essential to engineering” (007F) to appreciation for learning more about their chosen competency. Some students reported gaining a sense of awareness about “other” competencies (e.g., leadership and communication) besides technical ones (e.g., programming). Even further a few students reported learning about non-traditional competencies, such as adaptability.

Many students found the process of choosing a competency to be manageably challenging. Students struggled with choosing a single competency that was still broad enough to create an entire portfolio around. While many students found choosing the competency was an enjoyable part of portfolio development, some students struggled with the requirement to focus on one competency. For some students, the narrow nature of the task helped them. In order to deal with the challenges of choosing a competency and then writing the portfolio content, many students articulated sub-competencies within the main competency. This strategy helped the students balance an emphasis on single specific competency with a desire to include content from other areas. For example, one student (011F) described this process as

Choosing ONE competency that encompassed all the points that I wanted to cover was somewhat challenging. Sometimes it felt like a stretch, trying to tie certain things back into my competency. But perhaps this was part of the process as well.

C. Students' opinions about developing a second or third portfolio

Overall, students self-reported that developing a competency portfolio was a positive experience. More specifically, most students identified that constructing different types of portfolios (i.e., core, competency, and course-based) in the same format was positive. The same structure provided all students with a common portfolio language; as well as familiarity with the process and activities. Several students commented on this familiarity being a source of comfort during portfolio development.

Many students reported a positive experience with constructing a portfolio because this time was the second or

third time developing the portfolio. These students reported that they felt comfortable with the process, so they could dig deeper into more complicated areas of portfolio development, such as identity work. In becoming comfortable with the process, one student (103F) said she finally realized that there was no “right way” to build a portfolio:

I would say the portfolio studio in the spring, I felt like I was going into something that was supposed to be really formulaic, that there was a right way, you know. Even if [instructor's name] said, like, oh, there's no right way to do this, it's your portfolio, that's—I didn't really believe it, I guess, because, um—because I had never made a portfolio before, so I didn't really have any direction...

In this example, 103F recognizes that she thought the portfolio would have a right or wrong way; she attributes this mindset to the traditions of higher education, and school more generally. As she and a few other students experienced, through the process of developing multiple portfolios in the same way these students overcame this mindset, which made them less stressed and more focused on more important content issues, rather than just getting the portfolio “right.” 103F specifically attributed this mindset to the customs of school; therefore, it was difficult for her to overcome this mentality and truly embrace and trust the “liberating constraints” [10] characteristic of the portfolios.

A few students expected the competency portfolio to be a “wrap-up” portfolio, so they anticipated a different and/or new process that integrated the prior portfolio development experiences. For these students, they understood that this studio was the last portfolio in this series, so they reported expecting a wrap-up type of portfolio. In a wrap-up portfolio they anticipated to do something different or something broader that integrated prior portfolio work. More specifically, a couple students reported being “bored” of the same studio structure and activities applied to different content. In these instances a few students reported complaints about the similar structure for multiple studios. Even in the case in which students' expectations did not align with reality, the students still found the portfolio to be beneficial.

Finally, because this portfolio was constructed after the core and/or course-based portfolio, some students self-selected not to include an experience because it was part of a different portfolio. In these cases, this mindset might have contributed to a missed opportunity for students to think deeply or in a different way about an experience. However, for many students they reported thinking about these experiences in a new way (i.e., experiences they thought about in prior portfolio development, they reflected on for the competency portfolio).

D. Students' experiences in peer learning

Many of the comments about peer learning confirm prior results about students' experience developing a portfolio in a social environment. It is promising that students continued to experience the portfolio and the studio as an activity and space that supported peer learning. However, what is unique about

this experience is that students were developing a second or third portfolio. In this case, students had worked for multiple quarters alongside and with one another on portfolio development, as well as had the same facilitator.

In this environment, many students reported learning formally and informally from each other. The intentional structures of the studio environment (i.e., peer review, discussion) provided a certain level of scaffolding of peer interaction. For example, one student (103F) described learning through the structured peer review sessions—

Um, yeah, it does. I mean 'cause we are working together and doing the peer reviews, and it made you like look at other people's ideas, and also to like think of why they think that. So, yeah, it has prepared me to -- helped me to be more accepting of other people's ideas, I guess, and also to just -- just to look at their things, and, yeah...and also it helps me think about other people's ideas, be more accepting, because I feel like if I didn't do these experiences I might not be like as accepting of other people's ideas or I wouldn't be able to interact very well in the group setting, so it really prepared me, I guess, all these experiences have prepared me to be a better college student and as an individual, so that was really good.

In some cases students commented on learning from one specific person (e.g., learning programming from a CS student). Many students acknowledged one person's portfolio decisions becoming a benchmark for the rest of the group.

While most students felt comfortable with the peer review process, a couple of students reported feeling some angst about receiving peer review (something that has come up in prior studies). One particular student (103F) reported feeling quite a bit of anxiety with peer review in her first portfolio development, and through participating in a second portfolio she overcame this fear—

This quarter I felt a lot less awkward having someone else read my writing, and it -- I -- you know, maybe I'm coming out of my shell or something like that, but I just felt more okay with it, because I had had more -- I had had peer review experiences in the past, so, um, I felt like it was really helpful, and things were always -- every single time we had a peer review, there was something that was pointed out that I never -- that never even crossed my mind, so that did improve my portfolio. So, yeah, I think that I said in the last interview that I felt like peer reviews were awkward and maybe kind of, I don't know, self-conscious, and same with giving feedback, that I would have a hard time maybe being honest, because I didn't want to be too critical, but I felt a lot more okay with that this quarter, and it just seemed a lot more helpful.

In addition to these more formal structures that provided opportunities for peer learning (e.g., peer review, discussions), students commented on informally learning from each, and in a couple cases developed a friendship and/or business relationship. For example, a student who was starting a company invited another student to be part of the startup. The student was asked to join the company based on skills seen in the studio, as well as demonstrated by the portfolio.

Finally, even though the portfolio was not a team activity, students reported feeling as though the activity and structure helped prepare them to work more and better in groups. While prior portfolios might have contributed to such things as growth in collaboration ability, students recognized it more here. For example, students described being more aware of how to work with people generally. Furthermore, after portfolio development, students recognized their growth in openness to others' ideas. Finally, the entire process reminded students about the importance of giving and receiving feedback—recognizing peers as a powerful source of knowledge. One student (074M) described this learning as a surprise—

one aspect of how seeing other people's work is definitely helpful and fulfill the creating process, because at first I didn't really know how I should structure my portfolio, but seeing from the portfolios of my other classmates, it gave me, you know better ideas of what could work for me, what could not. And it was great, because each of the classmates or participants had a pretty unique portfolio, you know in a sense.

For a few students, they developed the competency portfolio in their last quarter as an undergraduate student, so they were able to relate to where peers currently were in their process, as well as to where their peers were heading. For these students, this peer involvement provided a sense relief for the upcoming finish line, as well as a source of pride. One student (056) described this comparison as an opportunity to see alternative undergraduate pathways, which resulted in personal satisfaction about his own choices and direction—

Um, I would say I learned, um -- I think it was learning about others' experiences, actually, like learning about what type of path I had taken in chemical engineering or in engineering in general, and then comparing it to others...it was interesting to hear other people's perspective on what they had been doing with their undergraduate studies, and then comparing it to what I did and where I ended up...

IV. DISCUSSION

To summarize the findings, we found that (a) students chose a variety of competencies, (b) students felt both enjoyment and challenge in the tasks of choosing and supporting the competencies; (c) the task of creating the competency-specific portfolio was perceived as slightly easier than their previous portfolio construction (i.e., core and possibly course-based) because of their prior knowledge; and

(d) students in this experience (as in their prior ones) had significant, positive things to say about the role of peer learning. Below we discuss each of these findings.

The findings concerning students' choices demonstrate that students are indeed capable of picking important competencies for powerful reasons. It is interesting also to see what students chose. For example, the fact that seven of the portfolios emphasized communication suggests that engineering students (at least these students) are clearly hearing the message that communication is an important competency for engineering. Also, students' identification of "independent research" and "adaptability," competencies that do not typically appear on competency lists, is worthy of discussion. Creating an entire portfolio around such competencies was an opportunity for creativity and a chance for the students to differentiate themselves. With more research, we could know even more about the kind of educational experiences made possible when students take such out-of-the-norm choices.

The additional findings concerning students' reactions to creating a portfolio around a self-selected competency provide further insight into what is entailed. For example, the results remind us that such a choice can be challenging for both the student and educator. Often, a pedagogy that supports individual choice involves a dramatic shift in power dynamics. Since our portfolio studio was not a graded activity, we likely did not have to contend with some of the power dynamics that might arise if the activity were to be graded.

Given the novelty and challenge of choosing a competency in order to develop it in a portfolio, it seems that it was helpful for students to have been familiar with the portfolio model and the studio approach (i.e., because of their prior experience). At the same time, the results about student confusion clearly indicate a need to improve the studio materials and the framing of the studio activity to the students. In terms of transferability, because our results are specific to the situation where students had built at least one portfolio prior to this experience, future research could help determine if our findings would accrue to students who are building a competency-specific preparedness portfolio as their first portfolio.

Unsurprisingly, the peer learning component continued to be perceived as a valuable part of the experience. It is interesting to read students' comments about learning to work with others as preparation more generally for teamwork or even team design experiences. While this area has not been a focus of our analyses, it is interesting to pursue in the future. While we did hear about peer learning in general, we did not hear as much as we had hoped about the participants learning about other competencies through the portfolios of their peers. Clearly there are many explanations for such an observation (i.e., we didn't ask the right questions, the participants are themselves uncertain what they learned from the other portfolios, or simply that the participants learned little about other competencies from other portfolios). Because such learning represents a valuable aspect of this type of portfolio experience, this area is something we plan to investigate further.

V. CONCLUSION

While recent work in engineering education has made it clear that students will need a diverse set of competencies to function effectively as engineers, open questions exist concerning: (1) how to help students develop specific competencies and (2) how to grapple with which competencies are most significant. In this paper, we have provided evidence concerning the potential contribution of an intervention that involves students advancing their preparation for a specific competency by explaining their preparation for a competency, of their choosing. More generally, we have opened up the question of the students' role in deciding which competencies to emphasize and also how to help students explain their own preparedness.

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Implementation of Enhanced Guided Notes to Promote Students' Metacognitive Self-Regulated Learning Strategies While Learning Electric Circuit Concepts

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Abstract—The current study was part of activities in a Work in Progress paper presented at the 41st Frontiers in Education Conference that focused on activity Phase 2. This study evaluated students' metacognition using the Self-Regulated Learning (SRL) framework while learning electric circuit concepts. Two research questions guided this study: (1) Was there any improvement in metacognitive self-regulation skills while learning using the enhanced guided notes (EGN) throughout the semester?, and (2) To what degree were students' monitoring strategies reflected in regulating strategies at the beginning and end of the semester? The subjects for this study were engineering students enrolled in the Fundamental Electronics for Engineers course at Utah State University during the fall 2011. Thirteen sets of EGN were developed and used in the semester. A survey instrument developed using Butler and Cartier's SRL model was used to capture students' metacognitive self-regulated learning strategies. Participants were asked to complete the survey twice; at the beginning and end of semester. Descriptive statistics and mean differences of SRL features were used to analyze survey data. Mean differences were conducted in two ways: (1) comparing mean values of the same SRL items, and (2) comparing the level/quality between SRL features for two themes (i.e., knowledge acquisition and problem solving) at the beginning and end of the semester. The findings suggested that there were improvements in some aspects of monitoring and regulating strategies. Comparison of SRL item mean values revealed that there was increasing awareness on specific SRL items. Students did a good job in monitoring and regulating strategies for knowledge acquisition and problem solving. They successfully improved the quality of SRL feature in knowledge acquisition and maintained the quality level in problem solving. This article will also discuss the potential implications for electric circuit concepts instruction.

Keywords—*electric circuit; enhanced guided notes; metacognition; self-regulated learning*

I. INTRODUCTION

Education literature suggests that, in general, classroom activity does not stimulate students to actively engage in learning. Specifically in engineering education, many instructors still focus on writing engineering formulas and

solving problems on the whiteboard, and sometimes ask the students to check their understanding. During traditional lectures, students are generally passive [1]. Information received passively with no attendant action is not readily retained in long-term memory.

A wide body of literature suggests that students learn best when they take an active role in learning through discussing, practicing, and applying concepts and ideas [2]; however, these activities are often impractical to conduct, particularly in large classes. A major concern of most instructors is about the effectiveness of the lectures in facilitating students' learning. Studies have found that students' attention during lectures declines after 10-15 minutes [3]-[5]. According to Hartley and Davis, the amount of notes written declined over the course of a lecture [4]. Unless the students' attention is focused on what the instructor is saying, there is little chance that meaningful processing and note-taking will follow.

The use of guided notes has been perceived by students as a supportive tool that helps them concentrate on the lecture [6]. Guided notes, prepared by instructors, contain incomplete texts, diagrams, and graphs. Students need to listen to their instructor and think critically to answer the prompted questions and fill in missing parts of the information. According to Kobayashi, one of the benefits of note-taking is the development of higher-order thinking skills [7]. Although previous studies have been conducted to develop and evaluate guided notes, a limited study has been conducted by involving a variation of metacognitive prompts in electric-circuit concepts. The primary objective of this study is to develop a new type of note-taking activity that not only helps engineering students to actively engage in learning during lectures, but also help them become better at note-taking.

II. RELEVANT LITERATURE REVIEW

A. Standard Guided Notes vs. Enhanced Guided Notes

Guided notes contain incomplete information with blank spaces consisting of essential concepts, ideas, diagrams, graphs, problems, and conclusions. Standard guided notes, also

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called semi- or skeleton-notes, have been used in undergraduate teaching for quite some time. Unlike the guided notes introduced in many studies [6][8][9], the enhanced guided notes (EGN) developed by this study include questions that prompt students to assess their metacognitive self-regulated learning (SRL) strategies. This component is not present in the standard guided notes. The questions appear throughout the guided notes, including the introduction of each topic, elaboration of the theoretical concepts, and during problem solving.

Through EGN, students engage in the learning process along with their instructor during lectures. Besides conceptual theories, formulas, and problems to solve, the EGN include questions that prompt students to assess their understanding about theories, problem-solving strategies, and the principal concepts related to the topic of discussion. Compared to the traditional lecturing method in most colleges, these new learning materials and strategies may offer students an enhanced learning experience that more effectively utilize lecture time.

B. Metacognition in a Self-Regulated Learning Framework

The function of metacognition is to control other cognitive processes. Zimmerman argued that self-regulated learners are “metacognitively, motivationally, and behaviorally active participants in their own learning process” [10, p. 239]. It is clear that metacognition is a major component of one’s self-regulated learning (SRL) strategies. In this article we used metacognitive SRL strategies to represent the link between metacognition and SRL. Butler and Cartier’s SRL model described the dynamic and iterative interplay between metacognitive and cognitive activities [11]-[13] which characterize SRL as a complex, dynamic, and situated learning process [14]. The model consists of six major SRL features that interact with each other: layers of context, what individuals bring, mediating variables, task interpretation and personal objectives, SRL strategies, and cognitive strategies.

This article focused on monitoring and regulating strategies such as metacognitive SRL strategies in order to capture and understand students’ activities in knowledge acquisition and problem solving, both of which are core to learning representations. Knowledge acquisition is “the attainment of information due to instruction” [15, p. 17]. Commenting on the relationship between learning and knowledge acquisition, Chandrasekaran stated “learning is one means of knowledge acquisition” [16, p. 339]. Moreover, in discussing problem-solving activity, VanLehn summarized that different difficulty levels of problems require different amount of knowledge [17]. One of main parts of the EGN provided concepts in which students were prompted to fill in the blanks and link one concept with other concepts. Another part of EGN provided a list of problems need to be solved. Metacognitive SRL strategies represented by monitoring and regulating strategies are essential to succeed in those activities. Monitoring strategies refer to one’s ability to make sure their activities are conducted as expected. Regulating strategies, which are closely related to monitoring strategies, refer to one’s ability to execute necessary cognitive actions based on monitoring efforts. In general, the implementation of SRL strategies benefits students

in improving their learning performance. According to Zimmerman, SRL refers to students’ “self-generated thoughts, feelings, and actions which are systematically oriented toward attainment of their goals” [18, p. ix]. Applying learning strategies is important; Borkowski and Thorpe suggested that low-performing students may not understand how to relate learning strategic behavior with learning efforts [19].

C. Information Processing

According to Miller, there are three kinds of memory: sensory registers, short-term (or working), and long-term [20]. The enhanced guided notes in this study utilized the second concept of the information processing theory introduced by Miller. While the first concept is associated with the capacity of short-term memory, Miller’s second concept suggests that information processing involves gathering and representing information (i.e., encoding), holding information (i.e., retaining), and accessing the information (i.e., retrieving) when needed. Effective encoding occurs when information received is meaningful and activates one’s prior knowledge. When students pay attention to information received by the sensory registers, the information is transferred to their short-term memory.

Popularly called ‘guided notes,’ these may reduce students’ cognitive load, thereby helping engineering students to focus attention on and engage in cognitive processing of the lecture contents while developing notes for later review. Guided notes help students focus on the lecture content. During lectures, students are expected to develop understanding far beyond knowing the surface facts. Instead, when they learn something new about a discipline, they integrate that learning with prior knowledge, resulting in a growing complement of knowledge. Miller argued that once the information is processed for 5 to 20 seconds in the students’ short-term memory; it will then be transferred to their long-term memory.

III. THE STUDY

A. Study Participants

Students enrolled in Fundamental Electronics for Engineers (ETE 2210) during the fall 2011 semester at Utah State University (USU) were invited to participate. One hundred and fifteen engineering students participated in this study. Eighty-six percent of the students who completed the survey had a cumulative GPA of 3.00 or higher. Fourteen percent had a cumulative GPA range from 1.00 to 2.99. Sixty-one percent were sophomores, followed by juniors (34%), seniors (4%), and freshmen (1%).

B. The Context of the Study

The Fundamental Electronics for Engineers is a fundamental electric-circuit course required for engineering students at USU who are not enrolled in electrical engineering. Similar circuit courses are offered at universities across the country. At USU, the students are from the mechanical and aerospace engineering, civil and environmental engineering, biological and irrigation engineering, and engineering education. The 3 credit-hour course is conducted for 50

minutes three times a week. Typically, students are required to participate in 11 laboratory activities during the semester, each 3 hours long.

The course covers the study and application of direct current (DC)/alternating current (AC) and digital concepts which include circuit fundamentals, theorems, laws, analysis, components, digital design fundamentals, and combinational circuits design, equipment and measuring devices. The laboratory will include circuit design, construction and analysis of DC/AC circuits, and the use of measuring instruments, power supplies and signal generators. In one class meeting, the instructor distributed several pages of guided notes to the students. The notes were used to replace the one-way communication that was typical of class meetings. Students were asked to fill in the blank spaces found on the pages. On several parts of the guided notes, students were prompted with “what,” “why,” and “how” questions to exercise their metacognitive knowledge about the material covered. The questions were provided to trigger students’ thinking about the materials, and the instructor sometimes raised the questions in a discussion setting, for example, “What would the equivalent inductive value for two inductors in parallel be? Bigger? Smaller? Why?” At the end of the class meeting, students were asked to evaluate their learning process in a “self-reflection” section. Multiple-choice questions were provided to evaluate student understanding on some concepts in a particular EGN. In this section, students were prompted with principles and methods related to the questions. Last, a question prompts the students to check their answer, for example, “Should the lengths be in centimeters or meters? Does it matter?”

C. Data Collection and Analysis

The metacognitive SRL survey used in this study was adapted from the Inquiry Learning Questionnaire (ILQ) by Butler and Cartier based on their theoretical model (Butler & Cartier, 2004; Butler & Cartier, 2005; Butler & Winne, 1995; Cartier & Butler, 2004). Students were asked to rate themselves on a 4-point Likert scale (1 = *never*, 2 = *sometimes*, 3 = *often*, 4 = *always*). Five subscales were developed to capture students’ understanding of learning activities and

metacognitive knowledge at the beginning and end of the semester.

The subscales were task interpretation, planning, cognitive, monitoring, and regulating strategies. However, this article was focused on monitoring and regulating strategies for two reasons. First, monitoring and regulating strategies are the core components of metacognitive self-regulated learning strategies and are closely related. They represent the essence of metacognition, ‘thinking about thinking’ activity. Second, the internal reliability scores show that both monitoring and regulating strategies have relatively high Cronbach’s Alpha scores, .870 and .801, respectively.

At the beginning and end of the semester, surveys were conducted to evaluate students’ perception about the use of EGN that they had experienced in the ENGR 2210 class. One hundred and fifteen engineering students participated in this study, but only 97 valid data sets were analyzed. There were 18 suspiciously completed surveys that required us to further investigate the validity of the responses. We found those students responded to each survey item with the same answers (e.g., marked “3” for all items or block of items). A survey questionnaire was delivered two times through Qualtrics™, an online survey tool, to assess students’ understanding of learning activities and their metacognitive SRL strategies (see Tables 1a-b for the detail of the survey items). The mean values of all questionnaire items were then calculated and compared across SRL features (e.g., monitoring and regulating strategies). In addition, paired-sample *t*-tests and Chi-squared tests were applied in the analysis.

IV. FINDINGS

A. *Research Question 1: Was there any improvement in metacognitive self-regulation skills (monitoring and regulating strategies) while learning using the enhanced guided notes (EGN) throughout the semester?*

The data analysis to answer the first research question was conducted by calculating the mean values of questionnaire items between two phases, at the beginning and end of

TABLE 1A. QUESTIONNAIRE ITEMS OF MONITORING STRATEGIES

| No. | When learning and solving math, science, or engineering problems involving new concepts, I... |
|-----|---|
| 1. | Identify what I do and don’t understand |
| 2. | Check whether I can describe the main topic of the subject |
| 3. | Check whether I have found all the important concepts |
| 4. | Check what I can remember from what I learned |
| 5. | Ask myself whether my methods for solving problems are good |
| 6. | Check to make sure I come up with an answer that makes sense to me |

TABLE 1B. QUESTIONNAIRE ITEMS OF REGULATING STRATEGIES

| No. | When I have difficulties learning and solving math, science, or engineering problems involving new concepts, I... |
|-----|---|
| 1. | Review the difficult concepts again |
| 2. | Try to make links between concepts |
| 3. | Make links between concepts I am learning and problem I solved |
| 4. | Try to memorize concepts |
| 5. | Try to use better methods for working |

the semester. Comparisons of SRL item mean values between two phases revealed increasing awareness of specific items between the beginning and end of the semester. Students' monitoring strategies significantly increased on "check whether I can describe the main topic of the subject" ($M_{early} = 2.72$, $M_{end} = 2.93$, $t = -2.032$, $p = .023$); "check whether I have found all the important concepts" ($M_{early} = 2.92$, $M_{end} = 3.11$, $t = -2.179$, $p = .016$); and "ask myself whether my methods for solving problems are good" ($M_{early} = 2.82$, $M_{end} = 3.02$, $t = -2.208$, $p = .015$). No significant increase was found in regulating strategies.

B. Research Question 2: *To what degree were students' monitoring strategies reflected in regulating strategies at the beginning and end of the semester?*

To address this question, drawing on findings from the EDQ, we first defined two themes regarding the use of EGN in the course: *knowledge acquisition* and *problem solving*. While knowledge acquisition (Theme 1) consisted of questionnaire items describing learning efforts to understand concepts, problem solving (Theme 2) consisted of items describing efforts to apply relevant concepts for solving problems.

Then, we calculated the mean value of each theme for monitoring and regulating strategies (see Figure 1). With most mean scores > 3.00 , there was an indication that the students had thought about both SRL strategies often during their learning. It was clear that students monitored and made necessary adjustments during their learning activity. It was also found that students scored a bit below 3.00 on monitoring efforts for knowledge acquisition at the beginning of the semester.

Based on those mean values, we then constructed a model that would help us better interpret students' metacognitive SRL profile. The model was constructed by plotting a pair of relevant SRL features on two different axes. To help us interpret the SRL profile, we used a mean score of 3.00, which indicated "often," as the cut-off score to differentiate between low and high SRL levels. Any mean scores < 3.00 were considered low level; scores > 3.00 were considered high level. Four different quadrants, A, B, C, and D, were then constructed from the model.

For example, students' monitoring and regulating strategies were plotted as shown in Figure 2. For these strategies pairs, we named Quadrants A, B, C, and D as an *ignorant*, *in-adaptive*, *adaptive*, and *chaotic quadrants*, respectively. From students' responses on one of the monitoring items, they scored 2.93 on a monitoring effort "When learning and solving math, science, or engineering problems involving new concepts, I check whether I can describe the main topic of the subject," and scored 3.26 on regulating strategy "When I have difficulties, learning and solving math, science, and engineering problems involving new concepts, I review the difficult concepts again." For problem solving in Phase 2, students scored high on monitoring strategy "When learning and solving math, science, or engineering problems involving new concepts, I ask myself whether my methods for solving problems are good" ($M = 3.02$, $SD = .78$), and they also scored high on regulating strategy "When I have difficulties, learning and solving math, science, and engineering problems involving new concepts, I try to use better methods for working" ($M = 3.08$, $SD = .73$). They seemed to be putting efforts toward making good monitoring and regulating strategies.

TABLE 2A. KNOWLEDGE ACQUISITION & PROBLEM SOLVING CATEGORIZATION: MONITORING STRATEGIES

| No. | When learning and solving math, science, or engineering problems involving new concepts, I... | Knowledge acquisition | Problem solving |
|-----|---|-----------------------|-----------------|
| 1. | Identify what I do and don't understand | √ | |
| 2. | Check whether I can describe the main topic of the subject | √ | |
| 3. | Check whether I have found all the important concepts | √ | |
| 4. | Check what I can remember from what I learned | √ | |
| 5. | Ask myself whether my methods for solving problems are good | | √ |
| 6. | Check to make sure I come up with an answer that makes sense to me | | √ |

TABLE 2B. KNOWLEDGE ACQUISITION & PROBLEM SOLVING CATEGORIZATION: REGULATING STRATEGIES

| No. | When I have difficulties learning and solving math, science, or engineering problems involving new concepts, I... | Knowledge acquisition | Problem solving |
|-----|---|-----------------------|-----------------|
| 1. | Review the difficult concepts again | √ | |
| 2. | Try to make links between concepts | √ | |
| 3. | Make links between concepts I am learning and problem I solved | | √ |
| 4. | Try to memorize concepts | √ | |
| 5. | Try to use better methods for working | | √ |

| PHASE 1: At the beginning of semester | | | PHASE 2: At the end of semester | | |
|--|------|------|---------------------------------|------|------|
| Theme 1: <i>Knowledge Acquisition (KA)</i> | | | | | |
| SRL Features (Phase 1) | Mean | SD | SRL Features (Phase 2) | Mean | SD |
| Monitoring Strategies (KA) | 2.97 | .530 | Monitoring Strategies (KA) | 3.10 | .561 |
| Regulating Strategies (KA) | 3.09 | .525 | Regulating Strategies (KA) | 3.11 | .533 |
| Theme 2: <i>Problem Solving (PS)</i> | | | | | |
| SRL Features (Phase 1) | Mean | SD | SRL Features (Phase 2) | Mean | SD |
| Monitoring Strategies (PS) | 3.20 | .518 | Monitoring Strategies (PS) | 3.31 | .533 |
| Regulating Strategies (PS) | 3.16 | .548 | Regulating Strategies (PS) | 3.17 | .563 |

Figure 1. Mean values of the two themes across monitoring and regulating strategies

By following the mean values of the two themes across monitoring and regulating strategies in Figure 1, we focused on Quadrants C and D to describe changes on the number of participants between Phases 1 and 2 for both themes on: the same quadrant (i.e., changes on Quadrants C or D), and the different quadrant (i.e., changes from Quadrants D to C). Chi-squared tests were applied by using 80% and 20% as expected percentages of score increment and decrement in Phase 2, respectively. Our findings showed an increasing number of students, from 28_(Phase1) to 31_(Phase2) (3% of total participants; $\chi^2 = 27.801$, $df = 1$, $p = .00$) in Quadrant C and a decreasing number of students, from 13_(Phase1) to 7_(Phase2) in Quadrant D (6% of total participants; $\chi^2 = 2.813$, $df = 1$, $p = .04$) for knowledge acquisition. A similar pattern was found for problem solving; there was an increasing number of students, from 24_(Phase1) to 30_(Phase2) (6% of total participants; $\chi^2 = 20.167$, $df = 1$, $p = .00$) in Quadrant C, and a decreasing number of students, from 4_(Phase1) to 2_(Phase2) (2% of total participants; no significant difference was found) in Quadrant D.

Moreover, when investigating the transition from the *chaotic* to *adaptive* quadrants, the findings showed an increasing number of students, from 13_(Quadrant D) to 28_(Quadrant C) in Phase 1 and from 7_(Quadrant D) to 31_(Quadrant C) in Phase 2 for knowledge acquisition. The increasing number of gaps between Quadrants D and C on Phases 1 and 2 was 9% of total participants, from 15 to 24 ($\chi^2 = 8.308$, $df = 1$, $p = .00$); Chi-square tests used 80% as expected percentage of score increment. The problem-solving theme showed a similar finding; there was an increasing number of students, from 4_(Quadrant D) to 24_(Quadrant C) in Phase 1 and from 2_(Quadrant D) to 30_(Quadrant C) in Phase 2. The increasing number of gaps on Phases 1 and 2 was 8% of total participants, from 20 to 28 ($\chi^2 = 14.083$, $df = 1$, $p = .00$). These findings suggested an improvement in learning on both knowledge acquisition and problem-solving activities, in that the number of students in Quadrant C was higher than in Quadrant D, and the percentage of students increased in Quadrant C and decreased in Quadrant D, between Phases 1 and 2.

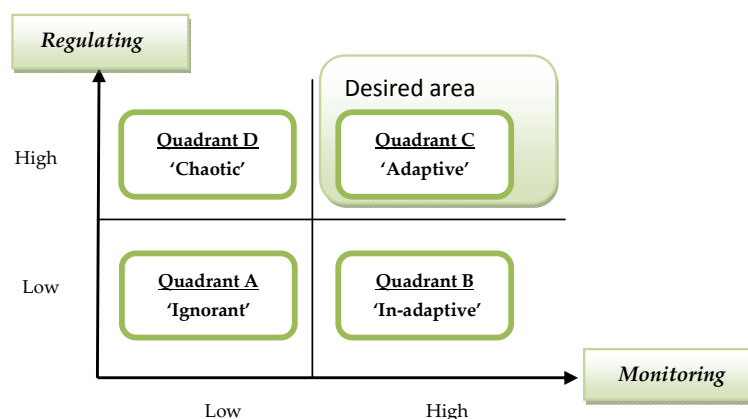


Figure 2. Level/quality categorization of SRL features

V. CONCLUSION

This study was conducted to evaluate undergraduate engineering students' metacognitive SRL strategies in an electric circuit course and identify the level/quality of the SRL features at the beginning and end of the semester. It was also the intent of this study to learn and develop a methodological framework for evaluating the extent to which students' monitoring strategies were reflected in their regulating strategies. From the findings, we found that students achieved significant improvements on some items of monitoring strategies. On the other hand, no significant improvement was found on regulating strategies. The findings indicated that the use of EGN benefits students more on their monitoring strategies. We suggested that improvements on metacognitive prompts must be conducted to trigger students to execute relevant cognition actions based on their monitoring efforts.

Furthermore, there was a transition on how students reflected their monitoring strategies on regulating strategies between the beginning and end of the semester. Positive changes were shown both in knowledge acquisition and problem solving during the semester, and more students were identified in the desired or *adaptive* area, Quadrant C, and fewer students were found in the *chaotic* area, Quadrant D. An increasing number of students in Quadrant C, problem solving, was relatively higher than on knowledge acquisition. Moreover, a relatively fewer number of students was found in Quadrant D on problem solving than on knowledge acquisition in both Phases 1 and 2. These findings may be explained by the different nature of knowledge acquisition and problem solving. Understanding concepts is a critical step in learning before students move to another activity such as problem solving. In this case, monitoring strategies were required at the same level of regulating strategies. Our findings showed that the numbers of students in Quadrant C were relatively stable on knowledge acquisition between Phases 1 and 2. However, the amount of learning resources may influence some students to focus more on executing cognitive strategies based on monitoring efforts at the beginning of the semester. During a problem-solving activity, students are triggered to find solutions. Every step in the activity should be checked to come up with a correct solution. Because problem-solving skills also rely on the understanding of concepts, it was found that the number of students in Quadrant C, problem solving, was relatively fewer than on knowledge acquisition at the beginning of the semester. It seemed that students may need more time to become acquainted with problem solving.

Lastly, from the current findings, we will use a multi-methods approach to gather more information related to students' metacognitive SRL strategies. Open-ended questions will be provided on the questionnaire to obtain more rigorous perspectives. In addition, investigating the correlation between students' metacognitive SRL strategies and learning achievement will be conducted.

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The Adjustment Experience of First-Year International Undergraduate Students in Engineering

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Abstract—To compare the challenges that domestic and international students experience in adjusting to college, we conducted a mixed-methods study of first-year undergraduate engineering students at a large public university in the Midwest. We administered a survey to all first-year engineering students. We conducted separate focus groups of domestic and international first-year students. While the domestic and international students identified similar adjustment issues, international students had more difficulty with making American friends, understanding cultural references, adapting to American food, and becoming acquainted with unfamiliar teaching methods and assignments.

Keywords—diversity; first-year students; international students

I. INTRODUCTION

In Mexico, Aarón Martínez (fictionalized name) was seen as the brightest student in his high school. He was one of the first in his area to be accepted to a top university in the United States to study engineering. When Aarón started his courses, however, he had to adjust to a new environment. He struggled to learn difficult mathematical material, and to read texts in English in history and humanities courses.

When courses in his second semester became harder, Aarón had no one on campus who really supported him. He tried communicating with other domestic and international students, but his thick Mexican accent made him feel insecure.

Eventually, he fell so far behind in assignments that he became depressed and stopped attending classes. Soon, he failed all of his courses and returned to Mexico. He concluded that college just wasn't for him, but his parents would not let him give up. His parents encouraged him to reapply, and in the fall, he returned to college with a new attitude.

Aarón studied harder, made a group of study friends, and graduated two and a half years later. Now he is pursuing a PhD in engineering. In retrospect, Aarón knows that he almost did not complete college because he never got the support that he needed. Since Aarón does not want other students to struggle as he did, he mentors Hispanic students to help them adjust to an unfamiliar learning and cultural environment.

Cases like Aarón's are common. While many domestic students also struggle through the first year, international students experience additional difficulties because they are unfamiliar with American culture and academic expectations. If

they do not receive the support that they need, they might become depressed, receive low grades, and drop out of college.

In this study, we addressed a fundamental research question: *What challenges do international students in engineering experience in adjusting to universities in the United States?* We found little previous research on the adjustment of international students. As the enrollment of internationals increases, particularly in engineering programs, it is vital to understand their adjustment experiences, so that universities can properly support them to help them succeed.

II. LITERATURE REVIEW

A. International Students in U.S. Colleges and Universities

International students are valuable to universities in the United States because they inspire intercultural learning, and they foster understanding of diversity and global issues. Upon graduation, international students can become business partners and political allies.

According to the Institute of International Education Open Doors [1], the United States hosts more international students in colleges and universities than any other country in the world. In the 2010–2011 academic year, the U.S. hosted 723,277 international students. Of the internationals studying in the U.S., 19% were in engineering. According to the American Society for Engineering Education [2], in 2010, internationals constituted 6.7% of 450,685 engineering undergraduates, 41.3% of 103,335 engineering master's students, and 54.9% of 67,369 engineering doctoral students in the U.S. Overall, internationals contributed approximately \$12 billion to the U.S. economy in 2005 [3].

B. The Adjustment of International Students

In adjusting to U.S. universities, international students experience challenges with academic expectations, language barriers, and cultural differences.

When international students first come to the U.S., they must learn how to adjust to a different classroom environment. For example, in Korea and Japan, the higher education classroom atmosphere is more competitive because students compete for a limited number of high salary jobs. On the contrary, in the U.S., the atmosphere is more cooperative, and students focus more on what interests them, rather than competing for jobs [4].

Language barriers can also hinder international students' adjustment. They may struggle to understand lectures and instructors who speak quickly and use advanced vocabulary [5]. According to Jacob [6], international students hesitate to participate in class discussions since they have difficulty understanding classroom lectures.

In general, culture can be considered the main factor in the adjustment to the U.S. Region of origin can affect cultural adjustment, and concerns vary from country to country. For example, according to Constantine et al. [7], African students value group survival, communalism, harmony, cooperation, etc., while domestic students tend to be individualistic and self-reliant. Since African students generally depend on a communal culture, they may be challenged by their absence from family when they have to rely on themselves. African students are less likely to utilize services such as professional counseling because of cultural beliefs about the treatment of mental health problems, commitment to their family values, or lack of familiarity with the services [7]. Klomegah [3] found that many international students rely on other internationals rather than on campus staff for social and emotional support.

C. Problems

Parents often push their children to study abroad, and U.S. universities vigorously advertise to pull them in. Although universities dedicate substantial efforts to attract the international students, most dedicate little effort to take care of these students once they arrive [8].

As observed by Reynolds [9] and Constantine et al. [7], when students lack support, their excitement and enthusiasm about academic life and career goals can quickly evolve into sadness and disappointment. When their experiences deviate from their initial expectations, they may have mixed feelings and confusion about how to adjust. They may experience psychological distress, physiological complaints, and mental health problems such as depression or anxiety [9].

Biases of faculty and staff can hinder the adjustment of international students. Many college counselors practice a theory based on a universal normal behavior that favors individualism, rather than collectivism. Biased counselors who favor individualism naturally conflict with international students who cannot always relate to individualism based on their own culture characteristics [10].

Like counselors, instructors may also misunderstand students' behaviors or needs. For example, an instructor might reject an international student's form of writing because it is expressed differently from academic norms in the U.S. Some instructors assume that students do not participate because they already understand the material, when in reality, the students may not be able to keep up with the pace of the lecture [5].

III. RESEARCH METHOD

To compare the contemporary challenges encountered by first-year domestic and international students in engineering, we conducted a mixed-methods study at a large public university in the Midwest, with the approval of the local Institutional Review Board (#11047). Nearly all undergraduate

students enroll full time and reside on campus. All 1,676 first-year students in engineering were invited by e-mail to participate in focus group interviews and in an anonymous online survey during the fall semester.

For the focus groups, separate recruitment e-mail messages were sent to all first-year domestic students; international students in the International Buddies in Engineering Program, which paired first-year international students with more advanced domestic student mentors; and all other first-year international students. Eighty-three students volunteered to participate in the focus group sessions. For each group, 8 to 10 participants were selected at random based on their gender and country of origin in order to ensure diversity. Not all chosen students actually participated, however.

We conducted three separate 90-minute, semi-structured focus group sessions: a session with seven domestic students, a session with four international students, and a session with seven international students in the International Buddies Program. Among the domestic students were three men and four women. Among the eleven international students were seven men and four women; there were students from Europe, Latin America, Southeast Asia, South Asia (2), East Asia (4), the Middle East, and the Caribbean. As compensation, each focus group participant received \$10 and free pizza.

The survey had 39 multiple-choice questions and two open-ended questions. It took about 20 minutes to complete. We received responses with consent from 312 domestic students and 108 international students, mirroring the actual proportions of each population of first-year engineering students.

The focus group interview protocol and the full survey appear in the first author's senior thesis [11].

IV. FOCUS GROUP RESULTS

The focus group transcripts were analyzed using a basic thematic analysis. Each of us first read through the transcripts individually, marking important ideas that were expressed by students. We then shared our notes and grouped the findings into themes. We considered a theme significant if it was raised by two or more students.

A. Communication

Past literature focused on the language barriers that international students must overcome in domestic universities. Andrade [5] and Lee [8] emphasized that international students often do not speak English fluently; therefore, they cannot communicate easily with other native speakers. However, the international focus group participants stated that they struggle less with their fluency in spoken English and more with understanding accents, American slang, cultural references, and different terminology. These particular barriers hinder conversations with the domestic students and communication with instructors and teaching assistants (TAs).

1) Accent

In the classroom, students must adjust to the accents of instructors from other countries. An accent can compound the challenge of keeping up in a fast-paced lecture. In the focus

group sessions, one international and five domestic students said that they had to adjust to an instructor's accent.

I have a professor whose accent is very difficult to understand. So I do a lot of extra studying in that class and I would say generally the classes are pretty fast. –Female, U.S.

International students have an added communication barrier when instructors cannot understand them because of their different accents.

If you take the TAs and stuff. The same thing happens if they are from another part of the world. Yeah, so sometimes you can't get your ideas across, through because maybe, you don't have good command of the language or you have a kind of accent slightly. You have to really keep repeating yourself, which can kind of be a bit annoying. –Male, South Asia

2) Cultural References

International students from countries dissimilar to the U.S. are unfamiliar with certain topics that may be interesting to Americans. Consequently, they find it arduous to join a conversation about an unknown subject.

I think, I just found it a little bit hard to make American friends. Because they have their same talkings and cultures and they become excited when they talk about some soap opera. But I know a little about that. I can't know why they are laughing or why they feel excited when they talk about some people or something. –Female, East Asia

Let's say, you have a group of Americans and you want to join in ... It can be a bit difficult because the topics they talk about aren't familiar to you ... Like for instance, "nerf wars." I had no idea about "nerf wars." So, things like that. People here, they know from like their childhood what these stuff are but you don't know these stuff. So, some conversations can be pretty one-sided. –Male, South Asia

Sometimes domestic students speak quickly and use slang without realizing that international students may not understand their conversation. International students quickly feel left out.

The most difficult problem that I face is to chatting with American people ... I find that they just talk really fast and a lot of American slang. I can't already know what they are talking about. Yeah, I can't get like all of their conversations. It's real bad. –Male, East Asia

In the classroom, some unfamiliar subjects are difficult for international students to understand. For example, domestic students take American history in high school, but international students do not always comprehend references to American history.

Maybe, some courses are easy for Americans or natives, but it's really hard for us. Like, the western history ... it's quite hard for the internationals because we really spend a lot of time on the readings of books and textbooks and extra stuff like that. Maybe the general of us can't understand what we've did so far. –Female, East Asia

3) Terminology

International students must become accustomed to the academic terminology used by instructors.

We say, 3 by 5 or something for fractions. And they say 3 over 5 and they don't get it when you say 3 by 5 or something, but it's like small things. I found that annoying when I first came. I'm trying to get used to the other way of saying it. –Female, Middle East

Internationals may also be unfamiliar with kinds of assignments and projects that are common in the U.S. Instructors often take common practices in the U.S. for granted and do not explain what they expect from their students.

In Italy usually in high school, we don't have any projects or study group. It's a very, I guess, it's more helpful and also interesting to get to know other people. Like how do they face different problems or assignments or whatever. –Female, Europe

B. Interpersonal Relationships

1) Friends

When students have difficulty with concepts or homework, they may ask a tutor or teaching assistant at office hours, use online lecture notes, or search for answers to their questions online. But most often, students ask their friends for help. Asking their friends for help is more convenient because friends are available more often and are easier to relate with.

My first step if I did have friends in those classes would be to go those friends and be like, "Hey, can you explain this to me?" cause that's a little more familiar and easier. But if I don't have friends in the classes that I've known previously or met, then I usually go to the TAs. Otherwise, I do use the online lecture notes, especially for my physics class. –Female, U.S.

Many domestic students may have the advantage of having a group of friends from high school at their same college. They can come to college feeling more comfortable with a group of people whom they already know.

I know people from high school who were in the engineering program and they're taking the same classes as me. So it's kinda like a built-in study group right there. –Female, U.S.

Unlike many domestic students, international students rarely have an immediate friend base. In fact, a disadvantage for some international students is integrating into pre-formed groups of domestic students.

Maybe just like knowing a lot of new people, and then especially my dorm, actually everybody comes from Chicago or suburb of Chicago. So, it's kinda hard to adapt with them, but actually it gets better and better. –Male, Southeast Asia

2) Working in Groups

Although domestic students are welcoming to international students, they find it easier to work with other domestic students in a study group. The domestic students mostly work with other domestic students by choice.

My [composition class] group is all domestic. It's not that I don't get along with international students, but uhm, it's whoever I can easily converse with and those are mostly domestic students. –Male, U.S.

C. Adjusting to Living

1) Roommates

Both domestic and international students had some concerns about mixing two different cultures. All students have to adjust to living with someone who may have different cultural views. Differences range from interests in music, daily schedule, religious views, or interest in American topics.

We had some, or well I had some problems adjusting 'cause we had some differences in our beliefs, our religion. By, I think by being more open-minded, I think I can deal with it. And sometimes it gets a bit too, too uncomfortable, I can just leave. –Male, U.S.

2) Food

In the focus group sessions, nine international students found it hard to adapt to Western meals. In the dining halls, there are few choices of food from their own countries, so they adapt to eating different types of food. Students complained about the high calories in meals and the lack of fresh fruits and vegetables. Also, American meal times were much earlier than meal times at home.

I would say the food is very American. And uh, if you eat too much, it will make you fat. –Male, East Asia

V. SURVEY RESULTS

Of the 422 participants who responded to the survey (25% response rate), 420 consented to allow their responses to be analyzed. Some students did not answer some questions; at a minimum, 336 responses were used, but mostly 415 to 420 responses were used. The two-sample t-test was used to check for significant differences between domestic and international students in the number of credit hours students took and the number of hours that students spent studying. The Mann-Whitney U test was used to check for significant differences for the remaining questions, where students were asked to rate a statement based on a discrete scale. When a test produced a p value of .05 or less, the difference was considered significant, and it is marked with an asterisk (*) in the tables below.

In the survey, students could respond to two open-ended questions:

- Do you have any comments you would like to share about your adjustment to the academic aspects of college?
- Do you have any additional comments you would like to share about your adjustment to the social aspects of college (for example, with regard to your interactions with peers or professors/TAs)?

Themes were created based on the students' comments and survey responses. With the exception of some noted comments, the quoted comments contain themes that were expressed by more than one student.

A. Time Management

Domestic and international students generally take the same number of credit hours of courses during their first semester, but they use their time differently for studying. International

students spend significantly more time with their humanities and social science courses ($p < .05$). See Table I.

TABLE I. TIME MANAGEMENT

| | Domestic | International |
|--|----------|---------------|
| <i>Reported to the nearest whole number 1, 2, ...</i> | | |
| How many semester hours of credit are you currently taking? | 15.20 | 15.22 |
| How many hours per week do you work outside of classes and labs for engineering, math, and science courses (homework, studying, attending office hours, etc.)? | 14.45 | 13.37 |
| How many hours per week do you work outside of classes and labs for humanities and social science courses (homework, studying, attending office hours, etc.)? | 4.14 | 5.19* |

B. Working with Others

Students occasionally do homework or study in groups, but domestic students are significantly more likely to do homework in groups, especially with students who are from their own country ($p < .05$). Both groups of students relate with their fellow classmates, yet domestic students feel that they have more in common with other classmates. See Table II.

TABLE II. WORKING WITH OTHERS

| | Domestic | International |
|---|--------------|---------------|
| <i>Rated on the scale 1 = Never, 2 = Rarely, 3 = Occasionally, 4 = Often, 5 = Very Often, 6 = Almost Always</i> | | |
| I study in groups. | 2.90 | 3.03 |
| When I study in groups, it is with people from my own country. | 4.39* | 3.47 |
| I do homework in groups. | 2.85* | 2.52 |
| When I do homework in groups, it is with people from my own country. | 4.42* | 3.20 |
| <i>Rated on the scale 1 = Don't Know, 2 = Strongly Disagree, 3 = Disagree, 4 = Neutral, 5 = Agree, 6 = Strongly Agree</i> | | |
| I can relate to the people around me in my classes. | 4.57 | 4.42 |
| I have a lot in common with other students in my classes. | 4.43* | 4.16 |

Many students were dissatisfied in different aspects with the integration of domestic and international students. Some domestic students said that they preferred not to work with international students because of the language barrier.

I hate people who can't speak English on par with a native speaker; they hinder a group's effectiveness. –Domestic

Many international students mentioned that it is difficult to integrate with domestic students who already have groups of friends. One international student from a less-represented country observed that other internationals from largely represented countries mostly associate with those from their own country instead of getting to know other students.

My comment is more for people from other countries (not the U.S.) who unlike me, came to the university with lots of others from their country and hence spend most of their time together sitting together in their huge groups and not really getting to know people out of their nationality. So maybe the larger non-U.S. groups could just gently advised to try break away from sticking together so much. –International

C. Abilities

Most students rated their self-confidence, leadership, public speaking, communication, and teamwork abilities as average to above-average. International students rated their math, science, and critical thinking skills as significantly above average ($p < .05$). See Table III.

TABLE III. ABILITIES

| | Domestic | International |
|--|----------|---------------|
| <i>Rated on the scale 1 = Lowest 10%, 2 = Below Average, 3 = Average, 4 = Above Average, 5 = Highest 10%</i> | | |
| Social self-confidence | 3.67 | 3.61 |
| Leadership ability | 3.78 | 3.63 |
| Public speaking | 3.32 | 3.31 |
| Math ability | 3.85 | 4.30* |
| Science ability | 3.76 | 4.19* |
| Verbal communication ability | 3.64 | 3.65 |
| Written communication ability | 3.62 | 3.56 |
| Ability to perform in teams | 3.92 | 3.92 |
| Critical thinking skill | 3.96 | 4.21* |

Many students commented on the importance of communication and their struggles to communicate with other students. International students mentioned that their accent and lack of familiarity of language and culture caused some problems with communicating with others.

Good verbal communication is needed in discussions, daily conversations, seeking jobs, problem solving, working in groups and almost everywhere if one wants to get involved. However, it is usually tough for international students who have disadvantages in language and culture to pick up everything in a short time. –International

Sometimes it takes a while for other students to understand what I'm trying to say but overall it has been a wonderful experience. –International

D. Course Load

Students generally agree that their classes are challenging, but not overwhelming. See Table IV.

I think the courses are challenging and require effort and time, but it is nothing that every student accepted into engineering cannot handle. –Domestic

TABLE IV. COURSE DIFFICULTY

| | Domestic | International |
|---|----------|---------------|
| <i>Rated on the scale 1 = Don't Know, 2 = Strongly Disagree, 3 = Disagree, 4 = Neutral, 5 = Agree, 6 = Strongly Agree</i> | | |
| I find my classes challenging. | 4.87 | 4.46 |
| I find my classes overwhelming. | 3.96 | 3.83 |

An international student had the difficulty of adjusting to the different academic level and the language barrier.

I have found adjusting to college academics very challenging, as my high school was a low-level school. Besides, I came from Europe two years ago, which made it even more difficult to catch up with other undergraduates (language barrier). –International

When students had difficulty with assignments or studying, they often asked their friends more than instructors or teaching assistants. International students asked questions in class and studied their notes before class significantly more often than domestic students ($p < .05$). See Table V.

TABLE V. COURSE HELP

| | Domestic | International |
|--|----------|---------------|
| <i>Rated on the scale: 1 = Never, 2 = Rarely, 3 = Occasionally, 4 = Often, 5 = Very Often, 6 = Almost Always</i> | | |
| My friends help me when I am having difficulty with the homework assignments or studying. | 4.09 | 4.10 |
| I attend the instructors' or teaching assistants' office hours when I need help. | 2.65 | 2.92 |
| I ask questions in class. | 2.85 | 3.02* |
| I study my notes before class. | 2.60 | 3.09* |

VI. DISCUSSION

A. Comparison with the Literature

1) Making Friends Is Important

According to Olivas and Li [10], international students who make friends with host students are able to reduce their stress and adapt to American culture differences. The focus group participants confirmed that making friends right away helped them feel comfortable on campus. With friends, they had people to do activities with, to eat meals with, and to help them with academics or living. One focus group participant said that he served as a “bridge” between East Asian international students and American students.

2) Homesickness

Andrade [5] cited previous research that found that international students feel more homesickness than domestic students because their families are farther away; thus, they have less support from their families. In the focus group sessions, however, international students did not mention homesickness as a major adjustment factor. With today's advanced

communication technologies, international students keep in contact regularly with their friends and families at home.

In addition, first-year domestic students also indicated that at times they missed their homes, but many were able to go home on the weekends to see friends and families. Because of travel expenses, many international students are not able to go home until winter or summer breaks. Despite these limitations, international students generally do not suffer from constant homesickness as previously believed.

3) Language Barriers

Andrade [5] stated that international students may have a more difficult time understanding lecturers because they speak quickly or use sophisticated vocabulary. As stated in section IV.A.1, however, international students agreed that they experience some difficulties in communicating with instructors, but the difficulty arises from understanding different accents. Domestic students struggle with the same communication barrier as well. In mathematics, science, and engineering, many instructors are internationals with accents, so all students need extra effort to understand and communicate with instructors.

As implied by Jacobs [6], international students are also more hesitant to participate in discussions in class because of their English proficiency level. The survey results show the opposite: internationals were more willing to ask questions in class. Recently, it seems that English proficiency may be less of an adjustment issue, because international students now have more opportunities to learn English in their home countries. Instead, as stated in section IV.A, international students have difficulty in communicating because they do not understand American cultural references and specific unfamiliar terms

B. Limitations

In the survey, some demographic information was not requested. Information such as gender and place of origin would have been useful in comparing the results. Without the demographic information, comparing the survey results with the focus group results based on location is not feasible.

Although the focus groups were diverse, many countries and regions of the world, such as Africa, were not represented. South Korea was not represented at all, even though the population of Korean students on this campus is very large.

VII. CONCLUSIONS

This study has found evidence that first-year international engineering students have more difficulties in adjusting than domestic students in communication, interpersonal relationships, and living at a university. Language poses many problems because international students are unfamiliar with American slang, cultural references, and technical terms. International students must also become familiar with American teaching methods and assignments. All students must adjust to living and working with different types of people in a new community. International students must also adjust to American food, but they do not seem to suffer homesickness.

According to the survey, in the first semester, international engineering students spend more time studying for humanities

courses than do domestic students. They study more because they require more time to read the texts and learn about subjects that are completely new to them. Domestic students are more likely to work with other students in groups. They may be friendly to other international students, but they mostly prefer working with other domestic students. The ease of communication between domestic students is a major reason to associate with each other.

All participants in the focus groups agreed that their friends were crucial in adjusting to campus. Those who had struggled at the beginning of the semester improved after making friends. International students who made friends with other internationals were able to survive the adjustment period. Those who became friends with other domestic students not only adjusted more quickly, but also understood American culture and customs better. Universities should help international students make friends with domestic students, so they can live comfortably and succeed academically.

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Work in Progress: A Holistic Approach to Re-Engineering the Freshmen Engineering Course

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Abstract— Engineering schools must strive to evolve a new paradigm for undergraduate education that recognizes the evolution of the skills and learning styles of its incoming students and prepares them to tackle society's grand challenges of the future, while at the same time increases the probability of their success in their chosen engineering program. Most researchers and experts in the field agree on some basic tenants of retention [1-3], which include developing community amongst freshmen, creating connections for freshmen through meaningful interactions with returning students and faculty, engaging freshmen in active learning environments, helping freshmen understand and internalize the vision and mission of the school, and assisting freshmen to develop a personal identity as an Engineer. This paper describes the creation of new freshmen engineering courses, taught in a new learning environment with a new instructional model that addresses all of these important tenants of retention.

Keywords- *freshmen engineering; first-year experience; multi-disciplinary; project-based learning; engineering design*

I. BACKGROUND

The freshmen introduction to engineering course has been the focus of research and experimentation for decades. There are countless models of instruction that differ in ways such as whether or not the course is general for all majors or taught to a specific major, the extent of project based instruction, and the optimal size of the class.

Common introduction to engineering classes are usually embedded in curriculum in which the institution has made a decision to admit students into a pre-engineering program in which all engineering students proceed through a set of mostly common courses. In this approach, students select a specific engineering major after several semesters of common courses. The primary rationale for this approach is to provide students with more time to explore their options before committing to a major. The challenges, of course, lie in structuring a curriculum with enough major depth that can be completed after the selection has been made. Potential advantages of admitting students into a chosen major include helping the student identify with their chosen profession earlier with more targeted classroom experiences as well as interactions with faculty in their chosen discipline. Introduction to engineering approaches vary greatly across institutions with both common and discipline specific first year programs, with some institutions requiring discipline specific or common introduction to engineering courses, while other institutions

offer only elective engineering courses or no required engineering courses in the first year [4].

It has been considered best practice for some time to include “hands-on”, team based projects in introduction to engineering courses [5-8, 9]. The type and duration of these projects, however, varies considerably and is usually constrained by class size which also varies greatly among institutions [4, 5, 7, 10, 11]. Some common introduction to engineering courses include a series of short projects or laboratory exercises to introduce students to each engineering discipline [10-13]. Others use project-based learning, in which engineering concepts are taught using a just-in-time approach in the context of a semester-long team design project, which may be discipline-specific or multidisciplinary in nature [4, 6, 14, 15, 16]. Both approaches have shown positive results and the approach taken depends on the structure of the curriculum and class sizes. There is also great variability in the number of credit hours (typically between 1 and 4) as well as the type and number of contact hours (i.e. lecture, lab, recitation) available in the introduction to engineering course, which impacts the structure and content of the course.

Common learning outcomes for the introduction to engineering classes most often include:

- Learning to work in teams
- Gaining an understanding of the Engineering Profession and Disciplines
- Developing Effective Communication Skills
- Improving skills that support academic success
- Learning and practicing the engineering design process
- Developing a sense of community with peers
- Connecting with elder peers and faculty

The specific content of freshmen introduction to engineering classes also varies considerably across institutions, depending on the desired outcomes of the course. Typical topics covered in freshmen engineering courses include the engineering design process, engineering analysis (general or discipline specific), engineering problem solving, engineering careers, academic success topics (time management, study skills, etc.), ethics, and communication skills as indicated by the learning outcomes above. Most of these topics are taught in a single semester or two semester introduction to engineering course at many universities, while at other

institutions topics are split between an engineering design/analysis course and a general university success course (not engineering-specific). Depending on the specific objectives of the course, some classes focus mostly on technical skills necessary for future courses while others focus more on non-technical 'soft' skills including teamwork and communication.

Despite the advances made across the freshmen year via these courses, retention remains a concern. Many institutions have found that active learning, working in teams, hands-on projects, and community building with peers and faculty can help improve retention and student success [1-3, 5, 7]. We hope to address many of the important factors contributing to retention and provide first year engineering students with a fun and rewarding educational experience in our new freshmen engineering courses.

II. HOLISTIC APPROACH TO FRESHMEN ENGINEERING EXPERIENCE

Our institution is a large state university which grants degrees in almost all of the engineering disciplines. Our freshmen engineering class exceeds 1,500 students. Our freshmen are admitted directly into the engineering discipline of their choice. The engineering school itself is not organized around traditional departments but instead consists of 5 schools, each of which contains faculty and students working together on theme based research and curricula. For example the School of Computing Informatics and Decisions Systems Engineering integrates faculty and students in the computer science, computer systems engineering, industrial engineering, engineering management, and informatics degree programs. Prior to the introduction of these new courses, freshmen students in each of the academic programs took a discipline specific introduction to engineering course. The content and instruction of each of these courses varied greatly both by design as well as quality of instruction. As part of a renewed commitment to improve our freshmen engineering experience incorporating the latest best practices, all aspects of these courses were analyzed leading to the new approach described in this paper. In particular we analyzed retention rates among the programs, differences in course content and project experiences, interviews with students leaving engineering and faculty focus groups to identify areas for improvement.

The discipline specific 3 credit hour Introduction to Engineering course was changed to an experiential multidisciplinary 2 hour lab and lecture course (FSE 100) complemented with a 1 hour engineering success class (ASU 101) both of which are described in detail later in the paper. Rather than create a common course that all freshmen would take, the FSE 100 classes are theme based closely aligned to the schools with projects that are closely tied and very relevant to the students' majors. The instruction of the new FSE 100 courses is primarily performed by a core of lecturers specifically hired to work together in the instruction, evaluation, and continuous improvement of the courses. The classes are taught in a newly constructed classroom environment (eSpaces) in class sizes of 40 to maximize instructional effectiveness. The new innovative eSpaces provide a collaborative learning environment in which students

sit at work tables in teams of four to complete a variety of hands-on engineering activities and projects. In eSpace, student teams have the opportunity to use electronic equipment, sensors, computers with engineering software, and hand tools to visualize designs, complete analysis tasks, and build prototypes. Throughout eSpace there are whiteboards and writeable glass wall panels to encourage student collaboration. All furniture in the room is mobile, with wheeled tool cabinets and demonstration tables, to make eSpace modular allowing for a variety of activities and courses.

All of the classes also utilize Undergraduate Teaching Assistants (UGTAs) who are current engineering students that are selected to assist in problem based instruction and to serve as role models. Each UGTA works alongside a Graduate Teaching Assistant (TA) and the faculty instructor to instruct and assist students in the laboratory portion of the course. UGTAs interact with the students primarily in class, answering questions, and offering assistance and suggestions as needed as students complete various engineering lab activities and design projects. As a near peer, the UGTA is able to relate well to students and their difficulties and successes, and offer them valuable insight that may help improve student motivation and confidence.

Unlike the FSE 100 classes, the ASU 101 classes are discipline specific and are typically taught by tenure track faculty with a class size limited to 19 with the goal of achieving a high degree of faculty-student interaction. The ASU 101 class is where students in the same major will build a community and identify most closely with their chosen profession. In the remainder of this section, the courses will be described in detail.

A. FSE 100 Introduction to Engineering

FSE100 is a 2 credit multidisciplinary lab and lecture course, where the focus is on hands-on active learning and working in teams. Class size is limited to 40 students to maximize interaction. The course introduces students to the engineering design process and some basic engineering tools and software, culminating in a 7-8 week team design project. Students attend one 50 minute lecture and one 3 hour lab each week for the entire 15 week semester. Faculty lead the lectures, introduce the labs and project, and are present in lab to assist students along with a graduate TA and UGTA. The lectures involve group discussions and student participation whenever possible, and are used to introduce and reinforce new concepts that are explored in the lab activities and projects. With the help of the tools and equipment available in eSpace, freshmen students have the opportunity to actually 'do' engineering in the lab throughout the semester. Lab activities range from building circuits, programming, or testing gear ratios to building functional prototypes for their design projects. The hands-on lab is the focus of this course, and the lecture supports the lab by providing students with the knowledge required to obtain deeper understanding of the concepts explored. Topics are presented in the context of the design project whenever possible.

There are currently three different versions of the FSE100 course in the college, each theme based with a project related to

the disciplines of students taking the course. The students are grouped by discipline into one of the three theme based versions of the course as follows: (1) ME/AE/EE: Mechanical, Aerospace, and Electrical Engineering; (2) CS/CSE/IE: Computer Science, Computer Systems Engineering, and Industrial Engineering; (3) CEE/ConstE: Civil and Environmental Engineering and Construction Engineering. The overall course structure is consistent throughout each version of the course. The general course structure begins with 6-7 weeks of introducing design and engineering topics/tools, and ending with a 7-8 week team design project. The specific engineering tools and topics covered in each School's course (with the exception of the design process), however, is related to the course 'theme' which is evident in the course design projects.

1) *Learning outcomes:* The specific learning outcomes for the FSE100 course are the same across all themes, and are closely aligned with the outcomes of introduction to engineering and introduction to engineering design courses at other institutions as well as ABET [16]. As a result of completing the FSE100 course, students will:

1. Understand and practice using the engineering design process;
2. Become familiar with tools, software, and terminology used in engineering;
3. Learn to use engineering models, physical principles, measurements and data to solve problems;
4. Gain the ability to work effectively in teams and recognize the importance of teamwork;
5. Gain basic skills in technical communication (oral presentations, technical reports, presentation of data);
6. Gain experience using basic project management techniques (scheduling, budgeting) to complete projects successfully; and
7. Use creativity to solve an engineering problem related to challenges facing our world.

2) *Major topics:* The main topics covered in FSE100 include teamwork, technical communication skills, and the engineering design process. Teamwork is learned through practice, with students working in teams of four throughout the semester. Both oral and written communication skills are emphasized through presentations and technical reports. Students gain experience working through the stages of the engineering design process in an introductory design process lesson or mini-project, and in their team design projects.

In addition to the major topics discussed above, students also explore various engineering topics related to the project theme in that particular course and are introduced to topics, tools, and software that are most relevant and useful for their major. For ME/AE/EE students, these topics typically include mechanical concepts (e.g. gears, motors, drag, friction, etc.), electrical concepts (e.g. basic circuits, power, etc.), multidisciplinary project topics (e.g. solar cell characterization, renewable energy, etc.), and general

engineering concepts including engineering drawing, measurements, and energy conservation. Other tools and software introduced to ME/AE/EE students include MATLAB, LabVIEW, and various measurement and construction tools. The course topics for CS/CSE/IE students typically include programming, robotics, manufacturing, system modeling and analysis, and various programming languages and software tools are introduced. In the third version of the course, CE/ConstE students learn and practice AutoCAD, an important tool in their field, which they use to visualize their prototypes during the design project.

3) *Project Information:* In the team design projects, students work as engineers to design and build a functional prototype of a system related to their field of study. Students are provided with a project description which describes the customer needs and constraints. Student teams are then required to work through all stages of the engineering design process to design and build a small-scale functional model. They develop engineering requirements, generate multiple conceptual designs, select a design, build a prototype, and test prototype(s), repeating steps when necessary as they experience the iterative nature of design. Modeling and analysis are included in the projects in different forms and to differing degrees, but all projects require some quantitative analysis.

All projects are multidisciplinary in nature and require students to learn and apply skills relevant to their majors. Whenever possible, students are placed in multidisciplinary teams so that they can work with students in other disciplines as well as their own. Projects that were done in Fall 2011 (and the disciplines involved in each project) include the following: Renewable Energy Power plant (including wind, water, and/or solar power) (ME/AE/EE), Solar-powered car (ME/AE/EE), Autonomous maze-solving robot (CS/CSE/IE), Sumo Robot (CS/CSE/IE), hydroelectric power generation system (CEE/ConstE). In all projects, students must design and build functional prototypes that meet functional requirements and other various project constraints. For the Renewable Energy, Solar car, and Hydroelectric projects students acquire various construction materials including wood, plastics, motors, gears, and various other raw materials from an in-class 'store' and must stay within a specified 'budget'. For the two robotics projects, each team is provided with a Lego Mindstorms NXT robot kit and use Microsoft Visual Programming Language (VPL) to program the robots.

Throughout the project, the student teams complete a series of project deliverables to document their progress and receive feedback throughout the design process. Deliverables include preliminary design proposals, progress report memos and/or meeting minutes, a final design report, a final presentation, and prototype demonstration (or competition). All project deliverables are completed as a team, and follow technical communication guidelines discussed in class.

B. ASU101: Engineering Success

ASU101 is a 1 credit lecture course intended to help students gain the skills they need to be successful students and engineers. The class meets once a week in classes of 19

students in the same major and is taught by a faculty member in that school. The small class size provides an excellent environment for the students to interact with other students in their discipline, and to make connections to a faculty member in their school. Through discussions and other active learning, students explore career opportunities in their discipline, start to develop personal goals based on their interests, and learn about the resources available at the university to help them reach their goals. This course helps students to really understand the missions and values of the school and what they can do as engineers, and helps them start to see themselves as future engineers.

1) *Learning outcomes:* The specific learning outcomes for ASU101 are all related to students gaining the skills they need to be successful students and professional engineers. These outcomes are those typically covered in introduction to engineering courses at other institutions that are not covered explicitly in our introduction to engineering course (FSE100). As a result of completing ASU101, students will:

1. Set Personal, Academic, and Career Goals to guide their success at ASU;
2. Learn about the resources available through ASU and the Ira A. Fulton Schools of Engineering that will help them to be successful in their academic careers;
3. Enhance skills to support academic success (time management, academic/career planning, study skills);
4. Understand the ethical issues related to a career in engineering and the role of academic integrity in becoming an ethical and responsible professional engineer;
5. Gain an understanding of the exciting career options available in engineering and what they can do as engineers; and
6. Become a part of the engineering community and learn about ways to become more involved in the School's and University's culture

2) *Major topics:* In the discipline specific ASU101 classes, students learn about their engineering major and career options, practice skills that will help them to be successful students and professionals, and learn about the resources available at ASU to support them through their studies. Towards the beginning of the course, students learn about engineering careers and career planning through a three week career exploration module. In the career exploration module, they first explore the wide variety of career options available to them as engineers, and the difference between engineering disciplines (majors) and job functions. In the second week, students have the unique opportunity to talk to working engineers from all engineering disciplines at the 'Career Exploration Night' event held specifically for Freshmen engineering students. The third week of the module discusses career planning, tools, and resources they can use to help them achieve their career goals.

Specific academic success related topics covered in the course include time management, learning goals, and learning from feedback. Additional topics covered in the course include opportunities in the college and/or university (e.g. clubs, research experience, etc.), Academic Integrity and Engineering Ethics, and academic resources (e.g. advising, library, etc.).

The course culminates with an oral presentation assignment, in which students complete individual or group presentations on a selected topic (topic areas vary between instructors and disciplines). Topic areas for presentations have included Engineering Failures, Top Engineering Achievements, National Academy of Engineering (NAE) Grand Challenges for Engineering, and other topics related to their interests and engineering.

III. EXPERIENCE WITH THE NEW COURSES

The new freshmen engineering courses, FSE100 and ASU101, were successfully implemented on a large scale throughout all disciplines mentioned above in the Fall 2011 semester. There were approximately 1,100 freshmen enrolled in FSE100 across 28 sections of the course (16 ME/AE/EE, 8 CS/CSE/IE, 4 CEE/ConstE). The total number of ASU101 sections across all engineering disciplines was approximately double that of FSE100, since the class size is limited to 19.

A. *Lessons learned*

Under the new instructional model, the student experience in FSE100 was more consistent across all disciplines involved with each course using an experiential lecture and lab format. The transition from a lecture based course to lab based course had a positive impact on the students' experience, as expected due to the increase in hands-on learning. Students also appreciated the opportunity to interact with and receive assistance from the faculty, TAs, and UGTAs when necessary throughout the design project and other lab activities.

The design project was well received by most students, and they enjoyed the opportunity of learning challenging concepts while actually 'doing' engineering. The opportunity to design and build a complete system from the ground up excited and motivated the students; they embraced the opportunity to act as engineers. The open-ended nature of the problem caused some students to be apprehensive and/or uncomfortable at first, but once the teams started working together on the designs they all appeared more confident that they could be successful. The multidisciplinary nature of the projects and the related lab activities completed in preparation for the projects gave students an opportunity to see how all engineering disciplines work together to solve real world problems. All students were able to complete the projects successfully and produced functional prototypes of the system explored in their project. The design project was cited as the best part of the course by many students, and students clearly were motivated by this type of activity.

One of the challenges with theme based courses is choosing a 'theme' or project that the majority of students are interested in. This fall, most students were genuinely interested in the projects, but at times it was difficult to maintain student interest

in some of the other lab activities, particularly if it was outside a student's chosen discipline. During the early labs, some students would complain or question why they needed to learn certain topics, but once they started their design projects they no longer questioned the concepts covered. Through this, we learned the importance of providing a context for all topics and activities, and the necessity of emphasizing how each lab or lecture topic connected to the course design project. As the course continues in the future, we hope to continuously improve the projects and content of the course, based on student and faculty feedback and interests.

Another challenge encountered is choosing an appropriate level of workload for the students for a 2 credit course. Although many students enjoyed the course, there were still several complaints about the workload associated with this 2 credit course. The additional workload for students also increases the grading workload for TAs and faculty as well, as it is multiplied by the number of sections taught. We are currently exploring this issue and are planning to try different forms of work and assessment to remedy this problem.

In the ASU101 courses, the student experience varied, and appeared to be dependent on the faculty and their level of involvement in the course. Overall, students enjoyed the small class environment and were happy to have met other students in their discipline and make a connection to a faculty member in their school. Students appreciated when faculty members were willing to help and showed that they cared about their success. Students enjoyed the opportunity to learn about engineering careers in the career exploration module, and especially interacting with professional engineers at the Career Exploration Night event. Student responses to academic success skills related topics in the course were mixed, with some students appreciating the information and others feeling that they already have the skills presented and thus found the course material to be 'common sense'.

B. What the students had to say

The majority of student feedback for FSE100 was positive, and the recurring theme of what students liked most was usually the 'hands-on' projects and activities. As seen in the student comments below from course evaluations, students enjoyed the opportunities to learn by 'doing' engineering.

"What I liked most about this course was EVERYTHING! Everything seemed applicable to my degree and I enjoyed the final project. I learned the most in this class and I wish there was another class like this to take next semester!"

"I like how it gave the students a glimpse of engineering. It helps show us that team work and critical thinking are essential in this line of business."

"I got to test engineering concepts and I worked with a group to design a mini-powered city to supply energy. The design project was very interesting and challenging."

"The thing that I liked most about this course was the ability to think creatively and express those ideas and opinions to my group during lab."

Most of the negative student feedback for the FSE100 course was related to the course load and grading, or the speed at which topics were covered. The number of different topics covered in some of the courses due to the multidisciplinary nature of the project was overwhelming at first for some students.

As mentioned above, student feedback on the ASU101 course varied greatly across sections and instructors. The majority of positive feedback commented on learning about engineering and their disciplines, and resources available to them as students. Student comments also indicated that they enjoyed having an opportunity to meet other freshman students in their discipline and to meet and connect with a faculty member in their school. Negative feedback included students feeling that some topics were 'useless', or that the course included too much 'busy work'.

Freshmen retention data for our Fall 2011 cohort of engineering students within the university improved to 96% from 94% the previous year. Freshmen retention within the engineering school also improved to 88% up from 85% the previous year. Drilling down into the data, retention in the mechanical engineering program increased from 85% to almost 92%. and retention in aerospace engineering increased from 79% to over 83%.

IV. CONCLUSION

Overall the introduction of our new freshmen engineering courses was very successful. Our freshmen welcomed the opportunity to "be engineers from day one". We have seen significant increased participation of our freshmen in engineering student organizations, undergraduate research programs, outreach activities and service learning projects. The quality and consistency of our instruction has improved through the coordination and communication of our freshmen engineering instructional team. Active learning is fully integrated into our courses. We are confident that we have developed a sustainable instructional model that will continuously improve over time.

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Work in Progress: A New Concept Mapping Approach in an Introductory Engineering Course: Correlation Between Students' Conceptual Understanding and Problem-Solving Skills

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Abstract—This paper presents a new concept mapping approach, called “Tree of Dynamics,” to enhance students’ perception (intuitive cognition) of the relationships among fundamental concepts in an introductory engineering dynamics course. In this approach, the relationships among concepts are represented by tree structures including roots, trunks, branches, leaves, and fruits, rather than by using linking words or phrases. A total of 76 engineering undergraduates participated in this work-in-progress study. Statistical analysis showed that moderate correlation ($r = 0.309$, $p < 0.05$) existed between students’ “tree” scores and exam scores. This research finding implies that the new “Tree of Dynamics” approach not only helps identify students’ misconceptions, but also provides a useful tool to help assess students’ problem-solving skills in the introductory engineering course.

Keywords: *Concept mapping; conceptual understanding; correlation; problem-solving skills; Tree of Dynamics*

I. INTRODUCTION

Dynamics is a sophomore-level course that nearly all students in mechanical, aerospace, civil, biological, and biomedical engineering programs are required to take. The course is widely regarded as one of the most difficult undergraduate courses to succeed in because the course covers a broad spectrum of foundational concepts such as force, velocity, angular velocity, acceleration, angular acceleration, work, energy, impulse, momentum, and vibration. Many students fail this course because they lack a solid understanding of these foundational concepts and do not know when and why to apply what concepts and associated equations.

Concept mapping, developed upon constructivist learning theory, is a graphical representation (like a flow chart) that shows how individual concepts are related to and connected with one another to form large wholes [1]. Extensive educational research has confirmed the effectiveness of concept mapping in improving student learning [2, 3]. However, in the conventional concept mapping approach, the relationships among concepts are indicated by linking words and phrases [1-3]. Students must “read” those linking words and phrases to

learn the relationships among concepts. Cognitively, this “learning by reading texts” activity might not be most effective.

To enhance students’ perception (intuitive cognition) of the relationships among concepts and also add an element of fun to learning, the author of this paper has developed a new concept mapping approach called “Tree of Dynamics.” In the new approach, the relationships among concepts are represented by tree structures including roots, trunks, branches, leaves, and fruits, instead of by using linking words or phrases. For example, the foundation on which all concepts are built can be placed as the root of a tree. The main concept can be the trunk. Concepts that derive from the main concept can be the branches.

This work-in-progress paper reports preliminary results of the new Tree of Dynamics approach recently implemented in a dynamics course. The primary assessment question is: Is there a statistically significant correlation between students’ conceptual understanding (measured by the scores of student-constructed “trees”) and students’ problem-solving skills (measured by students’ dynamics exam scores)? The answer to this question helps determine whether the Tree of Dynamics can be used as a tool to assist in assessing students’ conceptual understanding and students’ problem-solving skills as well.

II. STUDENT PARTICIPANTS

A total of 76 engineering undergraduates who took the dynamics course from the author of this paper in a recent semester participated in the present study. Among these students, 45 students (59.2%) were mechanical and aerospace engineering majors, 19 students (25%) were civil and environmental engineering majors, and 12 students (15.8%) were other majors such as biological engineering and pre-engineering students. Sixty-seven students (88.2%) were males and nine students (11.8%) were females.

III. STUDENT-CONSTRUCTED TREES AND SCORING CRITERIA

Because many students in the dynamics class did not have

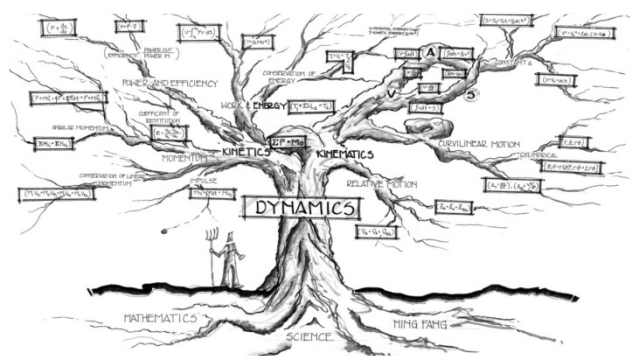


Figure 1. An example tree built by a two-student team.

prior experience with construing either concept maps or trees of dynamics, the instructor spent considerable time in teaching about concept maps and trees, and in demonstrating example maps and trees to the students. The students were then asked to construct “Trees of Dynamics” of their own by working either individually or collaboratively.

Among the 76 student participants, 35 students (46%) chose to work individually, and 41 students (54%) chose to work in teams of two to four students, forming 15 teams. Therefore, a total of 50 “trees” were generated, including 35 “trees” generated by individual students and 15 “trees” generated by student teams. As an example, Fig. 1 shows a “tree” constructed by a two-student team. Each tree was evaluated against the following criteria:

- The “tree” shows two main branches of “Kinematics” and “Kinetics,” or the “tree” shows that “kinematics” is the foundation (root) of “kinetics.” (+1).
- The “tree” correctly shows the relationships among displacement, velocity, and accelerations. (+1).
- The “tree” correctly shows that all six Dynamics principles stem from Newton’s Second Law. (+2).
- The “tree” correctly shows the hierarchal relationship between the “Principle of Work and Energy” and the “Principle of Conservation of Energy.” (+1).
- The “tree” correctly shows the hierarchal relationship between the “Principle of Linear Impulse and Momentum” and the “Principle of Conservation of Linear Momentum.” (+1).
- The “tree” correctly shows the hierarchal relationship between the “Principle of Linear Impulse and Momentum” and the “Principle of Angular Impulse and Momentum.” (+1).
- The “tree” correctly shows the hierarchal relationship between the “Principle of Angular Impulse and Momentum” and the “Principle of Conservation of Angular Momentum.” (+1).
- The “tree” shows only some (not all) hierarchal relationships among dynamics concepts (-1 point); or the “tree” does not clearly show the hierarchal relationships among dynamics concepts at all (-2).

- The number of technical errors (regarding the hierarchal relationships among dynamics concepts) contained in the “tree”: 1-2 errors (-1), 3-4 errors (-2), 5 or more errors (-3).

IV. MEASUREMENT OF STUDENTS’ PROBLEM-SOLVING SKILLS

All students took two dynamics exams to apply mathematics to get numerical answers to 31 technical problems (i.e., 31 assessment items). The coefficient of reliability (Cronbach’s alpha) of assessment instruments was 0.69.

Content validity, which was employed as a major measurement of construct validity in the present study, was measured by using Lawshe’s quantitative method [4]. Five veteran instructors were asked to respond to the following question for each assessment item: “Is the skill or knowledge measured by this item ‘essential,’ ‘useful, but not essential,’ or ‘not necessary’ to the performance of the construct?” The content validity ratio [4] was calculated based on the responses of the five veteran instructors. The results showed that the content validity ratio was nearly 1.0, which confirmed the content validity of the assessment instruments employed in the present study.

V. CORRELATION ANALYSIS

Statistical correlation analysis was performed between students’ “tree” scores and exam scores. For student teams, only team leaders’ exam and “tree” scores were used (team members had the same “tree” scores but different exam scores). The results showed that the Pearson correlation coefficient $r = 0.309$ with $p = 0.029$ (< 0.05). Therefore, moderate correlation (not causation) exists between student’s “tree” scores and exam scores, or in other words, between students’ conceptual understanding and problem-solving skills. This research finding implies that the new Tree of Dynamics approach also provides a useful tool to help evaluate students’ problem-solving skills in this important introductory engineering course.

VI. CONCLUSIONS

This paper has reported preliminary results of the new Tree of Dynamics approach implemented in a dynamics course. The results show that a statistically significant correlation ($r = 0.309$, $p < 0.05$) exists between students’ conceptual understanding (measured by “trees” scores) and problem-solving skills (measured by exam scores).

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Work in Progress: Describing the Responsibilities of Teaching Assistants in First-Year Engineering Programs

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Abstract—Many engineering programs have a common first-year curriculum required for all students. The courses tend to be large in size requiring the use of Teaching Assistants (TAs) for implementation. The responsibilities of TAs vary including lecturer, lab instructor, and grader. Despite their significant presence and varied functions, little is known about the roles of TAs as a whole across institutions. This study fills a gap in the literature by describing the roles and responsibilities of TAs in multiple first-year engineering programs across the nation, providing a foundation for future work investigating TA experiences, motivation, and identity development.

Keywords—teaching assistants, first-year engineering, survey

I. INTRODUCTION

Many engineering programs have a common first-year engineering curriculum required for all engineering students. The courses tend to be large in size requiring the use of Teaching Assistants (TAs), both graduate (GTAs) and undergraduate (UTAs). The responsibilities of TAs at each institution vary from lecturers to lab instructors to graders [1, 2]. Despite their significant presence and varied functions, little is known about TAs experiences programs as a whole. Because TAs spend significant time in undergraduate classrooms and directly impact undergraduate experiences, understanding the roles of TAs is an important step in improving and enhancing undergraduate curricula. This study fills a gap in the literature by providing descriptions of the roles and responsibilities of TAs in multiple first-year engineering programs to answer the question: *What are the commonalities and differences between how TAs are employed in different first-year engineering programs?* This study is part of a larger sequential exploratory mixed methods [3] project that examines the experiences of TAs employed in first-year programs, specifically targeting motivation and identity development.

To date, the literature related to TAs in engineering focuses on TA development programs, TA responsibilities, and TA evaluations [e.g., 1, 2, 4, 5]. Such research typically reports on the perspectives of faculty or students with regard to their TAs, not on the TAs' perspective. Recently, research has focused on the TA perspective, e.g., a study by Winters and Matusovich [6] explored TA feelings of autonomy, but more research in this area is needed. The larger project for this research builds

on existing work by focusing on TA perspectives in first-year engineering courses which has not been extensively studied. This paper is a foundational piece for that future work, where details about first-year programs were collected from program directors and administrators so that a baseline could be established and future TA participants could be identified.

II. THEORETICAL FRAMEWORK

Ultimately this work will build into the analysis of motivation and identity development of GTAs in first-year engineering programs. The theoretical framework for the larger study combines self-determination theory (SDT) and possible-selves theory (PST). SDT is a motivational framework based on three psychological needs, competence, relatedness, and autonomy [7]. Autonomy refers to a sense of ownership and control, competence refers to self-assessments of knowledge while relatedness refers to a sense of connection or belonging to a community [7]. Each of these components relates to individual intrinsic motivation where the context in which the motivation occurs is essential. PST is an identity framework wherein one looks towards who they could become in the future, both good and bad [8]. This future possible self, along with connections to your current identity and tangible goals, leads to identity development [9]. By combining these two frameworks for our future work, we can create a more complete picture of TA motivation with regard to their current context and their identity development related to future aspirations. However, before we can explore TA motivation and identity development, we must first understand the nature of the work they do in first-year programs. This study provides that knowledge foundation.

III. METHODS

Currently, our dataset includes responses to an online survey sent to 23 universities identified as having common first-year engineering curricula or programs. Based first on the researchers' familiarity with programs, an initial list of schools with first-year programs was generated. Contacts for each university were identified through internet searches and were limited to program directors, course coordinators, and general administrators. After the initial surveys were administered,

additional programs were identified by snowball sampling, where survey participants were asked to identify other universities that had first-year engineering programs. These programs were verified through another internet search which also produced contacts. Survey invitations were managed such that only one response from each school was obtained.

The survey consisted of questions focused on identifying the general size and structure of first-year engineering programs, the current responsibilities of both GTAs and UTAs, and the perceived pathways of TAs after they leave first-year programs. The survey consisted of nine main questions some of which were broken down into GTA and UTA sub questions. The survey took approximately 10 minutes to complete and asked for participants for future studies related to the motivation and identity development component of this work. To date, the response rate is 65% for a total of 15 responses, but the dataset is still growing.

IV. PRELIMINARY FINDINGS

Based on the preliminary analysis of the surveys collected, TAs who teach in first-year engineering programs are usually masters and/or PhD level students studying engineering. On average, first-year engineering programs have just over 800 students who participate in programs with varying content and structures including honors tracks, multiple course sequences, discipline specific sections, etc. Out of the responses gathered, only one university indicated that they did not use TAs in any capacity. Most UTAs involved in these programs are employed as graders while most GTAs are employed as lab or workshop instructors. See Figures 1 and 2 for more information about the responsibilities of TAs in first-year engineering programs. Note that totals can be greater than 15 since each respondent could mark more than one responsibility.

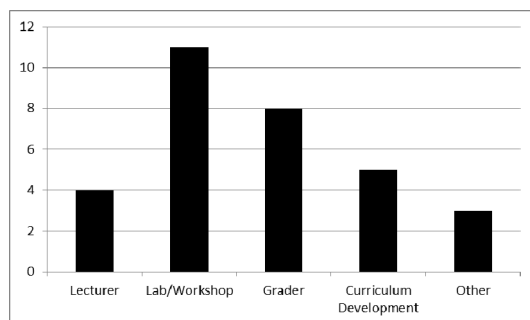


Figure 1: GTA Responsibilities in First-Year Programs

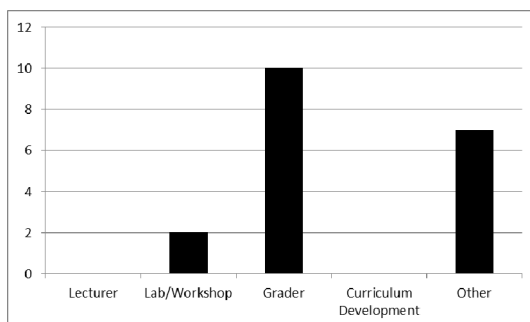


Figure 2: UTA Responsibilities in First-Year Programs

On average, from year to year administrators reported that approximately 50% of all TAs are new. They also indicated that they thought the most common reason for TA departure from teaching was simply graduating rather than pursuing other opportunities for teaching or even receiving funding to solely conduct research. As the database expands more results related to TAs roles and responsibilities in these programs will be explored.

V. CONCLUSIONS AND FUTURE WORK

The overall purpose of this survey was to gather information regarding TA involvement in first-year engineering courses. The results of this study provide a snapshot of the current state of TA involvement with these courses and set the stage for additional studies regarding TA motivation and identity development in first-year programs. We intend for the results of our future work to be used by program administrators, course coordinators, and even the GTAs themselves to help improve GTA instruction in first-year engineering programs. This baseline information on the type of work that TAs do is essential to be able to contextualize GTA experiences, motivation, and identity develop in our future studies. Future work will answer questions such as why do GTAs choose to teach in first-year programs? What causes them to leave after only a short time of teaching aside from graduating? How have their experiences affected their development as teachers? More work is needed to truly understand the impact that TAs have in first-year engineering programs, but this study is the first step in examining their importance to engineering education.

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Work in Progress: First-Year Engineering Students Development of Test Cases for Model Development

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Abstract—When developing mathematical models for authentic problems that draw on basic descriptive statistics, many first-year engineering students do not address data distribution when it is appropriate to do so. An assignment was created in association with such a problem that asks students to develop their own test cases as a means of getting students to think more deeply about the data provided and the models they are developing. In this work in progress, these test cases are analyzed. The means and standard deviations of the test cases are quite different than those provided with the problem. However, there is evidence that students may not be attending to the original problem context. Next steps are briefly indicated.

Keywords—mathematical modeling; statistics; first-year engineering

I. INTRODUCTION

Model-Eliciting Activities (MEAs), a manifestation of the models and modeling perspective [1,2], are a special case of open-ended authentic mathematical modeling problems. They have been used to provide engineering students with opportunities to engage not only in complex and iterative authentic problem solving [3] but also guided problem formulation [4], peer feedback [5,6], and reflection on solution development processes [7] and progress. At the heart of a decision to use MEAs in an engineering classroom is the desire to promote the development of critical mathematical modeling skills and the appropriate use of math and science concepts in context [e.g. 8]. MEAs help expose students' misconceptions to instructors [1] who may then provide immediate remediation or redesign instruction for later use.

This work in progress contributes to the research being conducted on first-year engineering students' iterative mathematical solutions to an MEA involving decisions with univariate data. In prior work, students' use of basic descriptive statistical concepts revealed that when a high quality model requires some quantification of the distribution of the data, student teams have a difficult time moving past looking at only measures of central tendency and variance even with instructor written feedback [9,10]. While analyzing student team solutions to this MEA and other MEAs, researchers have noted that student teams often treat the embedded test cases (data sets) as "the" problem. These test cases are intended to prompt the development of generalizable models that can be used to interpret other similar data sets. Many teams are failing to

anticipate other potential and plausible scenarios that could be used to (re)think their models.

To better understand what students think about the test cases they are given and to encourage them to think beyond these test cases, a new activity was added to the MEA implementation sequence. In this activity, students are asked to individually create data sets to further test their team's mathematical model. A preliminary study of students' explanations of their data sets was conducted [11]. The overarching finding was that students provide vague qualitative descriptions of their created data sets and little to no discussion of how their data sets further test their models. This work in progress is guided by the question: What is the nature of the data sets that students create to further test their models?

II. METHODS

This study is set in a second semester, required first-year engineering course that continues to develop students' engineering problem solving, design, and teaming skills while introducing students to computational tools (i.e. MATLAB and Excel). Sections of 120 students meet in two 110-minute periods each week led by a faculty member and supported by one graduate teaching assistant (TA) and four undergraduate TAs. Participants (~200) were enrolled in Fall 2011 [11]. Typically an additional 1800 students enroll in Spring.

This work focuses on the first MEA implemented in Fall 2011, *Just-In-Time Manufacturing (JITM)*. More complete descriptions of this MEA are provided elsewhere [e.g. 8-10]. In essence, a manufacturing company (DDT) operates in a JIT manufacturing mode and requires a shipping service to move materials between two subsidiary companies in a timely fashion. DDT needs a procedure to rank potential shipping companies. Students are provided with a historical data set that includes late arrival times (in hours) between two locations for 4 or 8 (depending on the solution iteration) shipping companies. This MEA requires students to use their knowledge of mathematics and statistics to develop a procedure (mathematical model) to rank shipping companies from most likely to least likely able to meet DDT's delivery timing needs. Teams work with the historical data sets to iteratively develop their generalizable solution. Teams formally submit a Draft 1 (which enters a double-blind peer review [12]), a Draft 2 and a Final Response (each is evaluated by a TA [13, 14]).

From the data set provided (summarized in Table I), the student teams should conclude that the mean alone cannot be used to differentiate shipping companies. Further, no shipping company has the lowest mean and lowest standard deviation combination. The shipping company with the greatest number of on-time (0 hr) deliveries (IHE) also has one of the highest number of late deliveries. Teams need to find a way to balance findings with regards to central tendency, variation, and distribution of the data in the problem context to develop their model. Many student teams struggle to recognize this need, even with peer and teaching assistant feedback [9,10].

TABLE I. SUMMARY OF DATA SET FOR *JITM* MEA. NUMBER OF HOURS LATE FOR SHIPPING RUNS FROM LINCOLN, NE TO NOBLESVILLE, IN

| Statistics | IHE ^a | DS | SC | UE | BF | DFC | NPS | FSP |
|------------|------------------|------|------|------|------|------|------|------|
| Mean | 1.49 | 1.51 | 1.49 | 1.52 | 1.54 | 1.52 | 1.60 | 1.60 |
| St. Dev. | 2.54 | 2.19 | 2.25 | 2.56 | 1.34 | 1.55 | 1.61 | 1.74 |
| Min. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Max. | 16.4 | 10.5 | 13.0 | 26.0 | 9.3 | 16.2 | 14.0 | 14.0 |
| Median | 0.74 | 0.62 | 0.65 | 0.95 | 1.13 | 1.13 | 1.06 | 1.12 |
| Counts: | | | | | | | | |
| 0 hr | 100 | 36 | 79 | 14 | 14 | 17 | 1 | 16 |
| < 2 hrs | 193 | 199 | 196 | 203 | 193 | 197 | 198 | 206 |
| > 8 hrs | 9 | 9 | 6 | 4 | 1 | 1 | 2 | 6 |

a. IHE= Iron Horse Expeditors; DS = Delphi Shipping; SC = ShipCorp; UE = United Express; BF = Blue Freight; DFC = Direct Freight Company; NPS = National Package Service; FPS = Federal Parcel Service

Between submission of Draft 2 and the Final Response, students were assigned the new task of individually developing two data sets (each with 100 data points). Students were also asked to explain how their two data sets are different from that provided (Table I) and how they further test their model [11].

All student work on MEAs are collected through a web-based interface connected to a database [15]. Students entered both their data sets and their explanations through this interface. The work of only those students who were issued a final course grade (N = 171) were considered for analysis. Eleven student teams (or 36 students) were randomly selected to bring the number of students for inclusion in this preliminary analysis up to roughly 20%. All student data sets were analyzed using basic statistics similar to that shown in Table I.

III. PRELIMINARY RESULTS

There were 47 complete data sets from 24 students. Data sets from four students were eliminated from further study because they had too few or too many data points in their data sets. Six students did not submit their data sets.

Fig. 1 summarizes the mean and standard deviation combinations of the student generated data sets versus the MEA provided data sets. Five data sets (from 3 different students) included negative values; one student explained that early arrivals are just as problematic as late ones in the JIT context [11]. While most student data contained only positive values, the combinations of high and low means and standard deviations do vary considerably, a fact that was unclear from the students' explanations alone. Table II lists three special cases. Each case contains one or more extreme data point values that seem to indicate that the student was not considering the context of the original problem. Take the maximum value of 569 hours late (24 days late)!

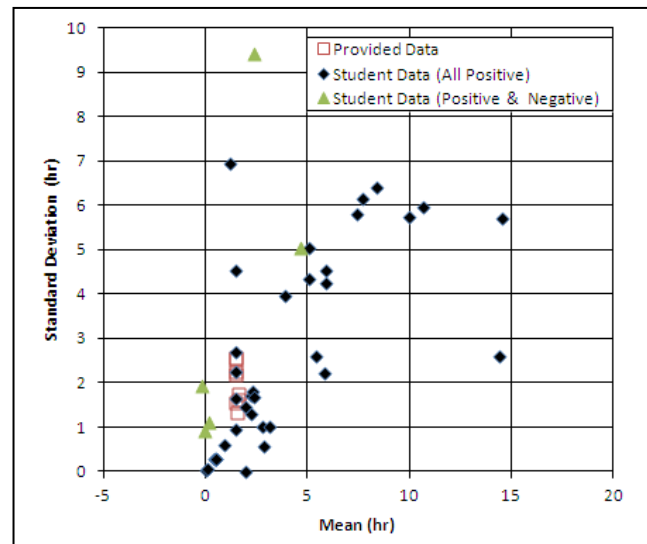


Figure 1. Mean and standard deviation combinations for provided and individually generated data sets.

TABLE II. SPECIAL CASES OF INDIVIDUALLY GENERATED DATA SETS

| Special Cases | No. of Data Sets / Different Students | Data left off Fig. 1 (mean, st. dev., max.) |
|--------------------------------|---------------------------------------|---|
| High Max. Value (70 - 569 hr) | 3 / 3 | (29.27, 49.10, 343) (17.81, 79.12, 569) |
| High Means (> 14 hr) | 3 / 3 | (24.50, 0.25, 24.99) |
| Two Extremes (All 0 or > 8 hr) | 2 / 2 | (8.98, 27.66, 134) |

IV. NEXT STEPS

A first next step is to expand the student work samples included in the analysis. This may move some seemingly odd cases into the main, such as the excessive high data point values. The second next step is to examine the distribution of the individually generated data sets. This may provide additional information about the nature of the students' data sets. For instance, a few students explained that they used a random number generator [11] but these students did not seem to acknowledge that a uniform distribution with values between 0 and 1 had been created. The degree to which uniform distributions were generated (even without explanation) can be detected from the data distributions. A third next step entails linking the nature of the data sets with students' explanations for their data sets. This may provide information about intentionality. For instance, excessively high values in a data set may have resulted from a student trying to achieve a certain mean or standard deviation. Finally, looking at which data sets the student teams carry into their Final Response (as a means of demonstrating how their model works) will reveal how teams vet the data sets for appropriateness in testing and demonstrating the functionality of their models.

The overall goal of this work is to understand how students think about data and testing their models. This work is beginning to reveal how students do and do not make sense of data they are provided to develop their models. Future findings will inform the design of the individually generated data assignment, content coverage of statistics, and classroom discussions about test cases and testing models.

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Work in Progress: Constructing a Multidisciplinary Design Project for First-Year Engineering and Computing Students

Traffic Simulation Engineering Design Challenge

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Abstract— Teaching first-year students is a balance between introducing technical content and providing perspective for students to forge connections to the context of what engineers do. Making the possible impact of engineers real and visible to introductory students in an authentic manner can be challenging. This paper describes the implementation and impact for a Traffic Simulation engineering design challenge in a freshman level “Introduction to Engineering Design” course comprised of both Engineering and Computing students at Arizona State University.

Keywords— first-year engineering, multidisciplinary, engineering design, programming, problem based learning, projects

I. INTRODUCTION

First-year engineering students are, no doubt, well aware of cars, roadways, traffic lights, etc. They may not have a perspective on the engineering efforts behind these systems however. Posing an engineering design challenge in a real world context can engage and motivate the learning of technical knowledge necessary to address this type of problem and to gain a broader context of understanding [1]. This paper describes a Traffic Simulation engineering design challenge given to freshmen multidisciplinary engineering students to introduce shared skills needed for their engineering success. The civil engineering context focuses on analysis of a transportation network and the optimization of transportation control systems after collecting data for a system involving randomness, decision making, and human users of the system in an environment with time pressure. The civil engineering nature of project theme was a guise under which a baseline of engineering skills and approaches was presented. These specific project goals are implemented within the context of a course with learning outcomes including the use of a design process, teaming skills, and communication skills. In addition, by using the Python object-oriented programming [2] language as a tool, students were introduced to engineering modeling,

incorporating computational modeling and algorithmic constructs, to complete the project-based learning course [3].

This first-year course was conceived and designed as a fusion of first-year engineering and computing students [4, 5]. Multidisciplinary teams of diverse students were tasked with applying their new-found computing skills to a scenario to model, prototype and test a system of stoplight traffic controls. The aim was to manage vehicle traffic in a simple, scaled-down road network. Students were asked to maximize the total throughput of traffic, measured as total trips between designated stations on a playing surface installed in a classroom space. The road network featured roadways, 4-way traffic lights and traffic sensors. A hardware interface with Arduino controlled the traffic lights and read optical traffic sensors. In addition to optimizing traffic throughput and controlling the traffic lights, teams of students remotely navigated a RC car through the road network with the goal of maximizing their car’s trips between a pair of designated stations.

II. PROJECT-BASED LEARNING AS CORE CURRICULA

In Arizona State University’s College of Technology and Innovation, the Department of Engineering houses both an undergraduate engineering program and multiple computing degree programs. In academic years 2010-2011 and 2011-2012, a common set of courses – Engineering 101/102 Introduction to Engineering Design I/II –with project-based learning experiences [3] was shared in the fall and spring semesters for both engineering and computing students. These courses built upon the pedagogical framework of a hands-on project spine in the undergraduate program in the Engineering Department. The programs have a core, project course each semester throughout the student’s tenure in the program from freshman to senior years. Within this multidisciplinary undergraduate engineering major there are opportunities for students to concentrate in civil and land development, electrical systems and mechanical

systems areas. Reference [4] and [5] describe the context of the undergraduate multidisciplinary engineering program, its origins, objectives and structure. Computing students can major in software engineering, applied computer science and computer systems. Reference [6] provide pedagogical descriptions of the software engineering program.

The freshman year provides some foundation in engineering process, an array of technical competencies, and practice in tackling engineering projects [7]. Table 1 lists the relevant Engineering Program learning outcomes connected to the Engineering 101 Introduction to Engineering Design course. Fig. 1 shows the matrix of core classes in the undergraduate program's first year mapped to specific learning outcomes.

TABLE I. ENGINEERING 101 COURSE LEARNING OBJECTIVES

| | |
|--------------------------------|--|
| Design (Level 1) | Recites the steps and information flow in the engineering design process and uses at least one organizational or technical tool in each step |
| Professionalism (Level 1) | Exhibits professionally appropriate behavior patterns, appreciates engineering as a learned profession and possesses daily success skills |
| Engineering Practice (Level 1) | Describes the essential elements of engineering practice including teaming |

from Engineering Program learning outcomes

Figure 1. Program learning outcomes aligned to first-year courses.

| Curriculum | Fresh 1 | | | | Fresh 2 | | | |
|----------------------|-------------------------|--------------------------|--------------------------|-------------------------|--------------------------|-------------------------|---------------------------|---------------------------------|
| | EGR 101 Intro Egr Des I | CHM 113/Science Elective | APW 265 Math of Change I | ENG 101 First-Year Comp | EGR 102 Intro Egr Des II | ENG 102 First-Year Comp | APW 266 Math of Change II | PHY 121 Mechanics |
| Outcomes | | | | | | | | EGR 104 Critical Inquiry I (L1) |
| Design | | | | | 1 | | | |
| Problem Solving | 1 | | | | | | | |
| Professionalism | 1 | | | | | | | |
| Communication | | | | 1 | | 1 | | 2 |
| Engineering Practice | 1 | | | | 1 | | | |
| Critical Thinking | | | | 1 | | 1 | | |
| Technical Competence | | 1 | 1 | | 1 | | 1 | 1 |
| Perspective | | | | 1 | | 1 | | 2 |

Number indicated levels 1-4 within each outcome the associated course aims to meet. Some Engineering Program learning outcomes are listed in detail in Table 1.

III. TRAFFIC SIMULATION PROJECT

Traffic flow and optimization was selected as an interesting application area for first-year engineering and computing students. The variety of electro-mechanical elements in the system as well as the mapping of a traffic control algorithm to the concept of a finite state machine in computing made this scenario a useful context for teaching computing outcomes in a problem based environment. Additionally, traffic flow control is an aspect of civil engineering involving logic, experimental data collection, human-centered systems, and transportation network design. This project balances engineering and

computing content within an interdisciplinary problem scoped appropriately for first-year science, technology, engineering and math (STEM) students. The learning objectives of the Engineering 101 course state that students should: (1) be aware of how team member behaviors affect teaming, (2) use design process steps and tools, (3) perform engineering modeling, (4) design solutions to problems incorporating computational and algorithmic constructs, and (5) gain experience in the object-oriented programming paradigm.

Students were given the following design brief for the Traffic Simulation engineering design challenge:

Your team will design a traffic control computing system to manage vehicle traffic in a simple road network. You are asked to maximize the total throughput of traffic, measured as total trips between designated stations. The road network features roadways, 4-way traffic lights and traffic sensors. A hardware interface controls the traffic lights and can read optical traffic sensors. In addition to optimizing traffic throughput, your team will remotely navigate a RC car through the road network to maximize your trips between designated stations.

The project requires effective teamwork and application of the software and engineering design processes (course objectives 1 and 2: teaming and design process) to perform physical analysis of the system to set light timing and create a path-finding strategy to maximize your car's trips between stations (course objectives 3 and 4: engineering modeling and incorporating computational and algorithmic constructs) to create a user interface (UI) for the traffic light controls and program a finite state machine to manage the traffic lights (course objective 5: gain experience in the object-oriented programming paradigm).

The project's basic criteria and constraints were also outlined and detailed, along with basic documentation of the hardware and software interfaces that to be used, and an explanation of the deliverables, rubrics, and rules of the project.

A. Teaming

Each section was divided into 10 teams of four students each. The Comprehensive Assessment of Team Member Effectiveness (CATME) [8, 9] team formation and team feedback tool were used to create diverse teams (by discipline, experience, gender, etc.). Teams remained the same over the entire project, spanning a standard four-month semester.

B. Design Process

As part of the pre-project preparation in the course, students were given exercises and information about a general design process and design language to be used in the class and the project. As the class was made up of students who would be advancing towards either a multidisciplinary engineering major or computing major (software engineering, applied computer science or computer systems), effort was made to include and discuss both an engineering design process and a slightly differentiated software development process. The concepts and processes introduced were the same but the differentiated language used was disciplinary specific. Table 2 lists both the

engineering design process and software development process used.

TABLE II. ENGINEERING DESIGN PROCESS AND SOFTWARE DEVELOPMENT PROCESS

| Engineering Design Process | Software Development Process |
|--|---|
| Problem Definition Criteria & Constraints Specifications | Planning Requirements Specifications |
| Concept Generation Concept Selection Architectural Design | Analysis & Design |
| Prototype Implementation Prototype Evaluation Communicate Solution | Implementation Testing & Evaluation Documenting |

To help students practice their design process steps and introduce the application area of traffic light design, an initial assignment was given to students to explore the front end of the design process. Students were asked to:

Discuss why a traffic engineer might select a “4-way stop sign” concept over a “stoplight” concept for an intersection. Engineers use numbers; what are some numbers this engineer would consider?

For individual student responses, a grading metric was used to reward (1) multiple criteria for concept decisions described and (2) a quantitative example of numbers an engineer could use as supporting evidence for a decision..

As teams developed models of a finite state machine for one traffic intersection, teams were asked to write-up an initial report and then create a poster on how they would solve the larger project at hand. Teams were asked to include a problem statement, criteria and constraints, a Finite State Machine design, a reflection on their concept generation and selection, a storyboard of the interactions at a traffic light and information on how they would implement a finite state machine in code.

Formal formative feedback on student communication of their design process was given by faculty at each project “checkpoint”, and student teams communicated their final design and experimental results. This documentation also included their graphical user interface design and final Python language algorithm code.

C. Modeling:Automated Control with a Finite State Machine

Students were required to first develop a Finite State Machine that would control one four-way stoplight intersection, and then second control a five intersection system as pictured in Fig. 2 and Fig. 3. Sensor inputs to the algorithm included sensors at each approach to an intersection, and the algorithm’s outputs are the red-yellow-green lights for the traffic lights.

Students were asked to create a Finite State Machine that managed traffic flow in a single intersection to meet specified design criteria as determined by their RC Car modeling and GUI modeling. The Finite State Machine algorithm optimally managed a single intersection light using only sensor input and no human intervention. Ideally, this algorithm was capable of generating more trips than would be possible using a manually

controlled intersection light. The most successful algorithm for automatic control allowed the most total scoring trips by all four driving teams on the roadway, as averaged over multiple timed runs.

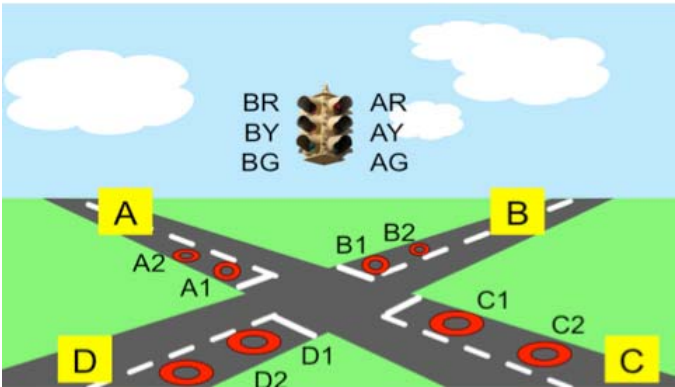


Figure 2. Representation of one intersection and its traffic lights

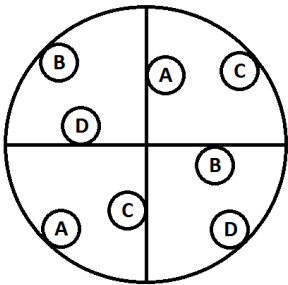


Figure 3. Schematic representation of the five-intersection traffic network designed for four teams (teams are A, B, C, D) to make “trips” traversing the network between a pair of “bases” assigned to their team.

D. Modeling: GUI for Human Operation of Lights

Student teams were also required to develop Graphical User Interface (GUI) control scheme to interface with their code and allow manual intersection control. A simplified example of the GUI is pictured in Fig. 4. During the running of the cars on “Race Days”, the expectation was that an operator could use manual control of a light mediated by a Finite State Machine that delivers traffic sensor and light states to the human intersection control operator in an easy-to-use manner and without reference to the actual traffic lights or RC car status.. The most successful GUI was the one whose human controllers allow the most total scoring trips by all four driving teams on the roadway, as averaged over multiple timed runs. In this test human operators were selected from among the members of the team that built the GUI. Also, the human operator is turned away from the roadway is to prevent the operator from obtaining visual information that is not provided by the GUI.



Figure 4. Simplified traffic light control GUI example coded in Python

Bonus points were given to the student teams that successfully integrated their Finite State Machine and user interface systems so that all five intersections were controlled from a single computer, using a single automatic algorithm, and which in separate runs a single GUI with which a single human controller runs all intersections. Students that were able to achieve this level of proficiency were then challenged with a stretch goal to demonstrate efficiency through integrated traffic management. By optimizing their automatic algorithm already implemented, students were asked to show that their integrated automatic algorithm produces better trip-scores for a network of traffic lights than the basic Finite State Machine that controls a single intersection independent of information about the other four intersections' states, using quantitative evidence that the integrated algorithm boosted trip counts.

E. Modeling: Human Operated RC Car Performance

Students were also required to conduct an engineering experiment to analyze the kinematic performance and reaction time of the human operated RC cars used for driving around the course and model that performance to choose optimal traffic light timing and sequence. A companion how-to video was produced by one of the course instructors to walk student through the necessary steps. This video can be viewed on YouTube at <http://bit.ly/egr101cars> [10]. Students captured video of the RC cars stopping and used Tracker Video Analysis and Modeling Tool, a physics-based freeware tracking software to do analysis [11].

Fig. 5 shows the general setup to capture video of the RC car. Lines with blue tape are spaced 12" apart next to the Traffic Simulation roadway as the test track. Three people are needed to do this experiment: a driver, starter and videographer. The car's driver begins driving at maximum speed when the starter provides a signal, and then brings the car to a complete stop when the starter provides a signal. The starter's signal and the entire path of the car must be visible in the video (a signal can be provided by lifting and dropping a foot, for example). It is important that the starter provide a "random" or surprising start and stop signal that cannot be anticipated by the driver, so that the driver's reaction time may be accurately interpreted from the video evidence. It is suggested that each member of the team understand and experience each role, and that several data collection runs be conducted with different members in different roles to generate a statistically meaningful sample of kinematic data.

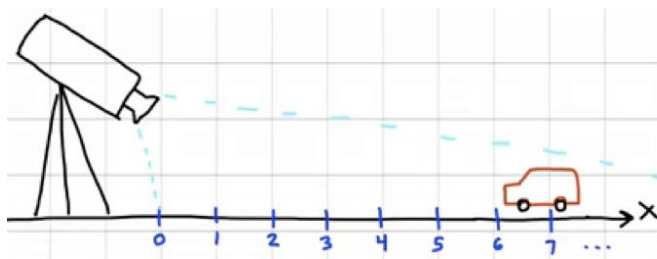


Figure 5. General setup to capture video of the RC car

The analysis tool used was Tracker Video Analysis and Modeling Tool version 3.10 [4]. It was the basis for recording the car's travel. Fig. 6 shows the Tracker software screenshot. Notice the blue tape lines and the red target marks capturing the RC car's travel trajectory at equal distances along the course.

Additional tools required in preparation were a custom Python code script to correct the effect of camera perspective on the car position data. Collected video was processed through Tracker. Axes were added and in clip settings set to advance 5 video frames at a time. Using the Point Mass Track feature of the Tracker software, students were able to map the travel of the RC car over time and create a track of pointed for its forward movement, stopping and reverse movement. This is shown in Fig. 6 by the red target marks. The collected data was then run through the Python code script to generate corrected data.

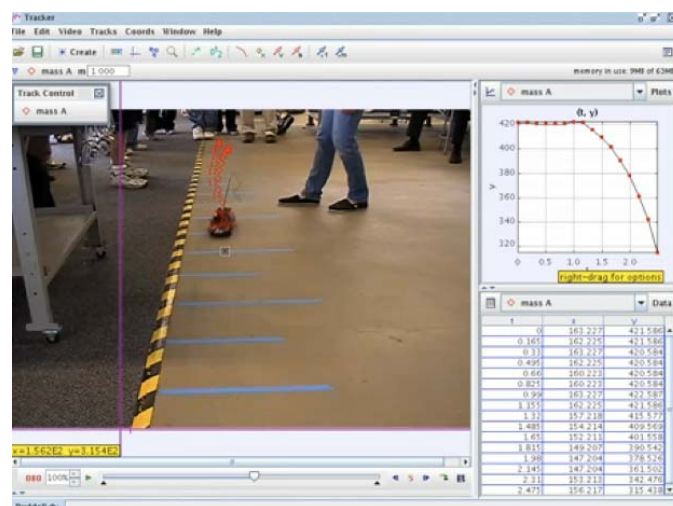


Figure 6. Tracker software screenshot

Student teams were asked to use Tracker and then generate plots in MS Excel of distance, velocity and acceleration over time. Braking time and reaction time may be calculated as the length in time between when the starter's visual signal is issued and when the car's acceleration changes. The results of all teams' analyses for rate of braking, acceleration, maximum velocity, and operator response time are shared with the class, providing a statistically meaningful sample of performance for the diversity of RC car operators in the class. Student teams then generated short reports analyzing the class's kinematic data, presenting estimates for acceleration and braking rates, peak velocities, and operator reaction times for the class. This information is utilized to choose optimal traffic light timings given the specific geometry of the traffic networks' roads and lights.

F. Learning Object-Oriented Programming

The programming basis for this class was Python 3.2. An online textbook, *How to Think Like a Computer Scientist* [2], was used in support of the programming content. A summary overview of concepts applied in this class are listed in Fig. 7.

| | |
|-----------------------|--|
| Python types/objects: | <ul style="list-style-type: none"> ▪ numbers (integers and floating point) ▪ characters ▪ lists/arrays/maps/dictionaries ▪ user defined |
| Statements: | <ul style="list-style-type: none"> ▪ programs are composed of modules ▪ modules contain statements ▪ statements contain expressions ▪ expressions create and process objects ▪ statements we have covered so far: <ul style="list-style-type: none"> ○ assignment, if/if-else/if-elif-else, while/for, return, def, import, global ▪ statements are used to provide program execution flow control <ul style="list-style-type: none"> ○ sequence, selection, iteration |
| Functions: | <ul style="list-style-type: none"> ▪ we use functions to: <ul style="list-style-type: none"> ○ to maximize code reuse, to minimize redundancy, to help in procedural decomposition ▪ functions provide scope ▪ functions have arguments/parameters |
| Modules: | <ul style="list-style-type: none"> ▪ organize components into a system; think about the modules we've used (tkinter, time, math, isec) ▪ aid code reuse ▪ provide namespace partitioning ▪ provide shared services |

Figure 7. Overview of course programming concepts

G. Design Solutions

Based on their finite state machine modeling and RC car kinematics analysis, students teams applied an array of strategies to optimize transit from one corner of the traffic simulation course to the other. Fig. 8 shows the name of the project as given to students to highlight the real-world application of the project. Fig. 9 shows the race course setup in the classroom.



Figure 8. Name of project as given to students. Attempt to highlight the application area of traffic simulation and to ground it in students' experience.

On "race days" at the culmination of the project, several pools containing four teams each took turns racing the RC cars using the automatic and GUI-driven manual FSM traffic control algorithms. Total trips between opposing "bases" completed by each of the four teams during the timed duration of each "race" was recorded. A "traffic cop" enforced timed penalties on any RC car driver who left the delineated lane boundaries, initiated collision with another driver's car, or ran a red light. Right turning on red lights was allowed in these races.

Following "race day", students analyzed the resulting trip data to generate empirical evidence that their automated and manual-GUI control algorithms performed optimally relative to the project's criteria. A modest number of "bonus" points were

allocated to the teams with the highest trip scores in the manual-GUI light control, automatic light control, and RC car driving categories, to incentivize effort toward efficiency and performance.

Following the project, student teams were asked to reflect on their design process and communicate project results in a written report. Students were asked to: (1) address each portion of the design process in some part of the report, (2) include schematics of their finite state machine and figures detailing results of analyses, (3) pre-competition testing and estimation of vehicle speed, stopping time, (4) pre-competition estimates of optimal light cycle times and light control algorithms, (5) pre-competition estimates of total trips and individual team trips, (6) pre-competition testing to validate estimates, (7) comparison of competition data with estimates based on pre-competition analysis and (8) suggestion of specific improvements to their control algorithms based on competition results.

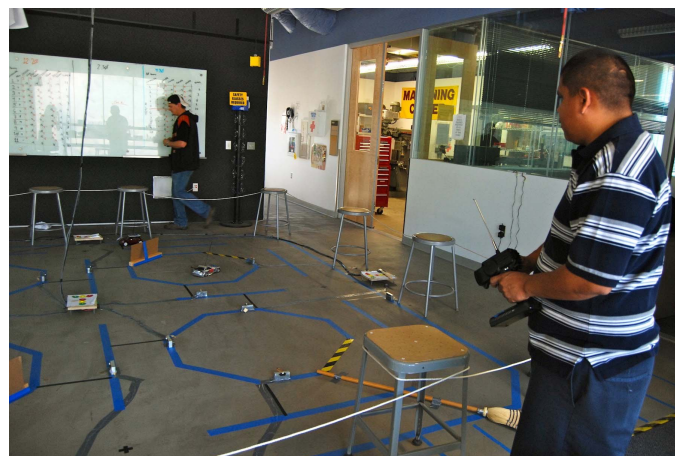


Figure 9. Race course setup in classroom; blue tape delineates lane boundaries, striped tape delineates entries to the "bases", and black tape delineates intersection stopping locations.

IV. DISCUSSION: INTEGRATED ENGINEERING SYSTEMS

Students were asked to reflect on their experience in a fused engineering and computing classroom experience. The analysis of their responses and emerging thematic analysis is still ongoing but there seems to be at least two surprising learning outcomes. The first is that even for those engineering students who were surprised at the amount of computing content, a confidence in thinking computationally seems to have emerged and fear of programming, debugging, and other computing activities has lessened. The other is a realization at how integrated computing and engineering disciplines are in embedded systems.

Another class project that is electro-mechanical in nature – to build an automatically functioning elevator – is being implemented in the spring semester freshman engineering project course. Future work may include comparison of this second project's added learning outcomes with those of the first project.

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Developing a Simple and Effective Method of Assessing Civil Engineering Student Outcomes

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Abstract— The assessment of student outcomes can be made easier if the proper plan and processes are put in place before starting data collection. The key to simplifying the process is to collect targeted data after developing performance indicators and mapping them to appropriate courses. The authors discuss the evolution of the Coast Guard Academy's Civil Engineering assessment process highlighting how the process has been streamlined and simplified through the development of assessment tools to measure achievement of performance indicators linked to each student outcome. The authors further discuss how the assessment data are analyzed holistically and used to guide improvements to courses and the curriculum.

Keywords—Accreditation, Assessment tools, Performance indicator, Student outcomes

I. INTRODUCTION

It is usually a challenge for undergraduate academic programs to determine with certainty the type and amount of data on student performance that should be collected to satisfy ABET (Accreditation Board for Engineering and Technology) requirements, ensure continued accreditation, and foster continuous program improvement. Academic institutions continue to struggle with the task of making data collection and the overall assessment process more manageable. This process becomes especially challenging with the dynamic nature of some of the ABET criteria. The importance of accreditation is valued by colleges and universities across the nation and overseas because it assures the quality of engineering and technology programs as well as facilitates the improvement of those programs. Furthermore, a degree from an ABET accredited institution is a requirement for licensure as a Professional Engineer.

In preparation for an ABET visit, academic institution must prepare a "self study" which can be considered a vital step for academic institutions to review the "health" of their engineering and technology programs and make improvements to enhance student learning. Cummings, Heng and Tsang, support the process of self critic before an ABET visit and wrote: "By providing a process to identify shortcomings with respect to student attainment of student learning outcomes, institutions or programs are better able to make necessary

improvements, as well as understand their institutional or program strengths" [1]. Some programs have used the weaknesses or concerns raised by ABET to foster support from the administration by requesting more financial support, more faculty and improvement of facilities and resources.

Since their establishment in 1932, ABET standards have evolved over the years and has resulted in nationwide curricular revision and the strengthening of engineering education [2]. However, the potential for this system to drive improvement of engineering programs at academic institutions continue to depend on how well the faculty understand, appreciate and support the changes to meet these standards [3]. To become ABET accredited, programs must have a set of Program Educational Objectives (PEOs) and Student Outcomes as well adequate facility, a certain number of faculty and institutional support [4]. In 2010, ABET reported that meeting the requirements on Program Educational Objectives and Student Outcomes continue to be the areas in which most institutions fall short [5]. Some of the shortcomings highlighted in the ABET report included:

- "Inadequate evidence that the process in which the objectives are determined and periodically evaluated is based on the needs of the constituents (Criterion 2)."
- "Confusion between the definition of program educational objectives (Criterion 2) and program outcomes (Criterion 3)."
- "Inadequate evidence of using the results of evaluation of objectives and/or assessment of outcomes for improvement."
- "Inadequate evidence demonstrating achievement of objectives or outcomes."

A key step in avoiding some of these shortcomings when assessing student outcomes is to develop specific and measurable performance indicators that students are expected to demonstrate in relation to the outcomes. The performance indicators can be mapped to appropriate courses and measured using assessment tools. Selecting appropriate assessment tools to adequately assess student performance on the outcomes is crucial since focusing on overall course grades may not provide important details. Performance threshold(s) for meeting the individual outcomes must be established before the assessment

data is collected and reviewed. Establishing a data collection cycle and looping findings to make improvements are also key components of the assessment process.

The authors discuss the evolution of the Coast Guard Academy's Civil Engineering assessment process highlighting how the process has been streamlined and simplified through the development of assessment tools to measure achievement of performance indicators linked to each student outcome. The authors further discuss how the assessment data are analyzed holistically and used to guide improvements to courses and the curriculum.

II. CIVIL ENGINEERING AT THE COAST GUARD ACADEMY

The United States Coast Guard Academy (USCGA) is a small undergraduate institution of approximately 1,000 cadets with eight majors. Approximately 10-15 percent of the cadet corps graduates with a Civil Engineering degree. Civil engineering graduates pursue a number of different career paths and many of them serve in the Coast Guard as practicing civil engineers, pursue professional licensure, and attend graduate programs in Civil Engineering. The Program Educational Objectives, listed below, are based on what civil engineering graduates are expected to have achieved within 4 to 6 years after graduation:

1. Graduates of the Civil Engineering Program perform effectively in a variety of career paths as Junior Officers in the Coast Guard.
2. Graduates of the Civil Engineering Program provide appropriate Civil Engineering expertise to the Coast Guard while serving in Civil Engineering related billets.
3. Graduates of the Civil Engineering Program demonstrate a commitment to intellectual and professional growth through activities and accomplishments such as graduate study, professional licensure, professional society activity, continuing education and promotion.

The Civil Engineering curriculum at USCGA includes a variety of required core courses in the humanities, science, engineering, mathematics, professional maritime studies, organizational behavior, management, leadership and law. The curriculum is broad and provides a solid background in the structures, environmental, geotechnical, and construction sub-fields of civil engineering. Similar to engineering programs at most academic institutions, the Civil Engineering Program at the USCGA is structured to meet ABET standards. It is a well known fact that these standards are dynamic-changing with technological advancement, societal and global trends, and advancement in educational instruction. The CE Program has made several changes to their assessment process since the last ABET visit in 2007. A brief description of the assessment process and highlights of the changes are presented in the following section.

III. COAST GUARD ACADEMY CIVIL ENGINEERING PROGRAM ASSESSMENT MODEL

The current assessment process used in the Civil Engineering Program consists of four main components:

1. End of Course Review (EOCR): An EOCR is conducted at the end of each semester for all required civil engineering courses offered that semester. Student success in meeting performance indicators is assessed and evaluated, and then recommendations for course improvements are made. Individual reports that documents details on how the course was conducted, assessment tools used, how issues were resolved, effectiveness in meeting the course objectives, students' performance and recommendations for future changes, are generated for each course. Results from the EOCR reports provide vital input for the Civil Engineering Program Review.
2. Civil Engineering Program Review (CE-PR): This is conducted every two years at the end of the spring semester. At this level, the achievements of all student outcomes for the entire program are evaluated holistically based on information from all end of course review reports. Achievement of the program educational objectives is assessed and evaluated using several surveys and other tools (alumni, senior exit, supervisor/employer, capstone surveys and interviews). The CE-PR is usually conducted in alternate years to a Departmental Review. Recommendations from the most recent Departmental Review are also discussed and implemented when practical. Results and recommendations from the CE-PR provide vital input for the upcoming Departmental Feedback the following year.
3. Department of Engineering Feedback: The Department of Engineering consists of four programs (Civil, Mechanical, Electrical, and Naval Architecture and Marine Engineering). At this level all four engineering programs are evaluated and changes for department-wide improvement recommended. A joint review with representatives from all four engineering programs is conducted every two year (in alternating years to the CE-PR) at the end of the spring semester. Other department level feedback is gathered and used in the assessment process.
4. Engineering Advisory Council (EAC): The EAC is a panel consisting of regular members from the Coast Guard and other federal agencies and episodic members from industry and academia. The EAC advises all four engineering programs in the Department of Engineering. The role of EAC is to distill input from students, industry, academia, and United States Coast Guard Engineering Commands. The purpose of a combined Engineering Advisory Council is to leverage the important professional, industry, and academic guidance within the framework of the needs of the United States Coast Guard engineering community. The EAC also reviews PEOs and comment on suggested changes to ensure that PEOs are in keeping with best practices in higher education. The Engineering Advisory Council meets annually in April

and the council's discussion and recommendations are summarized in the form of written meeting minutes.

These components and other assessment activities undertaken throughout the academic year are shown in Figure 1. Only details of the EOCR process are further discussed in this paper.



Figure 1. USCGA Annual Assessment Activities

A. End of Course Review

The end of course review plays a major role in the process used to assess individual student outcomes and to evaluate the effectiveness of the courses in preparing students to meet the outcomes. In preparing the EOCR for each engineering course, student assessments are conducted throughout the semester using both direct and indirect measures. The direct measures make use of a combination of specific homework assignments, projects, technical papers, oral presentations, specific exams questions and laboratory reports. Indirect measures include student self assessment using surveys and instructors' observations and evaluations.

In assessing the student outcomes, the Civil Engineering faculty has developed several performance indicators to serve as measurable criteria students must meet for successful demonstration of achievement of the outcomes. The performance indicators were developed through extensive discussions amongst faculty. They represent the Civil Engineering faculty's interpretation of the ABET outcomes and serve as measurable "skills, knowledge and behaviors" students are expected to demonstrate in regards to the outcomes. These performance indicators were then mapped to courses within the civil engineering curriculum. An example of the mapping for two specific civil engineering student outcomes (CE02 and CE03) is shown in Table I. An "X" in Table I indicates that the

course contributes to providing students' with the knowledge and experience required to be proficient in the particular performance indicator.

TABLE I. EXAMPLE OF MAPPING OF STUDENT OUTCOME PERFORMANCE INDICATORS TO COURSES

| | | Civil. Eng. Materials | Soil Mechanics | Environmental Eng I | Steel Design | Structural Analysis | Const. Proj. Management | Civil Eng. Design | Geotechnical Eng. Design | Environmental Eng. II | Reinforced Concrete Design |
|---|--|-----------------------|----------------|---------------------|--------------|---------------------|-------------------------|-------------------|--------------------------|-----------------------|----------------------------|
| Student Outcome | Performance Indicator | | | | | | | | | | |
| CE02: Can conduct fundamental civil engineering experiments, analyze and interpret data, and prepare engineering report. | CE02-1: Identify the important variables in laboratory or field experiments. | X | X | X | | | | | | | |
| | CE02-2: Use appropriate techniques and tools to collect laboratory/field data; follow standardized procedures to collect data. | X | X | X | | | | | | | |
| | CE02-3: Apply fundamental principles to analyze and interpret data including the identification of trends and range of expected results where applicable. Draw appropriate or reasonable conclusions by comparing test data with expected results. | X | X | X | | | | | | | |
| | CE02-4: Prepare written report in standard engineering format documenting details of the experiment. | X | X | X | | | | | | | |
| CE03: Can design a system, component, or process in the context of structural, environmental, and geotechnical engineering. | CE03-1: Analyze a practical civil engineering problem to identify need and requirements; list objectives and constraints. | | | | X | | | X | | X | |
| | CE03-2: Apply engineering principles and design concepts (including design codes and specifications) to solve a civil engineering problem. | | | | | | | X | | | X |
| | CE03-3: Identify and evaluate potential design solutions. | | | | | | | X | | | X |

For each performance indicator under each student outcome, at least one but usually two, assessment tools representing direct measures of student performance are used to assess outcome achievement. These direct measures are based on assessment tools that range from grades on particular exam questions or assignments to performance rubrics scores. Thresholds representing minimum student performance were also established for the successful achievement of the performance indicators as shown in Figure 2. As can be seen in Figure 2, different thresholds were set for exams and non-exam activities (projects, homework, reports, technical paper, oral

presentation, etc). At least two courses are mostly used to assess each performance indicator. The thresholds must be met for *all* the performance indicators (in *each course* mapped to that performance indicator) for an outcome to be successfully achieved. A table of student performance on the tools used to assess the performance indicators is included in the EOCR—an example is shown in Table II. The information in Table II is used to populate the percentage of students meeting the thresholds into a Program Outcome Achievement Matrix used for the Program Review.

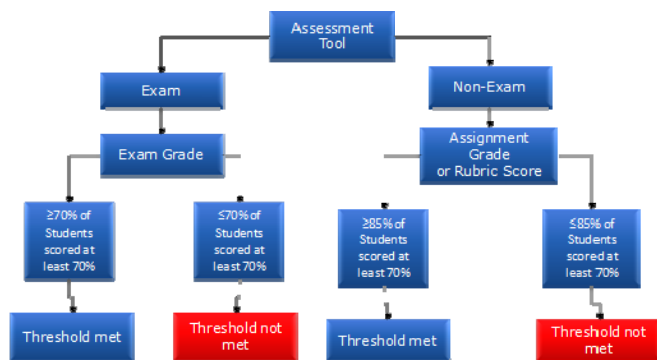


Figure 2. Assessment Tools Thresholds

Prior to the EOCR meeting, the course coordinator prepares a “read-ahead” document that includes a review of issues raised at the previous EOCR, an examination of assessment instruments used, the course’s contribution to the program in the context of the program outcomes achievement matrix and course changes (long and short range). The final EOCR report contains the read ahead material, issues discussed at the meeting, action items, and a number of attachments. The final reports are stored electronically for future use and historical records.

TABLE II. EXAMPLE OF STUDENT OUTCOME ASSESSMENT (SOILS)

| Outcome | Performance Indicator (PI) | Assessment Tool | Average score on PI (high, low) | % Students meeting PI threshold score | Achievement Threshold for PI met? | Achievement Threshold for Outcome met? |
|---------|----------------------------|--|---------------------------------|---------------------------------------|-----------------------------------|---|
| CE01 | CE01-1 | Final exam | 85.6% (93%, 75.4%) | 100% | Yes | Required information from other courses |
| CE02 | CE02-1 | Pre-lab Write & data sheet | 95.1% (100%, 70%) | 100% | Yes | No |
| | CE02-2 | Lab reports (procedure) /Instructor observation rubric score | 79.8% (100%, 50%) | 78% | No | |
| | CE02-3 | Lab reports | 86.1% (89.5%, 81.8%) | 100% | Yes | |
| | CE02-4 | Lab reports | 86.1% (89.5%, 81.8%) | 100% | Yes | |

The EOCR process has evolved such that linkages between courses and program outcome and performance indicators are strongly made. It is the general consensus that the process improves courses and the Civil Engineering Program by involving many stakeholders in meaningful discussion and evaluation.

IV. BENEFITS OF THE CURRENT PROCESS

The previous assessment model that was used prior to 2007 did not incorporate performance indicators. Student achievement of the outcomes was assessed somewhat directly based on the wording of the outcomes supported. Justification for using a particular course to assess specific outcomes was provided through a set of narratives. These narratives rated the level of development students were expected to achieve using a scale of 1 to 3. A lot of data were collected in each course but students understanding of the principles and concepts related to the outcomes were difficult to deduce from the data. For the most part, the overall course grade was used as the main tool to assess the achievement of the outcomes; this made it challenging to identify areas students had difficulties with for continuous improvement. Furthermore, thresholds for meeting the student outcomes were not clearly defined making it problematic to assess the level to which the student outcomes were achieved. The current assessment model is a result of several modifications made to address these shortcoming and to ensure more harmony with ABET expectations. A summary comparison of both assessment models is provided in Table III.

The revisions made to the assessment process have greatly improved and simplified our data collection efforts. Having developed suitable assessment tools, targeted data are now collected and this has resulted in a decrease in the overall quantity of data. It is also easier to identify areas where students are underperforming and recommend changes for improvements--leading to improved classroom instructions. This has been quite evident when the overall grade is broken down into categories based on the course objectives, by using performance rubrics that address specific performance indicators instead of using the overall grade. Examples of exam breakdown and the use of performance rubrics are shown in Figures 3 and 4. Both examples are from the senior year *Geotechnical Engineering Design* course. From Figure 3, it can be deduced that about 30% of the students scored less than 70% in dewatering design, retaining wall design and site investigation--areas that were identified for improvement during the next offering of the course. Similarly from Figure 4, student performance in each category of the rubric was good with 90% of students meeting or exceeding expectations--a direct indication that the course objective for this module was achieved. In most of the courses, new assessment tools had to be developed to ensure that relevant data are collected on the performance indicators. Instructors had to reevaluate the methods and tools used and this has led to an improvement of how student learning is assessed in our program. Additionally, faculty members have embraced the new assessment process because they were all fully engaged in making the changes.

TABLE III. SUMMARY COMPARISON OF CURRENT AND PREVIOUS ASSESSMENT MODELS

| Attribute | Current Model | Previous Model |
|--|---|--|
| Consists of a list of outcomes to address ABET Criterion 3 | Yes | Yes |
| Outcomes expressed in measurable terms using performance indicators. | Yes | No |
| Each outcome is described by at least two performance indicator | Yes | No |
| At which level is assessment data collected? | Assessment data is collected on the performance indicators for each student outcome. | Assessment data was collected directly on the student outcome based on the wording. |
| What tools are used for assessment? | Exams, lab reports, homework, technical papers, oral presentations, projects, instructor observation in labs, in-class student self assessment survey (mid & end of semester), performance rubrics. Particular exam question(s), rubric scores or individual components of the listed tools are used to assess specific performance indicators. | Exams, homework, projects, lab reports, technical papers, oral presentations. Course grade was widely used to assess student outcomes. |
| Performance threshold | Yes: At least 85% (70% for exams) of students should score 70% or better on the assessment tool. Detailed distribution of student performance. | No minimum threshold that should be met was established. |
| Outcome achievement criteria | Performance threshold should be met on ALL performance indicators for a student outcome to be considered achieved. | Final course grades were used somewhat subjectively. |
| Assessment coordinator | Yes: Full-time faculty responsible for ensuring that assessment processes are up to date and in line with current ABET requirements and advancement in pedagogy. Periodic updates and/or reviews twice a year. | No |
| Continuous improvement | Yes: Information from student performance on the performance indicators are evaluated and looped to improve courses and the Program. | Yes: Information from student performance on the outcomes are evaluated and looped to improve courses and the Program. |
| Student feedback | Yes: Newly developed mid-semester and end of semester in-class survey was introduced. Students assess their understanding of the principles and concepts, course objectives and provide general feedback on the courses. Particular emphasis is placed on the course objectives and assessment tools. Results readily available for use in End of Course Reviews. | Yes, but somewhat ineffective. No formal student feedback during the semester. A general standard online survey was conducted at the end of the semester, but the questions did not address specific aspects or uniqueness of each course. Results were not readily available to include in End of Course Reviews. |

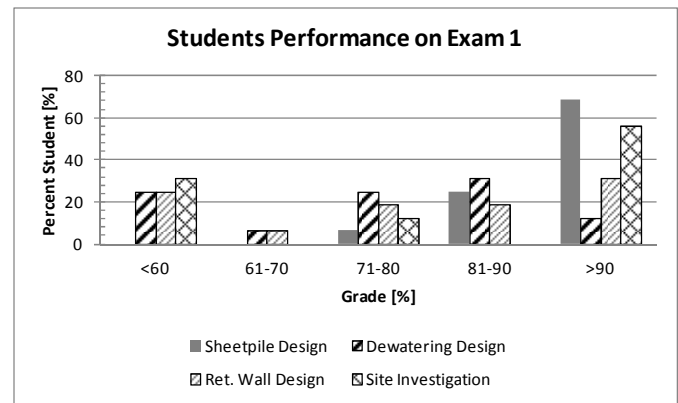


Figure 3. Performance distribution from Exam 1 (Geotechnical Engineering Design)

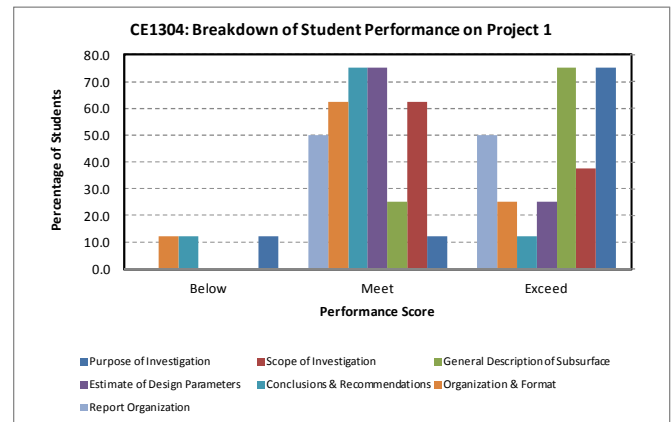


Figure 4. Performance distribution on performance rubric for Project 1 (Geotechnical Engineering Design)

V. CONCLUSIONS

The assessment of student outcome achievement at the United States Coast Guard Academy has been significantly improved and streamlined since 2007 resulting in a more effective and efficient assessment process. The major improvements over the previous system includes the development of specific and measurable performance indicators linked to each student outcome, the creation of multiple assessment tools for performance indicators, the development of consistent thresholds to gage whether student outcomes are achieved, and incorporation of the data into a holistic assessment process to ensure continuous improvement of the program. Our experience working together as a Civil Engineering Faculty to develop, refine, and use performance indicators and assessment tools demonstrates that it is feasible to craft an assessment system that is sustainable, consistent with ABET criteria, and embraced and used by an entire faculty for the improvement of an educational program.

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A Survey of Attitudes, Beliefs, and Perceptions Regarding the Internationalization of Engineering and Computer Science Undergraduate Programs at the University of Victoria

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Canadian undergraduate and graduate programs in Engineering and Computer Science attract a large number of international students. This is a relatively recent phenomenon with social and academic implications that are not completely understood. We are aware that more can be done for the recruitment, retention, and more generally for increasing the quality of the learning experience of our international students. More efforts need to be made in order to foster and expand social and academic interactions between Canadian and international students, as well as student-faculty interactions. The research described in this paper aims to identify the first steps in creating an inclusive environment that fosters academic, social, and personal growth for both international and Canadian students. This study discusses data collected about the experience of international undergraduate students in the Faculty of Engineering our university. The purpose of the data collection was to determine their specific needs, and to solicit suggestions and recommendations about ways in which to address them.

Keywords: *internationalization, global education, qualitative analysis, focus groups.*

I. INTRODUCTION

The Faculty of Engineering at the University of Victoria attracts a large number of international students. This is a relatively recent phenomenon with social and academic implications that are not completely understood. We are aware that more could be done for the recruitment, retention, and more generally for increasing the quality of the learning experience of our international students. More efforts need to be made in order to foster and expand social and academic interactions between Canadian and international students, as well as student-faculty interactions. The long-term goal of this project is to provide international and local students with the best education possible by positioning our students to become global citizens and leaders. We are particularly interested in fostering an environment in which students from different cultural backgrounds work together effectively within both

class and social settings. The research objective of this project is to identify the first steps in creating an inclusive environment that allows for this academic, social, and personal growth.

The remainder of the paper is structured as follows. Section II provides details about previous studies that are similar to ours. Section III describes the methodology that has been used in the proposed study. Section IV presents the results, while Section V provides a discussion of new strategies and recommendations in light of the results. Section VI concludes the paper.

II. BACKGROUND

The literature on strategies for successful integration of international students in engineering and computer science is somewhat limited; however, previous work has identified areas that need to be addressed by universities. Although engineering and computer science programs are often thought to be culture-neutral and not strongly influenced by individual factors, some authors believe that learning patterns in these programs vary by culture [1]. The study in [1] examines the learning patterns and strategies employed by students from different backgrounds at a college in Finland; a large majority of international students reported that they were unsure of the college expectations of them and had difficulties completing assignments due to difficulties in understanding instructions. Moreover, these students reported that they were not able to communicate this lack of understanding to faculty and staff, further complicating this issue. Interestingly, these difficulties were not strongly correlated with English language proficiency, suggesting this was not a matter of a simple language deficit.

Student surveys also indicated that international students, particularly those from third-world countries, were more accustomed to teacher-led instruction emphasizing a strong hierarchical relationship between student and professor [1].

This may contribute to difficulties in international student engagement in class discussions or group work as these students may not know or understand that Western learning styles emphasize student initiative, asking questions in class, and independent knowledge acquisition. This was also apparent in a study examining Chinese students' perceptions of their supervisory relationship while completing a thesis [2]. The authors of [2] found that international students often felt great anxiety in the first six months of the supervisory relationship, primarily due to differences in supervisory practice due to insufficient closeness with, joint research with, and guidance from the supervisor. Student expectations of the nature of this relationship were often unmet due to differences in cultural norms surrounding the supervisor-supervisee relationship. Many of these students experienced adjustment to the local cultural and academic norms after one year in the program upon viewing their learning environment in a different way from which they were accustomed.

One issue identified in the literature is the discrepancy in the definition of plagiarism and cheating across international university systems [3]. The authors of [3] suggest that international students may be particularly at risk of accusations of plagiarism due to differences in attitudes towards plagiarisms in their countries of origin, which may not be in line with Western views on academic integrity. This study [3] implemented a program for making Western requirements for academic integrity explicit for students; the program included an orientation to Western norms, provision of online resources, academic scholarship workshops, and assignments. Over a period of two years, the authors found a significant reduction in the number of students committing plagiarism. This suggests that engineering programs may need to implement similar programs that link international students with faculty and support staff to clarify the University regulations regarding plagiarism.

International students often have to manage many issues related to moving to a new country and adapting to a new culture, and therefore often have non-academic issues to contend with that may affect their classroom performance. Interviews with Asian students at an American university revealed that these students often carried heavy burdens of responsibility for the economic success of their families back home, which could affect their career aspirations [4]. These students often felt greater financial strain and stress than their local peers due to increased international tuition, as well as to financial requirements to reside in the United States. Finally, Asian doctoral students reported feeling socially isolated from peers, faculty, and staff, possibly due to the tendency of people in these departments towards socializing in culturally homogeneous groups. This limited social support group may contribute to students' sense of alienation within the department or within the larger institutional context.

III. METHODOLOGY

The purpose of this study was to gather information about the experience of international and Canadian undergraduate students in the Faculty of Engineering at the University of

Victoria. We were primarily interested in collecting data regarding the specific needs of international undergraduate students and participants' suggestions for ways to address any unmet needs. Further, we were interested in gaining a deeper understanding of the level and quality of interactions between people of different cultural backgrounds, specifically among the undergraduate students, and between the undergraduates and graduate students, faculty, and staff. Of particular interest are the attitudinal beliefs that are shaping these interactions, and how these beliefs shape the way these groups work together.

A. Research Design

Qualitative data analysis methodology was used to address the research question and objectives. The purpose of using this methodology was to gain information that is descriptive of the experience of students, staff, and faculty in the Faculty of Engineering at our university. This type of analysis is not highly interpretive, as we did not choose to interpret the data within the context of a particular theory. Instead, we attempted to be as unbiased as possible in providing a description of the current situation at the University of Victoria based on participant responses. A major goal of this approach is to provide a summary of the information provided at the focus groups and interviews that is descriptive of the responses of most participants and stays close to the data collected. Descriptive summaries of focus groups and individual interviews were collated and an iterative process was used to determine major themes and sub-themes that emerged from the data. Group consensus on themes and sub-themes was obtained from all authors.

B. Participants

Undergraduate students, graduate students, staff, and faculty in the Faculty of Engineering participated in either individual interviews or focus groups.

1) *Participant Recruitment*: Three focus groups and seven individual interviews were conducted to glean information from key stakeholders: five staff, four faculty members, six graduate students, and three undergraduate students in the Faculty of Engineering. Participants were recruited through use of targeted group emails through the Faculty of Engineering. Participants were asked to contact the research assistant if they met eligibility criteria and were interested in participating. At this time, they were given further information about the study, and asked to participate. We also employed targeted participant selection by personally emailing or calling staff and faculty members who had a particular interest in this topic or who were in roles in which they frequently interacted with international undergraduate students. These staff and faculty members were asked to participate as they were likely to have a wealth of knowledge regarding specific needs of this population.

2) *Inclusion and Exclusion Criteria*: The participants for this study were staff, faculty, undergraduate students, and graduate students in the Faculty of Engineering. Eligible staff and faculty were required to have frequent contact with

international undergraduate students in the department, either through their role as a professor, director of a lab that included undergraduate students, or through their staff position within the Faculty. Undergraduate students were required to be in their fourth year of studies, as this group of students has been in the University system for several years, and would likely have the most information to contribute to the study. Further, these undergraduate students will have completed at least one co-op placement, and would be able to provide information on this process as well. Graduate students recruited for participation were required to have contact with undergraduate students in the Faculty through their role as a teaching assistant (i.e. lab instruction, tutorial instruction). Both international and local (Canadian) participants were encouraged to participate in the study.

3) *Description of Participants*: Participants were asked to complete a short demographics questionnaire. The sample consisted of ten females and eight males who ranged in age from 24 to 66 years old (mean age: 37.6 years). Three separate focus groups were run by the research assistant/first author: the first consisted of two staff and two faculty members, the second consisted of five graduate students, and the third consisted of one staff and one faculty member. Seven in-person and one Skype-assisted interviews were conducted individually with two staff members, one faculty member, one graduate student, and three undergraduate students respectively. Of the graduate students, two were at the Master's level and four were at the Doctoral level of training. Of the fifteen participants who provided information on cultural background, ten self-identified as being international and five self-identified as being local (Canadian).

C. Data Collection Procedure

The primary data collection strategy consisted of in-depth focus groups and individual interviews. The focus groups allowed participants to share ideas and group discussion was encouraged by the interviewer to facilitate collection of rich data regarding relevant experiences. Open-ended questions and prompts were used to elicit participants' perspectives. The interviews began with the following two questions:

- "What does being a student/staff member/faculty member in the Faculty of Engineering mean to you?"
- "What does internationalization mean to you?"

The first two questions were aimed at beginning the conversation and helping participants become more familiar with the process of sharing their thoughts and opinions. The following questions being asked were:

- "How does internationalization influence your research, teaching or work?"
- "What are your experiences with competitive (individual) versus cooperative learning styles with undergraduate styles?"
- "How does internationalization come into play in teamwork?"

- "Are you aware of factors outside the classroom that affect students' performance and learning at the University of Victoria?"
- "Do you think the Faculty of Engineering provides an adequate learning environment for international students?"
- "Do you think the expectations of the students typically align with the expectations of the program, instructors, and teaching assistants?"
- "What are some strategies that could promote successful interactions among students, faculty, and staff in the Faculty of Engineering?"
- "What are your experiences as a teaching assistant with respect to internationalization?" (only grad students)

All focus groups and six of the individual interviews took place in meeting rooms in the Engineering/Computer Science building at the University of Victoria and one individual interview took place via Skype. Individual interviews were approximately 25 to 45 minutes in length and focus groups were approximately 45 to 90 minutes in length. The research assistant reviewed the audio recordings of each focus group and interview to transcribe the dialogue from these sessions.

D. Data Analysis

Qualitative data analysis techniques were used for this study as these methods are often more effective than qualitative methods to describe social phenomena [5]. These techniques are often of particular benefit in the early phases of research where detailed information about a particular topic can be collected from a relatively small number of participants. Results from qualitative analyses can provide a detailed description of the current situation (i.e. internationalization in the Faculty of Engineering), which can then be used to guide future quantitative studies. Gathering information through focus groups and interviews provides a rich basis of data that convey meaningful information beyond numerical summaries used in quantitative analyses [6]. As participant responses were unstructured (i.e. in response to open-ended questions), the main goal of our analysis was to classify participant responses into overarching themes to elucidate the main issues regarding internationalization of the Faculty of Engineering at the University of Victoria.

Data from this study were analyzed using an iterative approach for determining common themes emerging from participant responses. In this process, the researchers/authors with a psychology background performed individually an analysis of the responses to each question in order to determine emerging themes. This method allows for the comparison of each piece of data to all other pieces of data in order to determine emerging relationships among the data. Following this individual analysis process, the researchers met to compare and contrast the themes they had previously identified for each question. This comparison allowed for refinements of themes identified for each question.

After this process, data were examined holistically, and major themes that were apparent across questions were identified. At this point, five major themes were identified:

motivation, interactions between students and faculty, relocation issues, infrastructure, and student expectations. Through discussion, the themes were restructured and re-conceptualized to determine the broadest categories for the major themes of the data within which several sub-themes would fit. These abstractions were then shared and discussed with the entire research team for validation.

IV. RESULTS

Based on responses from participants, two major themes emerged regarding the experiences of international undergraduate students in the Faculty of Engineering. The first theme encompassed aspects of *expectations*, and the second theme was about *integration*. Each theme comprised several sub-themes, which were then classified as being primarily within the Faculty of Engineering and/or the University of Victoria, outside the Faculty and University, or applicable to both settings (Table I). Further, several potential actions were suggested to address some of the difficulties expressed by participants (Table II).

A major theme that emerged from participants' responses was the issue of expectations, including both student expectations of the program/faculty/university, and the expectations the program/faculty/university has of its students. Participants expressed concerns about international students' expectations of the program and university, including policy and regulations within Canadian practice. A specific example of an inconsistency between students' expectations and those of the university include differences in perceptions of plagiarism and cheating and the acceptableness of these actions within the Canadian learning environment. There are "certain backgrounds where plagiarism is the normal way of proceeding, but that is not accepted here." One participant remarked that the faculty members "need to try to clarify the goal of the plagiarism policies and the subtleties of the policy ... It may be harder for international students to understand these subtleties."

Of particular interest to the Faculty of Engineering are the suggestions put forth to improve the learning environment for international students. Implementation of several of these strategies may provide the University of Victoria with an opportunity to further engage, increase retention of, and better support international students in Engineering. Most respondents suggested that the Faculty could be doing more to support their international students and that a good first step would be to engage the staff and faculty in the process of making the Faculty more sensitive to issues of cultural diversity. Several participants noted that the faculty and staff lack sufficient knowledge, understanding, and sensitivity regarding this issue, which might impede future progress in this area within the Faculty. Of primary importance is the education of all members of the Faculty, including faculty, staff, and students, about issues regarding diversity as a step towards better understanding of international students and the particular challenges they may face. "Without compartmentalizing everyone, there are basic pieces of information about different cultures and what we can

anticipate about behaviours of people from different cultures" that should be provided for professors and staff within the faculty. Suggestions for this type of education ranged from formal lectures and information sessions to more informal presentations and handouts. This may be a role for a cross-department committee committed to issues of diversity who will provide ongoing support for strategies to promote successful integration of international undergraduate students.

TABLE I. THEMES AND SUBTHEMES EMERGING FROM FOCUS GROUPS AND INTERVIEWS

| Theme | Subtheme | Location |
|--------------|--|--------------|
| Expectations | Expectations about programs, UVic policy, regulations - Canadian practice | Within UVic |
| | Plagiarism, cheating | Within UVic |
| | Outcome of Canadian/ Engineering degree - Citizenship | Within UVic |
| | International research collaborations | Within UVic |
| | Expectations about student-faculty relations - Hierarchical - Role of gender | Within UVic |
| | Learning and teaching styles/ motivation | Within UVic |
| | Life in Canada - Housing on or off campus - Banking - Distractions | Outside UVic |
| Integration | Language / communication | Outside UVic |
| | Culture | Outside UVic |
| | Social isolation | Outside UVic |
| | Personal values - Pressure | Outside UVic |
| | Gender issues | Outside UVic |

Further, international students may have very different expectations regarding student-teacher interactions than local students, especially in relation to the hierarchical nature of this relationship. "Some students just assume the professor is always right." Several participants reported that international students may be less likely to participate in class discussions, ask for help from a faculty member when they need it, and engage in debate with a professor. One faculty participant noted that, "I am looking for students to challenge me, but some are not used to doing this based on their past experience." It was suggested that this might be due to cultural differences; these types of behaviours may not be acceptable in other learning contexts. This issue may be exacerbated by cultural differences in perceptions of faculty members of different genders. This also seemed evident in certain student-teaching assistant relationships in which there have been situations of "male students wanting to change their lab group because the instructor is female." Some participants also expressed concerns about student motivations for coming to the University of Victoria, noting that "sometimes I feel more like an immigration officer than a professor."

Participants also expressed concerns about discrepant expectations regarding learning and teaching styles between international students and the Faculty of Engineering. One participant noted that, “we do not spoon feed students, but they [international students] may expect it.” This was further built upon by one staff member noting that “I am sensitive to the fact that international students receive and interpret information in different styles... I want to help the student in the way I like to be helped, but it’s not always the way the student receives, processes, or analyzes information best.” There may be additional differences in expectations regarding support materials used within a teaching setting. One participant remarked that, “we need to recognize that one size does not fit all in terms of advising, teaching, and giving information.”

The second overall theme dealt with issues of integration into the Canadian society in general, and within the local environment in the Faculty of Engineering at the University of Victoria specifically. The sub-themes that emerged in this area were quite broad, and were thought to affect international students both within the university setting as well as outside of it. It was suggested that international students may not engage in group work as readily as local students, possibly because they “may not feel safe yet because of language barriers.” It was also suggested that the language barrier, or perceived language barrier, could discourage local students from forming groups with international students: “Canadian students may not have even given the language issue a chance... may happen because there is such a time pressure on students that they don’t want to take a chance on someone they don’t know.” Additional issues that may affect international students’ performance include difficulties adjusting to a new culture, social isolation, and adjusting to new gender roles. It was noted that there may be “isolation of international students who have few or no other students of similar background ... success comes from feeling that you are part of a group.”

Several excellent suggestions were put forth to address the needs of international students that are not currently being fully met. These suggestions for future steps are described in Table II, and are explored in the Discussion section.

V. DISCUSSION

The primary purpose of this study was to gather information about the experience of international undergraduate students in the Faculty of Engineering at the University of Victoria through focus groups and individual interviews with key stakeholders. Following data collection, the authors reviewed the data pieces multiple times to elucidate common themes that emerged among participants’ responses. Following an iterative process, these themes were revisited and refined to produce themes that were consistent with all authors’ interpretations of the data. Through consensus, two major themes were identified as being critical to the experiences of international undergraduate students in the Faculty of Engineering at the University of Victoria: student expectations and student integration. Several subthemes within each area

were identified, as well as strategies suggested by participants to address any unmet needs of international students.

TABLE II. STRATEGIES SUGGESTED FOR ADDRESSING THE NEEDS OF INTERNATIONAL UNDERGRADUATE STUDENTS

| Theme | Suggestions | Location |
|--------------|---|-------------------------|
| Expectations | Staff or student liason with Engineering Student Society | Within UVic |
| | Faculty mentor for international students | Within UVic |
| | Cross-department committee to address international issues | Within UVic |
| | Make classroom materials more clear for non-English speakers | Within UVic |
| | International students’ orientation within the Faculty | Within UVic |
| | Peer volunteers to help new students understand expectations | Within and outside UVic |
| | Column on international engineering in Engineering Student Society newsletter | Within and outside UVic |
| Integration | Faculty-student modeling/mentoring <ul style="list-style-type: none"> - Group supervision - Face-to-face - Make explicit where to get help | Within UVic |
| | Peer mentoring | Within UVic |
| | Buddy system for exam studying | Within UVic |
| | Opportunities for individual projects | Within UVic |
| | International student buddy system | Within and outside UVic |
| | Liaisons outside Faculty | Outside UVic |
| | International Students Society links | Outside UVic |
| | Housing | Outside UVic |

A further step that could be taken by the Faculty of Engineering is to encourage engagement of international students both socially and academically within the environment at the University of Victoria. It was suggested that international students are more socially isolated than local students, and thus may encounter challenges in forming peer relationships. It was noted that, “international students [are] more comfortable in pairs with someone from a similar country,” suggesting they may be less likely to engage with local students both academically and socially. This could have a negative impact on the educational outcomes within the University setting, as well as on the integration into the Canadian society more broadly. One participant remarked that, “our job is to train them to work in the real world where you will have to work with people who are not like you... we need to nicely tell them to get over it.” It is of great benefit to the University of Victoria to put in place support for international students that will increase the likelihood of student success and continuation in the program, and thereby future graduation of strong, confident, successful engineers and computer scientists.

Several participants suggested the formation of a mentoring system within the Faculty of Engineering as a particularly useful method to address this issue. This mentoring was suggested at both the student-faculty level as well as the student-student level. The main goal of student-faculty

mentoring was to provide an opportunity for international students to better understand the structure of student-faculty relationships within Canada, as well as a forum to get information from faculty about classroom expectations within this country. Peer mentoring was seen as a step towards providing further support for international students entering their first year at the University of Victoria; these freshmen students are facing several challenges related to transition and integration within this system. A buddy system whereby senior students, either local or international, could be paired with incoming international students would provide a context in which the new students had an opportunity to learn about Canadian customs and norms. This would also provide an opportunity for the international students to form bonds with local students, which could be of great value both socially and academically in terms of study groups and group projects. This system is in line with previous recommendations in the literature aimed at improving students' learning experiences by clarifying expectations [2]. While the main focus of this system is to support the international students, this will also be of value to Canadian-born student buddies who will gain exposure and better understanding of different cultures, which is of particular importance given the current context of engineering as a profession that is greatly globalized.

Students, staff, and faculty noted that the Faculty of Engineering has an excellent opportunity to put support in place for international undergraduate students during orientation week at the University of Victoria. While international students currently take part in a general orientation with students from other faculties, it was suggested that an additional orientation should be made available. Specifically, participants suggested an orientation for international students that would address many of the misunderstandings they are currently experiencing, with an emphasis on knowledge translation about the structure of the university, the faculty, and the common classroom set-up. This would provide an opportunity for sharing information regarding common classroom etiquette and customs in Canada, including an emphasis on expectations regarding active learning and critical thinking. This would also be an excellent venue for an in-depth discussion about the customs and norms about plagiarism in this country, and the specific regulations at the University of Victoria. Beyond information presented at this session, this would also be a way in which international students can identify resources that can help them best succeed in the coming years, both in terms of persons they can later turn to for help as well as more general resources (i.e. Counseling Services, International Students Society, Faculty Advisor, etc).

While the responses garnered in this particular study were of particular relevance to international undergraduate students at the University of Victoria, it is believed that other universities may experience similar issues as those presented here. Many of the suggestions for improvements at the University of Victoria could be highly applicable to other Canadian/US/European postsecondary educational institutions. While some these suggestions may appear to be cumbersome

and difficult to initiate at first, we strongly believe that they are necessary steps for Engineering faculties and universities to take to promote successful completion of engineering and computer science programs by international undergraduate students. These suggestions may require resources from the faculty as an initial investment, but it is expected that the benefits gleaned from these steps will far outweigh the initial costs of setting up such programs. As greater numbers of international students are accepted into engineering and computer science programs, the faculties accepting these students will have an increased responsibility to provide an environment in which academic success is best promoted.

VI. CONCLUSIONS

Qualitative analysis of participant responses regarding international undergraduate students in the Faculty of Engineering at the University of Victoria suggests that some needs of international students are currently unmet. These needs fall into two major categories: expectations and integration issues. This study identifies areas in which our Faculty of Engineering can improve to create a better learning environment for international students. Specific strategies include dissemination of information regarding cultural diversity, peer mentoring, student-faculty mentorship, and a faculty-specific orientation for new students entering engineering and computer science. Implementation of these strategies is expected to have a significant positive impact on the social and academic experiences of international students in these departments.

Future work involves the design of a longitudinal study that will follow a cohort on international undergraduate students in Engineering from the moment they enter the program to graduation. This study will inform us on the challenges that international students encounter as they adjust to the new environment, as well as on how they address those challenges.

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Work in Progress: Out-of-Class Learning: Shaping Perception of Learning and Building Knowledge of IT Professions

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Abstract - Freshman and sophomore college students, who have just begun their academic careers in Computer Science, are challenged by difficult courses while having little insight about the job demands in the information technology (IT) industry. This study adopts an out-of-class learning approach to discover how out-of-class learning (1) shapes students' perception of learning computer science subjects, (2) promotes understanding related to the challenges in IT professions, and (3) closes the gap between computer science education and the required IT skills in industry. The preliminary findings of this study demonstrate that interviewing IT professionals sheds light on the challenges of working in IT. Subsequently, students realize the critical skills in support of future success. This study proposes that course work in project management is a useful mechanism to bridge between the critical skills and technical skills, thereby better preparing students for careers in IT

Index Terms – out-of-class learning, computer science education, computer science learning outcomes, project management education in computer science

INTRODUCTION

Extant literature shows that there are many studies exploring different learning approaches for enhancing computer science education. For instance, Lingard and Barkataki [5] suggested that team-based learning with Web-based tools improved students' participation through collaborative learning and promoted insights into team progress. To accommodate different learning styles, Carver et.al [1] used adapted hypermedia courseware to allow students the ability to customize the course materials according to their learning habits. For augmenting learning effectiveness in computer science education, McIntyre and Wolff [6] applied the World Wide Web (WWW) as an interactive learning tool to teach an Introduction to C Programming course.

However, there are not many studies examining the impact of out-of-class learning on student learning outcomes. Based on a college impact model [4], this study defines out-of-class learning as the interaction between students and the institution's environment. In this respect,

out-of-class learning encourages students to step out of the formal classroom, studio, or laboratory setting to participate in activities relevant to their course work. Additionally, out-of-class learning transcends the traditional classroom and closed laboratory boundaries so as to broaden the student's horizon, augment their knowledge base, and cultivate attitudes and values attributing to future success [4].

In the context of computer science education, this study employs the college impact model and intends to discover how out-of-class learning would enable students to (1) obtain knowledge about real-life IT professions and (2) form more accurate perceptions about learning computer science subjects and shape attitudes and values attributing to their future success. In addition, this study intends to examine how out-of-class learning closes the gap between the computer science education provided by universities and the demand of IT skills in the real world.

THEORETICAL FRAMEWORK

The college impact model stresses the external environment (e.g. the IT industry), sociological conditions (e.g. diversity workforce) and origins of change (e.g. innovation, paradigm shift etc.) [4]. The college impact model suggests that learning outcomes associated with out-of-class learning includes knowledge and subject matter competence, cognitive skills and intellectual growth, psychosocial changes, attitudes and values, moral development, educational attainment, career choice and development, economic benefits, and quality of life after college [4].

As stated, college impact model highlights the value of out-of-class learning [4]. While in-class learning tends to be symbol-based (e.g. programming concept), out-of-class learning openly links to events and objects in the physical worlds (e.g. the most sought-after IT skills in the industry). This thereby suggests that learning well in the classroom does not necessarily mean that one will perform well outside the classroom [7]. Hence, using the college impact approach, this study seeks to assess the learning outcomes produced by the interactions between students and their institution's environments and to discover how out-of-class learning close the gap between the computer science education provided by universities and the actual skills demand in the IT industry.

DATA COLLECTION

This study was conducted at a college in the Midwest region. Students enrolling in an Introduction to Computer Programming course were randomly placed into different groups. It was mandatory for each group to interview an IT professional. Each group was assigned a different interviewee (IT professional). Upon completing the interview, every student was required to provide written feedback regarding his or her experiences for out-of-class learning. In two semesters, this study collected data from 7 groups consisting of 21 individuals. Overall, this study collected approximately 70 pages of transcripts with students' written feedback.

RESEARCH METHODOLOGY

Since all human experiences can be interpreted and understood as text [2], the data collected in written text from this study depicts student perspectives for out-of-class learning. The hermeneutic circle approach was employed to analyze the written feedback gathered from students. Mainly, the hermeneutic circle approach [3] proposes that an understanding of a complex whole comes from the preconceptions about the meanings of its parts and their interrelationships. Given that, the sentences written in student feedback are aspects that serve to shape an overall understanding of student perspectives regarding the out-of-class learning. This provides insight into how the global understanding of student perspectives concerning the out-of-class learning improves the understanding on each part.

DATA ANALYSIS

At the preliminary stage of data analysis, this study discovered that out-class learning experience enabled students to realize the importance of communication. A student mentioned:

"Surprisingly, I learned that communication is very important in the computer science major because to work efficiently in groups you need to communicate".

Additionally, students learned that there are job opportunities in computer science field:

"Overall in the interview, I learned that I shouldn't ever have to worry about job opportunities because job market is growing and will continue to grow".

Through the interview, students gained reassurance that they have chosen the right field:

"At times I wonder if I made the right choice but after interviewing [the interviewee] I see more and more that I did make the right choice".

Most importantly, students began to understand the insights of the IT industry. A student stated that his/her interviewee shared his/her pearl of wisdom. The interviewee mentioned:

"I think one of the big things that you can do is just try to stand out in IT....to really get yourself established and to get yourself built up in IT."

Also, an interviewee voiced his/her view to dissolve the stereotype of IT workers, claiming that IT workers are not insulated from social interaction in the workplace:

"A lot of people think that IT people are a bunch of loners. NOT TRUE! It's one of the most team oriented jobs I have ever had. A project requires so many talents...the people who make it look good aren't the same people who do the coding. It's a huge team thing."

Another interviewee shared the challenges he/she faced: *"[My client] insisted on using the wrong technology. There are times that you don't have a choice. You're told what has to be done and you do it."*

DISCUSSION, CONCLUSION AND RESEARCH IMPLICATION

The preliminary findings reveal that out-of-class learning promotes (1) insights into the IT field; (2) criticality of communication skills and teamwork; (3) awareness of the current IT job market; and (4) reassurance of choosing IT as the right field. In conclusion, the preliminary findings infer that out-of-class learning enables a new learning channel in computer science education. Mainly, out-of-class learning sheds light on the challenges in the IT industry, allowing students to decide whether they have made the right decision in choosing their majors. The insights gained from the interview also help students to justify their investment of time and money in learning difficult subject matter.

The implication of this study proposes that out-of-class learning enables students to shape perception based on the importance of communication and teamwork. This gradually forms student perceived learning about computer science. To close the gap between computer science education offered by universities and the required IT skills in the real world, the computer science curriculum may want to incorporate project management course work to cultivate communication skills and teamwork among students. This can prepare students for attaining future success. Finally, this is a research-in-progress, and therefore, more research is required to yield meaning findings.

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What Should I Do Next?

How Advanced Engineering Students Decide Their Post-Baccalaureate Plans

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Abstract—To describe how advanced engineering students decide their post-baccalaureate plans, we conducted a mixed-methods study with engineering students at a large public university in the Midwest. According to the surveys, there were no statistically significant differences between men and women in their choices of post-baccalaureate plans. Students who had positive undergraduate research experiences and students who felt attached to their departments as undergraduates were more likely to enter graduate school immediately after graduation. Students who had industrial internships were more likely to enter professional practice immediately. From the interview data, we defined eight decision style archetypes that characterize how students make post-baccalaureate plans.

Keywords—decision-making; post-baccalaureate plans; careers; graduate study

I. INTRODUCTION

Having graduated from Harvard College in 1955 with a degree in mathematics, I was confronted with a decision as to what to do next. Working for a living had little appeal, so graduate school was the obvious choice. —Richard M. Karp [1]

When approaching the senior year, many undergraduate students start to seriously consider their post-baccalaureate plans. Seniors ask themselves, “What should I do next?” Some of them may already have specific post-baccalaureate plans, while others may just have some vague ideas about their lives after undergraduate studies. Picking a post-graduation plan can be difficult. For engineering students, the most common two post-baccalaureate choices are working in industry and entering graduate school in engineering. There is little previous research on how engineering students make this choice, however.

In this paper, we address a basic research question: *What factors influence the post-baccalaureate plans of engineering students?* Through surveys and individual interviews, we determined what factors have influenced students’ decision-making processes when they choose between work and graduate school. We described eight different decision styles. This study may also provide some insights to engineering educators and administrators when they advise engineering students who are making post-baccalaureate plans.

II. LITERATURE REVIEW

Research on enrollment in undergraduate engineering programs has generally concentrated on factors that motivate first-year students to choose engineering and factors that affect students’ persistence in engineering programs [2, 3]. In particular, professional identity can influence the level of commitment to an engineering program [4]. Students who demonstrate some personal identification with engineering tend to persist to complete an engineering degree. By contrast, students who demonstrate poor connection with engineering tend to switch to other majors. Previous engineering experiences do not necessarily affect a student’s professional identity [5].

Meanwhile, there is limited literature on seniors, who are struggling with a significant choice for their future. In one of the few studies to include engineering seniors, Amelink and Creamer [6] point out that since peers can influence students’ career aspirations, gender biased behavior and male-dominated culture may negatively affect female students in engineering.

Basically, engineering students have two common choices for post-baccalaureate plans. The first one is to enter graduate school immediately. The Academic Pathways Study [2] shows that forty percent students are considering engineering graduate school, and more than sixty percent of engineering graduates have a combination of plans. The other common post-baccalaureate choice for engineering students is to enter the workplace to begin their careers.

Students’ choices of careers are influenced by many factors. Social Cognitive Career Theory (SCCT) organizes the factors that influence how students choose their career paths, and why students choose certain careers instead of others [7]. SCCT does not seem to apply to choosing graduate school, however.

III. RESEARCH METHOD

To determine the factors that influence engineering students’ post-baccalaureate plans, we conducted a mixed-methods study at a large public research university in the Midwest, with the approval of the local Institutional Review Board (#12244). All 2,293 seniors and all 664 first-year graduate students in the College of Engineering were invited by e-mail to participate in an online survey and an optional

follow-up 60-minute interview. The full survey and interview protocol appear in the senior thesis of the first author [8].

The survey for seniors had 25 questions, including 9 open-ended questions. The survey for first-year graduate students had 27 questions, including 10 open-ended questions. Sixty-two seniors and 43 first-year graduate students responded.

Among students who responded to the interview invitation, we selected eight students to participate in a semi-structured interview, based on their genders, majors, domestic/international status, and academic standing. We selected only graduate student interviewees who had entered graduate study directly after they received their bachelor's degrees. We assigned a pseudonym to each interview participant. See Table I.

TABLE I. INDIVIDUAL INTERVIEW PARTICIPANTS

| Pseudonym | Gender | Major | Academic Standing | Domestic/International |
|-----------|--------|-----------------------------------|---------------------------------------|------------------------|
| Patricia | Female | Bioengineering | 5 th year | Domestic |
| Jason | Male | Engineering Physics | Senior | International |
| Elizabeth | Female | Civil & Environmental Engineering | Senior | Domestic |
| Brian | Male | Industrial Engineering | Senior | Domestic |
| Richard | Male | Computer Science | 1 st year Graduate Student | Domestic |
| Lisa | Female | Computer Engineering | 1 st year Graduate Student | International |
| Jennifer | Female | Physics | 1 st year Graduate Student | Domestic |
| Daniel | Male | Mechanical Engineering | 1 st year Graduate Student | International |

IV. SURVEY RESULTS

A. Respondents

Students who were unsure about their post-graduation plans or had other plans besides work and graduate school were removed from the analysis. In total, 100 responses were analyzed out of 105 responses. In Table II below, "Work" counts the number of advanced undergraduate engineering students who plan to work in the industry after graduation. The "Graduate School" category combines all first-year graduate students with those undergraduates who planned to continue to graduate school.

TABLE II. DISTRIBUTION ON POST-BACCALAUREATE PLANS

| Work | Graduate School | Not decided | Military Service |
|------|-----------------|-------------|------------------|
| 39 | 61 | 4 | 1 |

Some students did not answer some survey questions; at the very minimum, for each question, 77 responses were used, but mostly 95 to 100 responses were used. We used Fisher's exact test for two-way contingency tables to check for significantly differences between students who chose industrial jobs and students who chose graduate study. We used the Mann-Whitney U test to check the influence of participation in student organizations. We considered a difference significant if the statistical test produced a p

value of 0.05 or less; these cases are marked with an asterisk (*).

B. Genders

There was no significant difference between men and women in their decisions between industrial jobs and graduate schools. See Table III.

TABLE III. GENDERS

| | Female | Male |
|-----------------|--------|------|
| Work | 15 | 24 |
| Graduate School | 23 | 38 |
| p value | 1.00 | |

C. Research Experiences

In Table IV, "Have research experiences" counts the number of engineering students who conducted research when they were undergraduates. Research-based internships are also included.

TABLE IV. RESEARCH EXPERIENCES

| | Have Research Experiences | No Research Experience |
|-----------------|---------------------------|------------------------|
| Work | 15 | 24 |
| Graduate School | 43 | 18 |
| p value | 0.0019* | |

According to Table IV, there was a significant difference between students who had research experiences and those who had none in their choices between industrial jobs and graduate schools. We should not conclude that an undergraduate research experience predisposes the students to choose graduate school, however: the quality of that research experience matters. Survey responses also indicate that research experiences have both strong positive and negative influences on students' decisions to enter graduate school. Even a single negative research experience can discourage students from choosing graduate school.

They showed me that I excelled in and understood the laboratory research process. Since this is what a large part of grad school looks like, I thought I would extend and improve those skills by pursuing a PhD. —Mechanical Science & Engineering, First-year Graduate Student

Undergraduate Research Lab. Worked with a grad student, topic ended up being boring, which caused me to be less interested in research. —Computer Engineering, Senior

D. Internships

In Table V, "Have Internships" counts the number of advanced engineering students who worked in industrial positions, in a form of summer internship or co-op. Very few survey respondents had previously worked full time. Research-based internships are excluded from this count.

TABLE V. INDUSTRIAL INTERNSHIPS

| | Have Internships | No Internship |
|-----------------|------------------|---------------|
| Work | 32 | 7 |
| Graduate School | 21 | 17 |
| p value | 0.014* | |

According to Table V, there was significant difference between students who had industrial internship experiences and those who had none in their decisions between industrial jobs and graduate schools. Survey responses also indicate that students who were positively influenced by their internships planned to work after graduation. Very few students reported negative industrial experiences.

Multiple internships and co-ops. They have exposed me to the working industry and have likely influenced me to search for a job as opposed to continue my education. — Mechanical Engineering, Senior

E. People

There was no significant difference between students who are influenced by people, such as mentors and friends, and those who are not in their choices between industrial jobs and graduate schools. On the other hand, survey responses suggest that people such as family members and advisors are indispensable in students' decisions on their post-graduation plans. See Table VI.

TABLE VI. PEOPLE

| | Large Influence from People | Little Influence from People |
|-----------------|-----------------------------|------------------------------|
| Work | 26 | 3 |
| Graduate School | 42 | 8 |
| <i>p</i> value | 0.74 | |

Mom and grandparents convinced me that learning more was essential. [Name of professor] has been so nice to me and convinced me that I need more experience in research. —Agricultural & Biological Engineering, First-year Graduate Student

F. Attachment

In Table VII, "Attachment to My Department" counts the number of advanced engineering students who felt connected to their departments when they were undergraduates. Students who reported such attachment as somewhat connected to very closely connected are included. Moreover, "No Attachment to My Department" counts the number of advanced engineering students who reported little connection to their departments as undergraduates.

TABLE VII. ATTACHMENT

| | Attachment to My Department | No Attachment to My Department |
|-----------------|-----------------------------|--------------------------------|
| Work | 21 | 18 |
| Graduate School | 43 | 13 |
| <i>p</i> value | 0.026* | |

According to Table VII, there was a significant difference between students who felt connected with their engineering departments and those who have little in their decisions between industrial jobs and graduate schools. Specifically, a good connection to the department can attract undergraduate students to stay in the same program.

I feel really close to the MatSE department and am applying there for grad school because of it. —Materials Science & Engineering, Senior

G. Student Organizations

In Table VIII, "Participation in Student Organizations" counts the number of advanced engineering students who participated in student organizations during their undergraduate study. We use a 1 (Very active) to 5 (Not active at all) scale to describe how actively students participated in the student organizations when they were undergraduates.

TABLE VIII. STUDENT ORGANIZATIONS

| | Participation in Student Organizations | | | | |
|-----------------|--|----------|-----------|-------------------|---------------------|
| | 1-Very active | 2-Active | 3-Neutral | 4-Not that active | 5-Not active at all |
| Work | 23 | 9 | 3 | 2 | 2 |
| Graduate School | 27 | 16 | 6 | 6 | 6 |
| <i>p</i> value | 0.12 | | | | |

There was no significant difference between students who participated in student organizations and those who did not in their choices between industrial jobs and graduate schools. On the other hand, survey responses indicated that participation in student organizations can help students develop professional skills.

They have significantly improved my network of professionals in engineering, allowing me further insight into the field. They have also given me great amounts of interpersonal experience, a necessity for any engineer. — Material Science & Engineering, Senior

IV. INTERVIEW RESULTS

The eight interviewed participants described similar factors that influenced their post-graduation plans. Although they shared some similarities, the eight interviewees expressed different personalities and decision styles. Obviously, various styles and attitudes played important roles in participants' decision-making process. To fully represent different styles, we used a grounded theory process to define eight archetypes. A student might fit several archetypes. See Table IX.

TABLE IX. EIGHT ARCHETYPES

| | |
|---|---|
| Avoider Attributes: Eschews intimidating situations that cause insecurity and reduce confidence | Opportunist Attributes: Seizes opportunities when they arise; seeks personal benefits |
| Drifter Attributes: Follows trends; easily influenced by other people | Planner Attributes: organized; systematic; following goals step by step |
| Pragmatist Attributes: Practical in actions and decisions | Idealist Attributes: Enthusiastic; passionate; optimistic |
| Tortoise Attributes: Content with current conditions; resists change; avoids potential risks | Adventurer Attributes: Takes risks; embraces change; loves challenges |

Avoider

The Avoider feels anxious and fearful in risky situations. Usually, the Avoider identifies these situations and understands their potential risks. Lacking confidence and courage, the Avoider intentionally avoids encountering

these risky situations. As a consequence, when confronted with an uncomfortable situation, the Avoider often hesitates, and then chooses to escape that situation with rationalizations.

I don't feel prepared for a real job yet ... I haven't had any winter driving experience at all being that far from parents (like Chicago) and being that far from everyone I know and having to drive myself all over the place to work, to the store, to the gym, everywhere all the time is really intimidating for me. —Elizabeth

Opportunist

The Opportunist takes advantage of an opportunity because of its long term benefits, even when the opportunity itself does not interest the Opportunist personally. If an opportunity could guarantee better income or career promotion, the Opportunist would grasp that opportunity immediately. The Opportunist prioritizes income and career promotion over personal interests.

To become, say, a professor is a little stressful and maybe not completely something I should do but I might as well try in a sense. To get to that level where people would trust you with that kind of thing, especially at the undergraduate university level, you need to have a PhD ... if I manage to complete a PhD that opens an extra door of saying maybe I can be a professor, maybe I can be trusted to be a mentor for other students. —Richard

The biggest difference between the Avoider and the Opportunist is their motivations. The Avoider tries to avoid uncomfortable situations, whereas the Opportunist seeks opportunities that are most rewarding. For example, when the Avoider decides on post-baccalaureate plans, the Avoider might wish to avoid social interactions required in an industrial position. The Avoider would choose graduate school because it would require fewer social interactions, rather than because of an interest in research. By contrast, the Opportunist might apply for job openings and to graduate programs simultaneously. When offered admission to a graduate program but no suitable industrial job, the Opportunist would choose to enter graduate school.

Drifter

The Drifter is greatly influenced by the environment and adopts the values and goals of others. Because the Drifter listens to different opinions, the Drifter tends to be indecisive. Rather than think independently, the Drifter imitates and follows the actions of most others. The Drifter enters professional practice or graduate school without clear reasons or goals.

Back in my undergraduate, most of the people go to grad school. It's like the trend. In that time, I don't have very distinct, clear plan for my future life. I just follow the trend. —Daniel

Planner

The Planner is highly organized and composes explicit plans for achieving goals. The Planner loves to schedule and prepare everything ahead of time in order to meet deadlines.

The Planner considers not only the overall goal, but also the details of each step. Compared with others, the Planner takes a long-term perspective on life, and invests time and effort planning for life-long benefits.

I like to plan for long terms. I planned my post-graduation plan long time ago. Now I am planning for my post post-graduation's plan, what I am going to do after my post-doc. Do I want to start a family? What kind of house do I want to buy? What should I start investing now? ... I start planning and thinking about it, start taking actions. —Jason

The Drifter and the Planner have different sources of influences. The Drifter is dominated by the trends and others' opinions, whereas the Planner follows specific plans. The Planner takes others' suggestions only for reference, whereas the Drifter blindly accepts those suggestions. For example, although the Planner consults people such as advisors and friends, the Planner will not change the original plan due to what most people has chosen. In contrast, if most of the Drifter's acquaintances choose industrial jobs over graduate school, the Drifter will do the same.

Pragmatist

The Pragmatist is unemotional and prioritizes the practical aspects and consequences of decisions. The Pragmatist chooses a career goal that is logically related to his or her academic program. Then the Pragmatist chooses an industry job or graduate school that is an essential step toward that goal. When making short-term career plans, the Pragmatist emphasizes financial compensation. The Pragmatist understands that some jobs have the potential for regular career promotion and advancement into managerial positions. Targeting at a better career path, the Pragmatist actively pursues higher education, such as a PhD degree, even with little interest in and passion for the degree itself.

Starting salary for a PhD will be around 7000 or 8000 per month, that give you 80,000 to 90,000 a year. That's why I do a PhD and it give you a good income. If you lose a job, with a PhD, you can go anywhere that is willing to accept you. —Jason

It would be relatively easy for me to get a job in Korea ... but I want to stay in the states. So one way I can do that is to get a job in the United States or go to grad school, don't want to go back to Korea, so I go to grad school. —Lisa

Idealist

The Idealist is driven by emotions and feelings, and pursues the ideal over the practical. The Idealist naturally follows feelings and disregards many practical concerns. Instead of evaluating both advantages and drawbacks, the Idealist concentrates only on the advantages.

Well, I always wanted to go. I feel like the reason I really wanted to go was that graduate school really makes you an independent scientist. —Jennifer

The Pragmatist and the Idealist hold opposite attitudes. The Pragmatist makes decisions logically and practically, while the Idealist measures different situations depending on

feelings. When the Pragmatist plans to work after graduation, the Pragmatist first considers the job expectations, such as income and promotion opportunities. When the Pragmatist plans to enter graduate school, the Pragmatist concentrates on the affordability of graduate school. In contrast, the Idealist puts personal interests as the highest priority. If a job could bring feelings of happiness and accomplishment, the Idealist would take that job even if the income is lower than alternatives. Similarly, to the Idealist, research areas are more important than whether a graduate degree could bring better career advancement. Therefore, the Idealist's decisions can be impetuous and lack practical consideration.

Tortoise

The Tortoise is content with the current situation and feels secure with low risk choices. The Tortoise is usually afraid of changing. For instance, the Tortoise feels uncomfortable adapting to a new environment or trying a new food. Since changes can bring unnecessary troubles and uncertainties, the Tortoise avoids the potential risks.

I'm not really a big fan of change so I don't really feel like embracing the giant change from being a student to being an adult yet so I'm totally cool with sticking around and being a student some more. —Elizabeth

Adventurer

The Adventurer approaches difficulties with a positive attitude and is not afraid of failure. Even if the initial attempt fails, the Adventurer is still optimistic about other possible solutions. The Adventurer is passionate about challenges in the life. Besides, the Adventurer actively explores, analyzes, and solves challenges.

I wanted something that I found more challenging or that would engage my brain a little bit more than just interacting with people all of the time. —Elizabeth

Even though I want to get things done, I'm a perfectionist, I'm not seriously minded nor say afraid to fail than some of the other students I see. So this is why I'm like - it's okay to fail grad school - just go to it. —Richard

The Tortoise and the Adventurer hold opposite attitudes toward risk. The Tortoise hates risky changes, while the Adventurer prepares for encountering new challenges. When the Tortoise makes post-baccalaureate plans, the Tortoise finally chooses the one that requires fewest changes and involves least risk. Considering job offers, the Tortoise picks the one with a stable position and salary. On the contrary, the Adventurer strives to accomplish daring goals. The Adventurer might choose a position at a start-up company that involves interesting people and projects. Meanwhile, the Adventurer is willing to risk losing that job or receiving a lower income. The Tortoise and the Adventurer take the different approaches to graduate school. The Tortoise would be inclined to a program with a high ranking and sufficient resources for financial aid. However, the Adventurer would value a program with exciting research projects and faculty members.

A. Findings

1) Research Experiences

We usually assume that research experiences allow students to figure out their future concentration areas and prepare them for doing more research in the future. Meyers et al. [5] also point out that research experiences can help students identify and confirm their interests. Our study indicates that research experiences are correlated with interest in graduate school, but the direction of influence is unclear. A research experience could motivate an undergraduate to consider graduate study, or conversely, an undergraduate interested in graduate study might choose to obtain a research experience.

Our results also indicate that many students suffer negative research experiences. Such negative research experiences directly cause students to stop considering graduate school any longer. Specifically, a single negative research experience can lower undergraduate students' passion for research.

2) Industrial Internships

In the surveys, when undergraduate students recalled their industrial internships, nearly all of them described their experiences as positive. Specifically, among the survey respondents, many undergraduate students chose to directly enter engineering workplace due to their internship experiences. Very few undergraduate students reported their internships as negative. Those students chose graduate school over industrial jobs.

3) Attachment

In the surveys, around sixty percent of the first-year graduate respondents reported close attachment to their engineering departments when they were undergraduate students. Most important, because of close attachment to the department, through interaction with faculty members, those first-year graduate students chose to enter graduate school. Some of them even stayed in the same department because they had bonded with faculty and staff in their department. According to the surveys, for many first-year graduate students, when they were undergraduate students, faculty and staff not only provided them abundant resources and suggestions for graduate school, but also encouraged them throughout the decision processes on post-graduation plans.

Several undergraduate survey respondents reported that they felt attached to the department, but such attachment did not influence them to choose graduate school over industrial jobs, or vice versa. Moreover, most undergraduates have little connection to their departments and most of their post-graduation plans are barely influenced by the disconnection.

4) Decision Styles

By studying the interview participants, we developed eight archetypes of decision styles: Avoider, Opportunist, Drifter, Planner, Pragmatist, Idealist, Tortoise, and Adventurer. The Planner, Idealist, and Drifter archetypes

resemble the Rational, Intuitive, and Dependent styles of students' career decision-making defined by Harren [9].

The behaviors of interview participants who fit one archetype are dominated by that single decision style. Moreover, when the influence of one decision style becomes dominant, a student might not be influenced by the research and internship experiences. The decision style of one interviewee, Daniel, matches perfectly with the Drifter. In Daniel's undergraduate institution, most seniors entered graduate school immediately after graduation. Moreover, Daniel's parents believed that Daniel should stay in school as long as possible, and so did Daniel's peers. However, Daniel had little passion for research, even though he had one experience in a research lab in the United States. He mentioned that entering graduate school would help him postpone an industrial job, since he felt unprepared for real-world jobs. Otherwise, he had no particular reason for graduate study. Daniel just drifted into graduate school.

Meanwhile, when the interview participants fit into two or more archetypes, the influence of decisions styles and research/internship experiences can be important. For instance, Brian fit both the Adventurer and the Planner styles. Brian loves challenging problems and prepares himself to solve those problems throughout the undergraduate study. As an Adventurer, Brian is energetic, optimistic, and confident. He joyfully explored his talents and took advantage of them as he proceeded to enter professional practice. Moreover, Brian's aspired to become a future leader and impact his workplace. Through internships, he realized that an industrial job could help him pay off his college debts and prepare him financially for further education in the future. Thus, Brian targeted his post-graduation plan in industry. To become a future leader in engineering, he took leadership roles in the student organizations to further sharpen his interpersonal skills. Brian's decision process illustrates how two archetypes can co-exist in one person and guide him through choosing his post-graduation plans.

B. Limitations

This study was conducted at only one institution, a large public research university. Therefore, the results of this study might not apply to other colleges and universities, which have different institutional cultures.

Because of delays with approvals, both surveys were conducted around the time of final exams in the fall of 2011. The timing of the surveys may have reduced the response rate to below 10% of the entire population.

VI. CONCLUSIONS

To investigate how advanced engineering students decide their post-baccalaureate plans, we gathered data using surveys and individual interviews. In the survey, we investigated six factors that may influence students' post-baccalaureate plans: gender, research experiences, industrial internships, people (e.g., faculty and family members), attachment to the department, and student organizations. For three of the six factors, we found statistically significant differences in students' decisions between industrial jobs

and graduate school: research experiences, industrial internships, and attachment to the department. Students who had research experiences were more likely to choose graduate school, but even a single negative research experience can discourage students from further considering graduate school. Students who had no research experiences were inclined to choose industrial jobs. Students who had industrial experiences were more likely to work in industry after their undergraduate study. When students felt connected with their engineering departments when they were undergraduates, they were more likely to continue to graduate study.

In the interview results, we found that students' post-graduation plans are influenced by their decision styles. From the interview data, we described eight decision style archetypes: Avoider, Opportunist, Drifter, Planner, Pragmatist, Idealist, Tortoise, and Adventurer. By realizing how students fit into one or more archetypes, mentors and advisors can effectively guide students through their decision processes on post-graduation plans.

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“Need to Know” in Engineering Programs; STEMing the Uncertainty around Graduate Education

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Abstract - A country's leadership in global technological and scientific development depends on its ability to recruit and retain students into engineering master's and doctoral programs. This qualitative study aims to develop a fuller understanding of the factors driving U.S. students' decision-making processes with respect to pursuing a graduate degree in engineering. During the fall of 2010, more than 1400 undergraduate engineering students and 800 graduate students at four universities across the United States completed surveys containing open-ended questions that allowed students to express their thoughts about and experiences in engineering graduate education. Thematic analysis of 256 undergraduate student responses focused on the barriers and supports underlying their decisions to pursue graduate education (including uncertainty in the application process, availability of funding, and concern about the grade point average requirement). The responses of 220 graduate students focused on the steps important for successful preparation for and navigation of graduate school (including strong theoretical and research preparation, clear goals for pursuing the degree, choice of advisor/research group, and selection of an engaging research topic). These results clarify the factors influencing undergraduate students' decision-making regarding graduate engineering education, and the qualitative training experiences of students in graduate school. These findings provide undergraduate students a starting point on questions to ask when considering graduate school while alleviating their potential misconceptions. The results also help engineering faculty and administrators improve recruitment of potential graduate students and improve their training experiences.

Index Terms – graduate, undergraduate, qualitative

INTRODUCTION

With expected growth in employment in engineering positions, long-term economic competitiveness and global leadership depends on a country's ability to cultivate a vibrant domestic engineering workforce [1, 2]. The masters and doctoral workforce is of particular importance due to their contributions to research, innovation, and teaching [3]. However, the percentage of US masters degrees earned by

Americans grew only slightly during the 2000s (56.2% from 2001-2004 v. 58.7% from 2005-2009), while the percentage of doctorate degrees earned by American citizens and permanent residents decreased throughout the decade (42.8% from 2001-2004 v. 38.7% from 2005-2009) [4]. Thus, there is a need to better understand the decision-making process of undergraduate students with respect to the pursuit of graduate engineering degrees.

In this study, we qualitatively explore the student decision making process using responses from both undergraduate and graduate engineering students. By integrating these perspectives, we are able to offer guidance to academic departments interested in recruiting undergraduate students, and to undergraduate students seeking guidance in their decision.

QUALITATIVE RESEARCH METHODS

This study analyzed the qualitative responses to a survey that included both quantitative and qualitative items [5]. The following sections present detailed information on the respondents, and the qualitative data collection and analysis methods. The survey was administered to undergraduate and graduate engineering students at four universities across the United States; shown in Table 1.

TABLE I
PARTICIPATING SURVEY INSTITUTIONS

| Institution | Engineering Departments | Engineering Graduate Students* | Engineering Undergraduate Students* |
|-------------|--|--------------------------------|-------------------------------------|
| EPUB 1 | Aerospace, Chemical, Civil, Electrical and Computer, Industrial and Systems, Materials Science, Mechanical | 2,000 | 5,800 |
| EPUB 2 | Chemical and Biochemical, Civil, Computer Science, Electrical, Mechanical, and Systems | 950 | 1,500 |
| MPUB | Aerospace, Chemical, Civil, Electrical and Computer, Industrial and Systems, Materials Science, Mechanical | 2,600 | 5,300 |
| WPRI | Aerospace, Chemical, Civil, Electrical and Computer, Mechanical | 4,100 | 2000 |

*Student populations are approximated to mask the particular institution

All institutions are considered Very High Research Universities (RU/VH) based on their Carnegie Classification [6]. The first two universities, EPUB 1 and EPUB 2 are public institutions on the east coast of the United States. Next is MPUB, a public university located in the Midwest, followed by WPRI, a private west coast university. Students from more than 14 engineering disciplines responded to the online survey, resulting in 256 undergraduate student responses and 220 graduate student responses to two open-ended survey items. Undergraduate students were asked the following question: “Is there any additional information you would like to provide regarding your decision to attend (or not attend) graduate school in engineering?” Graduate students responded to: “Knowing what you know now, what would you tell undergraduate students who are considering graduate school in engineering?” Demographic information on the participants is shown in Tables 2 and 3.

TABLE 2
UNDERGRADUATE PARTICIPANT DEMOGRAPHICS

| Gender | Year in Program | Ethnicity*/Nationality |
|-------------------|-------------------|-----------------------------------|
| Male – 173 (68%) | First – 31 (12%) | Caucasian – 176 (72%) |
| | Second – 43 (17%) | African American – 6 (2%) |
| | Third – 92 (36%) | Hispanic – 10 (4%) |
| Female – 83 (32%) | Fourth – 72 (28%) | Asian/Pacific Islander – 34 (14%) |
| | Fifth – 18 (7%) | International – 20 (8%) |

* 10 students declined to answer this item so the numbers do not add to 256. Percentages shown are relative to the adjusted number of respondents.

TABLE 3
GRADUATE PARTICIPANT DEMOGRAPHICS

| Gender | Year in Program | Ethnicity/Nationality* |
|-------------------|-------------------|----------------------------------|
| Male – 149 (68%) | First – 58 (26%) | Caucasian – 104 (49%) |
| | Second – 64 (29%) | African American – 5 (2%) |
| | Third – 32 (15%) | Hispanic – 5 (2%) |
| Female – 71 (32%) | Fourth – 27 (12%) | Asian/Pacific Islander – 17 (8%) |
| | Fifth – 40 (18%) | International – 89 (39%) |

* 6 students declined to answer this item so the numbers do not add up to 220. Percentages shown are relative to adjusted number of respondents. Ethnicity shown only for U.S. citizens.

Thematic analysis of open ended responses was used to generate individual codes, categories, and ultimately themes [7]. Two members of the research team independently coded the graduate and undergraduate responses. These codes were then integrated into larger categories, and ultimately into broad themes [8]. The findings were then discussed together, to better understand the commonalities between the data sets. Themes, categories and codes are shown in Table 4 for the undergraduate data set and in Table 5 for the graduate data set.

TABLE 4
UNDERGRADUATE THEMES, CATEGORIES AND CODES

| Themes | Categories | % | Codes |
|----------|--|-----|--|
| Barriers | Not Required for Career Goals | 8.2 | <ul style="list-style-type: none"> • Get desired job without advanced degree • Graduate degree = over qualification • No disposable income |
| | Funding Issues | 15 | <ul style="list-style-type: none"> • Can't afford tuition • Pay off student loans |
| | Grades | 8.2 | <ul style="list-style-type: none"> • Grades not good enough • Grades below required minimum • Deadlines |
| | Admin and Application Questions | 8.2 | <ul style="list-style-type: none"> • Who to direct questions • General lack of knowledge about the process |
| Supports | Talked to Faculty or Current Graduate Students | 2.3 | <ul style="list-style-type: none"> • Faculty encouraged student to consider graduate school • Discussed questions with current graduate students • Undergraduate research |
| | Create Career Opportunities | 3.5 | <ul style="list-style-type: none"> • More employment opportunities • Enhance academic record |
| | Personal Growth and Development | 3.9 | <ul style="list-style-type: none"> • To learn more • Pushing personal limits • Learn to think independently |

TABLE 5
GRADUATE THEMES, CATEGORIES AND CODES

| Themes | Categories | % | Codes |
|-------------|-----------------------------------|----|--|
| Preparation | Theoretical & Research Foundation | 29 | <ul style="list-style-type: none"> • Advanced math, engineering, and coding fundamentals • Undergraduate research experience |
| | Clear Goals | 11 | <ul style="list-style-type: none"> • What benefits will graduate degree give? • Long-term career goal |
| Navigation | Advisor/Research Group | 40 | <ul style="list-style-type: none"> • Advisor relationship • Support • Work environment |
| | Engaging Research Topic | 23 | <ul style="list-style-type: none"> • Earnest interest • Passion |
| | Independence | 9 | <ul style="list-style-type: none"> • Take initiative • Self-motivated |
| | Funding | 7 | <ul style="list-style-type: none"> • Funding-source • Outside funding |
| | Begin Research Early | 5 | <ul style="list-style-type: none"> • Find topic early • Start your research early |

QUALITATIVE FINDINGS

Undergraduate responses were divided into 18 different codes (the amount required to fully describe the responses), listed in Table 4. These codes were grouped into 7 broader categories. Finally, the categories were clustered into two main themes: barriers to attending graduate school and supports for the decision to attend. Barriers included: mismatch to career goals, issues with funding, poor grades, and administrative questions. Supports for attending graduate school included talking to professors or graduate students, creating career opportunities, and personal growth and development.

The graduate student responses were described by 15 codes, which clustered into 7 categories and two themes: preparation (the things one needs to do and consider prior to pursuing graduate education) & navigation (the things one must do and consider to successfully complete the degree once admitted). Regarding preparation, respondents indicated that students must have a solid base in research and theory, and have clear goals for pursuing the graduate degree. With respect to navigation, respondents indicated that students must carefully select their advisor/research group, select interesting research topic, cultivate independence, secure funding, and start research early.

In the following sections, the undergraduate findings are discussed using the two main themes: barriers and supports for attending graduate school. We then present detailed findings on graduate student advice to undergraduate students considering graduate school. Finally we will consider these findings together in the discussion section to highlight areas where improvements might be made to recruit undergraduate students into graduate engineering programs.

I. Undergraduate Barriers and Supports to Attending Graduate School in Engineering

Overall, 30 (11%) of the 256 respondents said they were considering graduate school in the future, most often after working a few years. However, it should also be noted that 28 (11%) were considering pursuing a graduate degree other than engineering. The most popular alternative degrees were an MBA (7%) and MD (2%). Other degree programs of interest included public health and law.

The largest barrier reported by undergraduate students surrounded issues of funding for graduate school (15%). This was manifested in several ways, including: the absence of disposable income while attending graduate school, not being able to afford the tuition, and needing to pay off student loans accumulated during their undergraduate years. As a fourth year male mechanical engineering student noted,

Even if I was well funded, I still wouldn't have any disposable income. That means no money to start a family, and no money for hobbies, such as working on my car. I don't live to go to school; I live for the outside activities. If I can't afford those, school isn't worth the torture.

Other notable barriers included the notion that graduate school was not required for the career students thought they wanted (8.2%). A female, third year chemical engineering student felt

...open to the idea of graduate school, especially since I am considering doing research. However, I do not plan on attending graduate school at this point in time because I do not think it is necessary if I want to work in industry.

Several respondents also felt that graduate school would over qualify them for jobs, as a fourth year Aerospace engineering student inferred: "PHD seems to over qualify people for a lot of jobs." Another 8% of students discussed issues with grades, most commonly that they did not think they were good enough to get into graduate school. Several students had comments similar to another fourth year aerospace student who said

I really want to attend my undergraduate institution; however my GPA is 0.2 points (on a 4.0 scale) below the benchmark of what the department wants masters applicants to have. The chair of the graduate board has discussed with me that it is highly unlikely I can get in and my application will not even be considered unless I have the minimum GPA that they require, even despite having a minor in mathematics, excellent research experience, taking graduate courses during my undergraduate years, and having a personality.

Finally there were 8% of students who mentioned confusion with the admissions process and the variety of questions they had about graduate school that they were unsure who to go to for help. Specifically students mentioned a lack of information about deadlines, how the admissions process worked and who to talk with if they were considering going to a school other than the one they attended for their undergraduate program.

Despite identifying several barriers to attending graduate school, students also described several factors that support(ed) their decision to apply to graduate school. These were organized into three categories: talking to professors or graduate students, creating career opportunities, and personal growth and development.

Four percent of the responses centered on students' desire to apply to graduate school as a means of personal development. Specifically students mentioned wanting to learn more, push personal limits, and learn to think independently. A second year male engineering mechanics student noted that "graduate school would provide a great learning experience because so much of your success depends on your ability to think independently."

Discussions with faculty or other graduate students were mentioned in 2.3% of the student comments. Specifically, students mentioned talking directly with a faculty member, participating in undergraduate research with faculty and graduate students, and discussing graduate school with other graduate student teaching assistants or classmates. A fourth year female systems engineering student replied that "I was not interested in attending graduate school in engineering until a professor approached me with his thoughts on it. It called my attention and now I am applying to get into [university's] engineering graduate program."

Finally, there were students (3.5%) who felt that graduate school would create more opportunities for them in

the future. A fourth year electrical engineering student explained

I want to go to graduate school to not only learn more, but also to enhance my academic record With a graduate degree, I will be able to have more employment opportunities in industry and a higher starting earning potential. So, I want to have many career options available to me after I graduate.

Based on our findings, undergraduate engineering students focused on a variety of issues relative to their decision process ranging from very practical (admissions process) to the impact of this decision on their future careers. To better understand the student decision process, we considered the reflections of current engineering graduate students.

II. Graduate Student Reflections on Graduate School in Engineering

On the other side of the decision process were students already in graduate engineering programs. Again, we asked them to reflect on information they would like undergraduate students to know when considering graduate school. The results clustered around the themes of preparation and navigation. With respect to preparation, 29% of respondents emphasized the need for undergraduates to develop a solid foundation in both theory and research prior to pursuing graduate education. Several students made comments similar to these from a third year biomedical engineering (BME) female student:

A degree in a basic engineering discipline, eg Electrical Eng [EE]... is the best way to really learn your fundamentals. Some other BMEs are having trouble with circuit analysis and complex mathematics, and I have a very strong background with these subjects due to my degree in EE.

Similarly, a fifth year computer science student said:

It is very helpful to get involved in research projects while pursuing an undergraduate degree. Being in a research group gets one into the habit of reading and critiquing papers as well as writing, presentation, and deliberation. It helps one think about new problems, different ways to question, and learn about methodology.

The other category regarding preparation (11%) was the need for students to clarify their goals in pursuing a graduate degree. In other words, how does pursuing a graduate degree fit into your long-term career goals? A female fifth year information systems student said

I'd tell undergraduates to think long and hard about why they truly want their PhD degree. It's a long and stressful road. Don't pursue the degree just to have "Dr." before your name. What benefits do you expect to

receive from having a PhD? How interested in, or even passionate about, your field are you? What will your life be like as you are pursuing your degree (e.g. do you really have the time, money, interest, motivation)?

The most commonly reported category with respect to successful navigation of a graduate program was the importance of selecting the appropriate adviser and research group (40%). Distinct from funding and prestige, respondents indicated the quality of interactions with and mentoring support from advisors would "make or break" their graduate school experience. As a fifth-year electrical engineering student indicated,

Find an advisor who is willing to actively participate and invest time in your work. Having an advisor who cares about you as a person and about your career and life aspirations is extremely important, and that kind of advisor will support you to finish your studies no matter what.

In addition to picking the appropriate research group, 23% of graduate respondents indicated the importance of selecting an engaging research topic to successfully navigate through graduate education. A second year engineering mechanics student noted that she warns undergraduates to only pursue graduate education, "if they have a[n] earnest interest in the topic" because "writing a thesis without passion or interest is very difficult."

There were a few other navigation-related categories of responses worth noting. First, students should cultivate a greater sense of agency/independence than in undergraduate education (9%) because "you are in charge of your own success and ability to complete the degree." Second, students should secure funding (7%), because without funding "it will be much more difficult to graduate, and take longer." Finally, students should begin research early in their graduate careers (5%) as this shortens time to degree completion and allows students to "accomplish much more in the long run."

Pairwise comparisons of the percentages of graduate students responding in each category between female & male respondents or American & international students revealed no statistically significant differences ($p > 0.1$, two-tailed t-test). This suggests that the themes emerging from the coding scheme address the structural realities of graduate education that similarly impact students across gender and nationality. The number of American students with coded responses who identify as belonging to underrepresented minority groups (African-American, Hispanic, Native American) was too small ($n=10$) to allow for valid comparisons to the responses for American students from other ethnic backgrounds.

DISCUSSION

To many engineering faculty members, these results are not particularly surprising, since they align with conventional

wisdom about graduate school. However, they highlight the lack of a systematic means for all engineering undergraduates to find out about and fully consider their options for graduate school. To address this, we have used our findings to compile a list of considerations that undergraduate students can use to guide them in the decision process. These recommendations could also be used by graduate programs as recruiting tools to provide information to prospective undergraduate students to start them thinking about graduate school.

1. What do I *really* want to do, and what type of degree is required to achieve it? Reflect on any research experiences you've had, particularly those you enjoyed. Talk to prospective employers at career fairs to gather information about the types of jobs engineers with undergraduate degrees can do versus applicants with a masters or PhD.
2. Engineering departments that offer graduate degrees have a graduate student advisor/director. If you have questions about graduate school at your department, start there. Questions might include how admissions works, GPA requirements, degree program requirements, etc. If you are at an undergraduate institution, undergraduate advisors (including faculty advisors) are also a good initial contact.
3. There are several funding packages available at the department level for research or teaching. Also, there are many national fellowships that provide even more financial support. Talk to other graduate students about typical funding amounts and look at your budget so you can make an informed decision about the financial costs of graduate school. In many cases, U.S. citizens attending U.S. institutions can have most or all of their PhD covered through assistantships and fellowships. (At the graduate level, these types of awards are much more likely to cover tuition and a living allowance vs. smaller undergraduate scholarships.)
4. Selection of the "right" graduate program includes the institution, department and advisor. In addition to considering reputation, make sure that you have similar aspirations and work styles. Have I talked to the advisor that I am planning to work with? Have I talked to their current/recent graduate students about their training experiences, support, post-degree career options, etc.?

CONCLUSION AND IMPLICATIONS FOR GRADUATE PROGRAMS

For current graduate students, the relationship with the advisor and research group were the most frequently mentioned factor affecting the graduate school experience. While preservation of academic freedom is important, graduate deans should consider mentoring or management training for faculty members to help guide them in working

with their respective research groups. Previous research has explored the influence of research group size in student learning [citation blinded], and offers suggestions for faculty relative to managing these groups.

Undergraduate students reported varying degrees of confusion about the application process, who to discuss graduate school with, and how their undergraduate education would prepare them for graduate school. Administrators and academic personnel should keep these things in mind when recruiting for their graduate programs. Information sessions with the graduate program director, or given by current graduate students, could help alleviate this confusion and increase the likelihood that students will feel comfortable applying to the graduate program. Conversely, undergraduate students who had discussions with faculty and current graduate students responded positively about their decision to apply. Faculty members working with undergraduate students, either in coursework or in undergraduate research, should be sure to discuss graduate school with their students or assign more experienced graduate students to answer students' questions and provide assistance.

FUTURE WORK

This study also offers several possible areas for future research. Knowing that a strong theoretical foundation is important, what mechanisms exist to help students refresh some of the basics? Might optional weeklong theory "bootcamps" prior to matriculation make the transition better for both students and faculty? Also, what sort of financial and programmatic supports exist to allow students to begin research early? In the biological sciences, students do research rotations, allowing them to get a sense of the lab environment before joining. Are there funding opportunities that are available only to first year students? How do decisions made in the first year of graduate study influence retention and ultimately degree completion in later years?

For recruiting undergraduate students into graduate programs, how might current graduate students be used to help recruit and assist students through the process, perhaps at a college scale rather than just the department? To what extent might this individual mentoring increase the representation of women and other underrepresented minorities in graduate engineering departments?

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Work in Progress: Smart Teaching: Capture Lectures and Keep Students Engaged Online and in the Classroom

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Abstract—

Classrooms of today are often present on the computer monitors, iPads, and Smart Phones of students. In order to keep the students engaged, professional educators need to utilize the technologies of the digital age to capture and maintain the interest of the students (Salazar [1], 2010). When students are in the traditional face-to-face classroom environments, the use of educational technology can be instrumental in student engagement and learning (Lisenbee [2], 2009). The use of Smart Boards, a technology interactive whiteboard, is one tool that educators can use to increase engagement in the classroom. The ability to present content on a SMART Board and capture the lecture for online learning is step further into the digital age for most institutions. By combining strong curriculum with educational technology, schools can utilize the assets of their faculty expertise to educate students in both on-ground and online venues. The use of the Internet is a powerful educational tool when it provides multimedia technologies for its students (Dey, Burn, & Gerdes [3], 2009). Capturing and delivering the lectures of faculty on the web allows students to engage the learning at their convenience and pace. Enhancing the lecture capture with the use of SMART Boards can provide a multi-sensory learning experience for the instructor as well as the student. When a lecture utilizes an instructor's presence and voice with written content (e.g., PowerPoint), the multimedia content engages the cognitive structures of the students in a positive manner (Dey et al. [3]). The study results presented by Dey et al. [3] suggest that students prefer to see their instructors during a lecture and their learning outcomes are enhanced by lecture capture technologies. National University (NU) is conducting a pilot project that utilizes SMART Board technologies with lecture

capture software. The project's goals include the integration of SMART Boards in on-ground classrooms, capturing lectures for immediate student use (e.g., reviewing content), and developing a video library of lectures for embedding in online courses. This presentation will provide an overview of the work in progress and a review of its current status.

Work in Progress: Smart Teaching: Capture Lectures and Keep Students Engaged Online and in the Classroom

I. INTRODUCTION

A key to effective teaching is keeping students engaged in the learning activities, which includes lectures in on-ground as well as online classrooms (Garrett [4], 2011; Palloff & Pratt [5], 2007). Garrett [4], in a discussion of the literature and research activities relating to student engagement to content, provides this definition of the goal of teaching: "I propose that engagement is the interactive space, or lack of space, between student and the subject, and we, as teachers, hope that, as an outcome, deep learning arises or is produced from that interaction." (p. 7). Palloff and Pratt [5], in discussing the importance of creating an engaging learning community in the online classroom environment advocate for faculty to promote "honesty, responsiveness, relevance, respect, openness, and empowerment." (p. 22). In any classroom, these goals and values can be enhanced through the effective use of educational technology (Salazar [1], 2010; Lisenbee [2], 2009; Akbas & Pektas [6], 2011).

The use of various technologies in the on-ground and online classroom can facilitate the engagement of students (Salazar [1], 2010; Lisenbee [2], 2009; Akbas & Pektas [6], 2011). Salazar [1], in a discussion of various educational technologies that may be a part of an online program, states "Video lecture capture technology (VCLT) supports student retention by engaging students, increasing student satisfaction, and promoting student achievement" (p. 54). The convenience for students in being able to download and view lectures at times as well as on devices of their choice is key attribute of VCLT according to Salazar [1]. Lisenbee [2] discusses how the use of interactive whiteboards can engage young students. The ability to provide an interactive technology rich environment is an advantage of this tool according to Lisenbee [2]. Akbas and

Pektas [6] discuss the effects of interactive whiteboards on the academic achievement of university students. In the discussion of the results of their research, Akbas and Pektas [6] summarize their findings in this statement:

“Even though interactive whiteboard use might not increase students’ academic achievement significantly, it was seen that it encouraged student participation in the lesson, created a more exciting and enthusiastic atmosphere, and led to more enjoyable lessons. In addition, many students in the experimental group stated that interactive simulations and virtual experiments involved situations that they did not normally encounter in real experiments and this enabled them to visualize the topic.” (p. 13)

The integration of VLCT and interactive whiteboards are two educational technologies that form the core of the work in progress at National University.

II. WORK IN PROGRESS PARAMETERS

National University (NU), which is the state of California’s (USA) second largest non-profit private university, is conducting a pilot project that integrates the use of VCLT with interactive whiteboard uses. The scope of the project includes using VCLT to record lessons and activities in traditional classroom settings for future uses. These uses include review by the traditional classroom student population as well as archiving the recordings for online courses. Based on the literature review presented in the introduction, the researchers expect the project will be beneficial to the students in the traditional classroom as well as those that may view the lectures or activities in online environments.

III. RESEARCH QUESTIONS

The primary research questions for this work in progress are as follows:

1. What are the benefits of using interactive whiteboards in combination with VCLT?
2. What are the challenges of using interactive whiteboards in combination with VCLT?
3. How can the use of interactive whiteboards in combination with VCLT be improved?

A. Participants

The participants for this project include the students and faculty that sign the informed consent form (Institutional Review Board approved). The participant pool will involve the students and faculty involved in coursework in the NU Teacher Education Department. A subset of research questions may come from the work with the students and

faculty members working in the department of Teacher Programs that lead to credentialing. These potential participants may present the researchers the opportunity to create a longitudinal study on the effect of exposure and use of educational technology has on future educators.

B. Method of inquiry

A survey to collect qualitative data in response to the three questions is in the beta development stage for this project. The survey will use an online delivery system to promote anonymity and encourage participation. The collecting of additional qualitative data may implemented by using one-on-one interviews or focus groups.

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Quality of Service, Quality of Experience and Online Learning

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Abstract— Online learning tools are widely used in engineering education. This includes traditional face-to-face, but also distance education. Since these tools rely on Internet connections, the performance of those connections (speed, latency) can impact on how learning tools are experienced by students. Quality of Service (QoS) describes technical performance parameters that reflect the quality of an Internet connection. Quality of Experience (QoE) on the other hand has been widely used to describe how users experience a particular service. In the context of this work, users are students undertaking learning tasks. While technical literature addresses QoE and educational literature discusses online learning, a gap exists describing the relationship of QoS and the quality of the learning experience. This work uses a mixed methods approach to address the research question: What dimensions of QoE of online learning can be affected by QoS? To answer this question, two groups of students were exposed to changing QoS conditions while they were undertaking an online learning activity using remote access technology. Both technical performance parameters, as well as, the impressions were recorded. Subsequently, a focus group was held to get a better understanding of the students' perception of the relationship between QoS, QoE and online learning tools. It is concluded that QoS factors only have an intermediate impact on the quality of the learning experience of the students. Factors such as course design and pedagogy largely determine the quality of online learning.

Keywords—online learning tools; quality of service, quality of experience; quality of learning experience performance; distance education.

I. INTRODUCTION

Online learning activities are often seen as tools to assist student learning and to improve their engagement. This is of particular relevance for students that are remote from campus such as distance education students. Information and Communication Technology (ICT) is used to provide equitable learning opportunities for those students. Examples include audiovisual lecture recordings but also remote access to software and hardware experiments. As these tools depend on telecommunication infrastructure and the Internet; technical performance depends on Internet access speed, location and network traffic. These technical parameters are generally referred to as Quality of Service (QoS). "QoS is defined as the ability of the network to provide a service at an assured service level" [1, p. 3] and includes performance parameters such as

delay, jitter and throughput. These parameters can be measured, but are unable to capture the experience of a system user, e.g. whether the system is suitable to perform a particular learning task.

In recent years, the telecommunication industry has placed a higher focus on the consumer experience and Quality of Experience (QoE) has become a major research area. QoE is frequently used in a technical context and "refer(s) to the overall acceptability of an application or service, as perceived subjectively by the end user" [2, p. 216]; "how satisfied he or she is with a service in terms of, for example, usability, accessibility, retainability and integrity of the service." [1, p. 3]; or "as the basic character or nature of direct personal participation or observation" [3, p. 619]. However, no QoE definition is universally accepted or widely used. The term is also well established in psychology and other disciplines (e.g. [4]), where it has a more general meaning. Much of the educational literature in this area has focused on understanding QoS for online tools without reference to the significance of QoS for QoE of learners. QoE research in the technical domain does not directly apply, as learning is very different from the general consumer experience.

Online learning tools are becoming increasingly prevalent in education. This applies to both, face-to-face as well as distance education. Understanding the impact of technical limitations on learning that is occurring is therefore an important research area. This work takes a step forward from the current focus in educational literature on QoS to QoE. This is only a stepping stone as the ultimate goal is to understand the impact of QoS on learning, and not only on user experience. Understanding factors in online learning that are susceptible to changes in QoS is by its own right relevant and can lead to better online learning environments. Using the work of Mayer [4] and Gilbert, Moreton and Rowley [5], this study has developed a model which maps the factors contributing to the quality of the learning experience in online environments. Using a mixed methods approach, it addresses the research question: What dimensions of QoE of online learning can be affected by QoS?

The remainder of this paper is organised as follows: Section II discusses the general context and the background of this study. Section II introduces the interest in QoS for the quality of the learning experience and provides the framework

for this study. Section III outlines the methodology that was used and Section IV highlights initial findings. These are discussed in Section V and implications and further work are outlined in Section VI.

II. CONTEXT AND MOTIVATION

This section provides an introduction into the general context and the motivation for this study, the details do not directly relate to the research question. The University of Southern Queensland and the Faculty of Engineering and Surveying have a distinct student cohort with 76% of students studying in a distance mode, not located on campus. Courses are generally offered in an on-campus and external mode in parallel. Traditionally, print material has been used as means to provide learning materials; today teaching relies heavily on ICT tools and Internet technology. This includes the course management system, a branded Moodle instance as well as electronic lecture recordings. In an attempt to provide equitable learning opportunities, the Faculty of Engineering and Surveying has developed Remote Access Laboratory (RAL) technology [6] that provides external students with access to hardware and software experiments on campus.

The engineering courses that are offered by USQ are accredited by Engineers Australia, the Australian equivalent of ABET. To give students the opportunity to practice practical, hands-on skills, students have to attend practical on-campus sessions, so-called residential schools. During these residential schools, external students travel to Toowoomba to attend a week of laboratory sessions, usually one per semester.

Due to the cliental, the external student cohort is different from the traditional student body seen at many Universities. Most students are mature age and are working full time. The average age depends on discipline and cohorts, but is around 30. Generally they are highly motivated but time poor as they have competing family and work commitments. The quality of the learning experience becomes very important in this environment.

III. THEORETICAL FRAMEWORK

The field of research into online learning is very broad and detailed. Within this body of work, many studies with a technical focus pay particular attention to understanding the effect of QoS on QoE in the learning environment. This focus derives from related studies of QoS in telecommunications or other consumer-based Interactive Multimedia Environments (IMEs). As a result of this heritage, the QoS literature tends to treat users of technology for learning as consumers, with the associated needs and expectations [7]. Where multimedia environments are consumer driven, decades of market driven research into consumer uptake and acceptance of ICTs provides researchers with explicit understandings of what users expect, and how they behave and how they perceive the technology that they are ‘consuming.’ This ‘consumption approach’ is demonstrated by [8] who cite various formal and informal definitions of QoE from the available literature which reflect this: “the degree to which a system meets the target user’s tacit and explicit expectations for experience”; “subjective measure of a customer’s experiences with a

vendor”; “user perceived performance”; and, “the degree of satisfaction of users” (p. 483).

The consumption approach contains a shortfall in attempting to understand how users experience quality in online environments when the task at hand is learning. In attempting to adapt the broader body of knowledge about IME, consumption to environments where users are learners, it is necessary to address the fact that the relevant dimensions that make up QoE are unlikely to be the same. For example, the nature of technology use will be different in terms of users’ motivation, their purpose in completing tasks, as well as the nature of the tasks themselves. Each of these variables significantly influences user behavior and perception, and, thus, the nature of QoE. In evaluating the effect of QoS on QoE for learning, it is necessary to specifically consider how system performance issues have affected the learner in the process of carrying out their (learning) tasks. In other words, this requires observing if, rather than assuming that, QoS issues have affected the learning and what the effect has been.

Wu [8] make a significant step in this direction with a shift of focus from a system-centric view of IMEs to a human-centric one, encompassing theoretical frameworks from psychology, cognitive sciences and sociology as well as information technology. They attempt to “map the QoS-QoE relationship” by “capturing the human-centric quality modalities.” (p. 481). In doing so, they define QoE as “a multi-dimensional construct of perceptions and behaviours of a user, which represents his/her emotional, cognitive, and behavioural responses, both subjective and objective, while using [an IME] system” [8, p. 483]. Their model maps the relationships among various QoS and QoE factors drawn from these disciplines. This definition of QoE is useful in that it highlights that QoE must derive firstly from the “user.” Experience is necessarily based on perception, which derives partly from the characteristics of the user, but this definition also captures the complex, “multi-dimensional” nature of the environment in which the perception is based. Despite this step forward, Wu et al.’s model does not take a specific focus on experiences in learning environments.

The wide range of available literature on online learning highlights the many course design, learning tool design and pedagogical factors which have a significant influence on quality in online environments [9]. Sambrook’s [10] in-depth study demonstrated that many factors, such as user-friendliness, presentation, structure of tasks and navigation within tasks, all affect the perceived quality of online learning tools. Importantly, these are design and pedagogical issues that are central to how the learning takes place. Further, fundamental learning theory holds that factors such as a clear set of instructional goals, the perceived relevance of tasks in relation to these goals and the resultant motivation and cognitive processes of learners, are all central to how learners behave and perform [11]. In this respect, there are influencing factors in online learning environments that are not common to more general online environments. The effect of QoS on how these environments are experienced by users can be expected to be different than for general consumption. To understand the effect of QoS in online learning, it will be necessary to describe how it interacts with these other factors.

In attempting to deal with the issue of perception during learning, Moebis' [12] work focused on the effect of 'flow' (defined as complete immersion within a task, leading to intensive interaction within an activity) on QoE for learners. Flow is directly affected by QoS issues such as access speed and consistency. The detailed QoE model included many factors present in the learning environment which can mediate the relationship between QoE and QoS. These factors include "choice of learning path, learning styles, feedback, interaction" and "clear sets of goals". Despite this, her quantitative method of measuring the effect of flow on QoE did not account for these factors, and consequently, the model is not capable of explaining the relationships among all of the elements that are presented. The author uses a Delphi panel of technical (QoS) experts, rather than an instrument which captures data from the learners or the learning environment. Although flow is expected to be highly relevant to the effect of QoS on QoE, until it is understood how it is mediated by other factors and the learning tasks, the picture is incomplete

IV. METHODOLOGY

A mixed-methods approach has been chosen to capture data about learning from the learners themselves. The study was undertaken in two stages, a pilot study to explore the relevance and coverage of the original model [13] and a main case study to identify dimensions of QoE that are affected by QoS. Initially it was also intended to collect data at the actual student locations via traffic loggers [14]; however, due to unavailability of hardware this was not possible. The methodology, discussed below, was chosen instead.

A. Pilot Study

The purpose of the pilot study was to identify the data that needed to be collected in the main study to address the research question. The pilot consisted of a focus group and a student survey exploring their experience with online learning systems in a third year computing course; and any issues – technical as well as non technical they encountered. The survey questions were based on a comprehensive description of the learning environment by Sambrook [10] as tabled in [13, Table 1]. A focus group session was undertaken to validate the survey instrument and explore the answers in more detail. The pilot highlighted two key issues with implications for the main study [13]:

Students do not have a common understanding of "online learning tools" or "tools for learning". Student perceived many functions of tools of the Learning Management System (LMS) as administrative in nature rather than supporting or promoting learning. The implications of this were that what students perceive as significant for the learning experience may largely depend on how students understand the function of the tools. The pilot also highlighted another issue – the participants focused mainly on issues of course design and delivery when speaking about issues that were significant for their learning. This raises the question if QoS issues can be sufficiently isolated from education design and delivery issues to understand the effect of QoS on QoE.

To avoid these issues in the main study, a learning activity in the context of Remote Access Laboratory was used as the learning tool. These activities are perceived by students as sophisticated enough to be understood as a learning tool. Furthermore, variations in QoS such as issues with delay or bandwidth have a direct impact on the performance of the interactive system and help to create a better picture of the impact on QoE. To address the second point and to isolate design and delivery issues from the impact of QoS, students undertook RAL activities that were self-contained and not integrated into a scaffold learning program. Students also undertook the same activity several times, so they were aware of the expected outcomes

B. Main Study

The main case study was based on two groups of students of diversely situated distance students who were on campus for residential school. Due to their mix of near and far, urban and rural locations, these students routinely experienced different QoS in the same academic courses. During their time on campus they were each asked to perform a laboratory experiment, first under normal laboratory conditions and then remotely via computer using RAL technology. During the remote session they were given several attempts at the activity and in each attempt the QoS was varied. Subsequent to the experiment sessions, the students took part in focus groups to explore factors impacting their QoE both for their routine studies, and the test experiments.

To replicate different QoS conditions, a Wide Area Network (WAN) Emulator was used. It is based on NetEm [20] to emulate various network conditions including delay and bandwidth limitations. The emulator was placed in-between the user workstation and the corporate network. Testers configured network conditions with a simple web interface. To make the test environment more accessible to the test subject, network parameters were related to practical access options and locations. The following locations and associated RTT were selected as typical locations for potential system users: Local – Toowoomba (<1ms), Melbourne (50ms), Perth/New Zealand (100ms), Singapore/USA (200ms), Europe/Dubai (300ms) and other locations. These are only indicative values; in practice, RTT largely depends on routes packets take to their destination and routes depends on Internet Service Providers (ISP) and peering arrangements.

The first group of seven students was taking part in a second year hydraulics practice class on campus; a class providing "a broad introduction to the practical aspects of water engineering and focuses on the development of analytical, manual, diagnostic, communication and group interaction skills." The RAL activity was a hardware-based experiment setup of a *tapered passage (Bernoulli)* experiment, where students determine flow rate and pressure heads.

The second group of eleven students was taking part in a third year residential school on operating systems and computer networking. The RAL activity in this example was largely software-based around Ubuntu 9.10, hosted on a virtual machine which can be accessed remotely. The activity includes a shell scripting exercise and control of a web-relay on the

local network. The main aim of this activity is to expose students to shell scripting and the control of a relay via a network connection without the need to install a Linux distribution on their own computers and to purchase the hardware.

Both activities required students to apply theory learned in academic courses to an instance of practice.

V. FINDINGS AND ANALYSIS

This section summarises the outcomes of the student focus groups. All participating students were normally studying by distance education and from different disciplines within engineering. This proved to be an advantage for this study as the students were well practised. This meant that the students were capable of discussing their perception of the QoE of both their general online studies from home and the specific experiments conducted on-campus during residential school. This included being able to report on the specific factors which had an effect on their perception of QoE and what this effect was.

A. Factors Impacting QoE for Routine Studies

The problems that students reported in relation to general online learning included:

- Inconsistent delivery of online courses,
- Disorganised learning environment,
- Learning tools not functioning properly,
- Lack of support from staff,
- Insufficient opportunities to interact with staff and students,
- Inflexible options for how students learn,
- Incomplete materials,
- Lack of pre-existing skills or knowledge.

Predominantly, these problems reflect issues with the design and delivery of courses in the online environment and, consequently, how students are able to engage with online study. This list indicates that participating students were conscious of and thoughtful about their own perceptions and experience of the learning environment, and that they understood how these problems affected the quality of their learning.

The focus groups showed that participants often understood such problems well enough that they could make practical suggestions for how they could be addressed. For example, they suggested lecturers could provide last year's recordings of lectures as a backup for when a recorded lecture was unavailable, or provide amendment pages to study guides to address gaps and errors in these materials, without the need to rewrite. Further, alongside these suggestions they could comment explicitly on how such improvements would reduce their frustration and make achieving their learning tasks easier. Significantly, these students showed remarkable awareness of the realities and difficulties of designing and delivering

teaching and learning, including the difficulties for time poor academic staff and equity issues for online versus on-campus students. These observations do not directly relate to the research question, but document the unintended outcomes of this study. This degree of awareness and concern also suggests that the picture of QoE which emerges from their accounts can be considered as thorough, thoughtful and detailed.

B. Factors Impacting QoE for the Test Experiments

In commenting on the specific RAL sessions in which QoS was intentionally varied, participating students showed equal awareness of the environment and their perceptions and experiences of the learning. In addition to the remarks above, the students made two specific comments in regards to the RAL experiments:

- Lag time in the system,
- Lack of feedback from the system.

Lag time relates to poor network performance or QoS; and resulted in increased frustration and difficulty of the task. Students "don't know if they have made an error or if the program is just not working." This sometimes prompted students to go back and check over their work. In both cases, the feedback the systems are able to provide is limited and the lack of feedback from the system makes mistakes or problems hard to identify and resolve.

This is particularly true for students that are not sure about the experiments. Students reported a reduced confidence in their knowledge of the task, and an increased level of frustration when dealing with problems. A reduced sense of achievability is associated with not being able to identify what a problem is, or how to solve it. In the RAL experiments, instances of poor QoS had a clear effect on how students experienced the task. However, despite increasing the difficulty and frustration involved, it also had the positive effect of prompting students to review their work and spend more time ensuring they had completed it correctly.

A more significant problem that students encountered in the experiment was that the design of the RAL activity gave them insufficient feedback on their progress, whether QoS was poor or not. If this was not an issue their overall frustration and difficulty may have been lower. In one instance in the water experiment, a student could not commence the activity because the system did not give him the information that the experiment was not prepared properly. He lost his scheduled session and had to simply try again another day. In a proximal experiment, the nature of the problem would be immediately evident as the student could do a visual check of the apparatus in order to identify what was wrong.

In discussing their problems with online learning and how they dealt with them, the participating students demonstrated a high degree of persistence and motivation. They discussed the enjoyment of learning in their chosen fields, despite the difficulties and frustrations they regularly encountered. Across the board, all reports were that they were time poor, with work and family obligations competing with the demands of study. It was in this light that the significance of the problems they were dealing with emerged. For every instance of frustration and

unnecessary time taken to complete a study task, it was their professional or personal life which was impacted. Ironically, participants implied that it was because of their jobs or family commitments that they had opted to study online, and that on-campus learning was not an option, despite being viewed as preferable.

In analysing the overall picture of students' comments on their experience, distinct categories of factors which make up QoE emerged. These are summarised in Table I. The factors are largely expected and supported by the literature. The interesting result is that only Frustration, Achievability, Flow and Extra Time are affected by poor performance; and only if there is an impact on the functionality of the online learning tool, the impact of QoS on Consistency and Quality of learning materials can be avoided.

TABLE I. FACTORS AFFECTING QoE FOR ONLINE LEARNING

| <i>Factors Affecting QoE for Online Learning</i> | <i>Relevance of QoS</i> |
|---|---|
| Satisfaction Level of satisfaction experienced upon completing the learning | Not relevant |
| Frustration Level of frustration experienced in completing the learning task | Relevant only if reduced functionality of tool/program due to reduced QoS disrupts the processes involved in the learning task |
| Achievability Sense of achievability of completing the learning task | Relevant only if reduced functionality of tool/program due to reduced QoS disrupts the student's ability to complete the learning task |
| Consistency Consistency of the overall learning environment (e.g. consistent provision, layout and design of tools, materials and activities) | Not relevant |
| Quality Quality of learning materials provided (e.g. clarity of recorded lectures, currency and relevance of study guides) | Not relevant |
| Flow Sense of flow when undertaking a learning task (e.g level of interruption to concentration on the task or process due to missing information, poor functionality of tools) | Relevant only if reduced functionality of tool/program due to reduced QoS significantly interrupts the sense of flow of the learning task |
| Extra Time The amount of time over and above what would required for achieving the relevant learning goal or completing the task if learning was not online (e.g. face to face/on-campus, or in print mode) | Relevant if functionality of the tool or learning environment is affected by poor QoS |

For example students reported being frustrated while undertaking activities with low QoS; however, they also reported that this did not impact on the level of satisfaction they felt once the activity was successfully completed. Students in the study also reported that the factors with a positive influence on QoE included a sense of satisfaction from completing a task and the perception that a task was going to be achievable. Detracting from QoE were a variety of problems, primarily deriving from the design or delivery of the online courses, including the quality of tools and materials used for learning. These problems include lack of consistency in how tools are designed and provided, inadequate functionality of tools for the task at hand, lack of support at the times students need it and poor quality and irregular provision of course materials or resources. Poor QoS was only reported as significant in relation to these wider problems or where wider problems were present. Students reported that experiencing any or all of these issues increased the time it took them to complete a task, the level of frustration they experienced during learning, and interrupted their preferred learning processes. Where these problems occurred concurrently, the quality of the students' learning experience was extremely low. Although QoS was sometimes mentioned in reference to these wider issues, in speaking about the factors associated with QoE, students were much more concerned with the design and delivery issues associated with their online coursework.

VI. DISCUSSIONS

These findings suggest that QoS only acts as an intermediary factor between quality of design and delivery of the course and the students' QoE. Given this and the students' overwhelming awareness and concern with the factors which impact design and delivery, pursuing a better QoS in online environments is not likely to have a significant effect on optimizing online learning. The fundamental design and delivery of a course, and students' characteristics and learning processes are much more significant in determining what goes on in the learning environment, how it is experienced, and the outcomes that result. The amount of feedback the students received from the system is also crucial as it allows students to assess their progress. The participants in this study were notably persistent and motivated in pursuing their online learning. They were all relatively competent and confident in using ICTs and operating in the online environment. They were also all studying within the field of Engineering. However, these characteristics are expected to amplify rather than detract from the findings of the project. This is because this cohort's persistence and ingenuity in pursuing solutions and the thought that they gave to understanding their experiences revealed more about the online learning environment than if they had displayed a tendency to simply give up in the face of difficulty. It is reasonable to expect that a different cohort of students, studying in different courses and disciplines would present an entirely different set of learner characteristics and learning processes. However, the problems they would be likely to encounter in the online learning environment may very well be similar or the same, deriving from the same causes. This supposition is borne out by much of the available literature on best-practice in course design, pedagogy and online learning. For example, it is known from an abundance of studies that

online learning is optimal when it is interactive, supported and collaborative. It is also well known in general learning theory that making learning more flexible is a reliable means of improving learning outcomes. The assertions made here would be testable in further studies into design and delivery and QoE for online learning.

VII. IMPLICATIONS AND FURTHER WORK

The observations in the study allow for broader conclusions about the importance of QoS to the QoE of learners. The main results of this study suggest that QoE of well designed online courses is only degraded if bad QoS means that the learning activity is no longer usable. This indicates that a QoS threshold exist which is also supported by [15]. If QoS is above the threshold, the QoE is good for well designed and supported activities, if it is below the threshold the learning activity is no longer possible and this impacts on the learning experience. For badly designed learning activities, QoE will be low, independent of QoS. As long as a learning activity is readily usable, improving QoS has little impact on the QoE. For these reasons great attention should be paid to the quality of design and delivery of online learning tools and courses. To achieve high QoE, well integrated and scaffold learning experiences are more important than high QoS, e.g. fast Internet access. Specific aspects of these assertions can be tested in future studies. The natural step to continue this work is to move from assessing the perception of students of the learning experience to assessing learning itself. This is an interesting, but difficult investigation. Assessing learning on a large scale while adjusting QoS is problematic. Another direction for future work is to research how the perception of QoE itself influences learning.

The study also led to the unintended positive insight that students can be an important source to improve course design and delivery. This opens up an interesting new research direction: Much has been written about student evaluations, but very limited work exists that has explored students as a source of pedagogic knowledge and the use of student expertise to improves learning and teaching.

VIII. CONCLUSIONS

This paper has discussed the relationship of QoS and QoE in the context of online learning and was able to address the research question of which dimensions of QoE are affected by QoS? Students reported that the factors with a positive influence on the quality of the learning experience included a sense of satisfaction from completing a task and the perception that a task was going to be achievable. Detracting from QoE were a variety of problems created by the learning environment; the online tools, materials themselves or the online course design. QoS was only reported as an issue where these problems were also present. If these problems increased the time required to complete a task, the level of frustration experienced during learning, and interruptions the students' preferred learning processes were evident. Where these problems occurred concurrently, the quality of the students' learning experience was extremely low. These findings suggest that the influence of QoS is less significant than course design and pedagogical concerns in determining QoE in online

learning. This is significant since online learning is often regarded as a means to providing more equitable opportunities for learners that do not have the option of undertaking study in face-to-face modes. Despite this, the project found a number of circumstances in which online students were specifically and significantly disadvantaged compared to on-campus students, for example in opportunities for discussion with peers and teachers, and in accessing incidental and extra materials and information from course staff.

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Quantifying learning from web-based course materials using different pre and post tests

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Abstract - Engineering instructors seek to gauge the effectiveness of their instruction. One gauge has been to use standardized tests, such as concept inventories and to quantify learning as the change in score over the semester. Here we question whether that approach is always the best practice for gauging the effect of instruction, and we propose an alternative of administering different tests at the start and end of the semester. In particular, to gauge the influence of one aspect of instruction, the use of interactive web-based course materials that had been developed for Statics, we administered the Force Concept Inventory at the start of the course, and the Statics Concept Inventory at the end of the course. Correlations and then linear regression were applied to study how conceptual knowledge measured at the end of the course depended on conceptual knowledge measured at the start and the amount of use of the web-based courseware. Usage of the web-based courseware was found to promote conceptual knowledge at the end of the course in a statistically significant way only after accounting for initial knowledge as judged by the different conceptual test administered at the start of the course. Thus, it is not necessary to measure gain on one test; instead each test should capture well the variation in relevant ability across students at the time the test is administered.

Keywords-web-based courseware, concept inventory, interactive learning, pre-post tests, measures of knowledge, Statics

I. INTRODUCTION

Standardized tests of conceptual knowledge, such as concept inventories are of increasing interest nationally [1], and they have been used as benchmarks to gauge the effects of instruction [2, 3]. Concept inventories were inspired by the Force Concept Inventory [4], which is sometimes used in Physics courses. The most common approach to gauging effectiveness of instruction has been to administer the test at the start of a course (pre), and near its completion (post). Learning is taken to correspond to the gain, or increase in the test score (post-pre). In addition to this raw gain, Hake [5] has popularized the use of normalized gain: increase in score normalized by maximum possible increase in score. Either way, gain on the same test has been often embraced as a means of quantifying learning, with different instructional approaches being the experimental variable to be tested.

Of course, when using any test at the start of a course we are presuming that it captures meaningful variation in the initial, relevant knowledge of students. In this paper, we

consider whether using the same test as both the pretest and posttest is necessarily sensible.

II. BACKGROUND

The Force Concept Inventory (FCI) is multiple-choice test used by some instructors in physics courses to gauge the degree to which students have embraced a Newtonian viewpoint regarding forces and acceleration. While there is some dispute as to the validity of this test with respect to the meaning of scores on individual questions or groups of questions [6, 7, 8], the total score on the FCI remains a readily quantifiable measure of conceptual knowledge of Newton's laws. The FCI has been used as both the pretest and posttest for quantifying learning gain in introductory physics courses [5].

The Statics Concept Inventory (SCI), also termed CATS – Concept Assessment Test for Statics, is one of a number of concept inventories that were developed in recent years [9], following the Force Concept Inventory as a model. Psychometric studies of the SCI [9,10,11] enable one to argue in favor of its validity as a measure of conceptual knowledge of statics in students near the end of, or after, a statics course. In particular, across a wide range of institutions, it is generally found that the SCI correlates reasonably well with scores on the final examination of the local institution.

While the SCI effectively captures important aspects of students' statics conceptual knowledge at the end of a statics course, this does not imply that the SCI is the best measure of relevant incoming knowledge, especially when one's goal is to assess the effectiveness of instruction. In fact, one expects most students to have had little prior experience with statics before an introductory statics course. Indeed, it has been demonstrated [11] that SCI scores for students who have not studied statics previously, are roughly consistent with random guessing. That is, mean scores are typically on the order of 1/5 or 20% (each question has 5 answer choices). Moreover, for one class of 130 students, which was studied in detail, the actual distribution of scores on the pretest was consistent with a binomial distribution, corresponding to random selection of one of five answers on a 27-item test.

Instead, as a pretest one should use a test that better captures the variation in students' incoming abilities. Prerequisites for engineering statics courses nearly always include physics, as well as some level of mathematics. Given

the subject matter of statics, forces and equilibrium, it would appear that Newtonian mechanics is the prime scientific background to statics. Thus, the Force Concept Inventory, while it also tests aspects of motion that are not central to statics, provides a plausible measure of initial relevant knowledge for students entering a statics course. The investigation now described explores a two-test approach that is likely to be useful in many circumstances. We demonstrate the approach with a statics course for which we quantify the effect of varying usage of web-based statics exercises; the Force Concept Inventory serves as the pretest and the Statics Concept Inventory serves as the posttest.

III. METHODOLOGY

A. Participants and Data Collection

Participants included students in the mechanical engineering statics course at Carnegie Mellon University in fall 2011. The total class consisted of 150 students. As a pretest, just prior to the start of the course, students took on-line the Force Concept Inventory. As a posttest, just before the end of the course, students took on-line the Statics Concept Inventory. Students received a small amount of credit for completing each conceptual test, but, as was made clear to them, the actual scores did not count towards their course grade. In this study, the variable *FCI*, which is the fractional score on the FCI pretest, is the measure of initial knowledge. The variable *SCI*, which is the fractional score on the SCI posttest, is the measure of final knowledge. The semester-long course included 3 hours of lecture and one hour of recitation per week. Besides some written homework, students were required to use a web-based statics course [12]. The implementation of these materials utilizing an inverted classroom format was described in [13]. This instructional intervention is described next, together with the variable used in this study to quantify the amount instruction received by each student.

B. Instructional Intervention: Web-based Engineering Statics Course

The web-based OLI Engineering Statics course, described in more detail elsewhere [12, 13, 14], is freely available to individual learners and institutions, and consists of twenty modules, akin to chapters [15]. Each module is composed of several pages, each devoted to a single learning objective. Concepts are explained using not only text and graphics, which are typical of textbooks, but also through simulations. In developing the course, problem solving tasks, particular complex ones, have been carefully dissected analyzed. The resulting procedural steps are presented, first with worked-out examples and then often with "Walkthroughs", which combine voice explanation with evolving graphics. Students themselves engage in problem solving through interactive exercises in which they can practice the new skills and concepts as they receive detailed hints and feedback. Wrong answers provoke feedback that may be generic ("That's not right"), or specific feedback for each incorrect answer if a diagnosis of the mistake can be made. The hints are often provided in succession: the first hint reminds the student of the relevant underlying idea or principle, the second hint might link the problem at hand to the

general idea, and a final hint might explain how to get the answer. At the conclusion of each learning objective, students are offered brief summary and final exercises to further assess their learning and determine whether further study of the material is warranted. For students who use OLI as part of an instructor-led course, there is a quiz at the end of each module, which can be graded. Student work on hundreds of exercises are recorded and analyzed to provide overall and detailed feedback to the instructor, who can then track individual students and the class as a whole.

It is important to explain how OLI was assigned in the particular class context, how it was weighed, and hence the motivation of students to use the materials. All of students' work, aside from performance on examinations, account for only 5% of the final grade. Of that 5%, 2.5% consists of written homework, and 2.5% consists of (2/3) OLI end-of-module quiz scores and (1/3) writing a brief explanation of what they found difficult in a module. It was made clear to students that the interactive learning activities within a module before the quiz, which constitute the vast majority of activities, are there for students to learn the material to prepare for the OLI quizzes and the class exams. But, the number of the pre-quiz activities undertaken, and their performance on them, contributed nothing directly to students' grades. Thus, students regulate their usage of OLI materials, choosing which of the activities to undertake, solely with the goal of learning the material, not fulfilling an assignment.

The variable *Activities* captures the fraction of all recordable interactive activities which a student initiated. For the purpose of the present analysis, we take *Activities* to be the amount of instruction received.

C. Analysis

The analysis addressed the relationships among the three variables: *FCI* (initial knowledge), *Activities* (instruction), and *SCI* (final knowledge). In particular, we studied correlations between final knowledge and the two input variables, initial knowledge and instruction. In addition, linear regression was carried out to determine if final knowledge could be modeled as a linear function of the instruction alone, and then as a linear function of both initial knowledge and instruction.

IV. RESULTS

A. Basic Statistics

A histogram of *FCI*, the measure of initial knowledge, is shown in Figure 1 (mean = .76 and SD = .14).

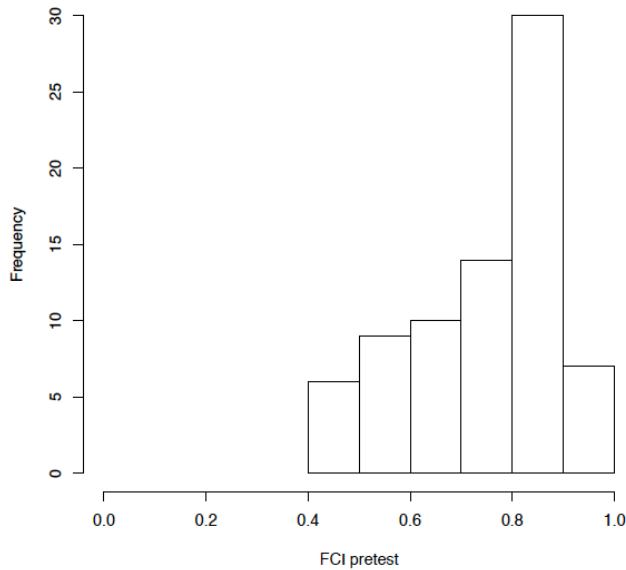


Figure 1. Histogram of Force Concept Inventory pretest scores.

The FCI consists of 30 questions, each having 5 answer choices. Hence, random guessing one of the five answers for each question would provide a mean of 0.2. Not surprisingly, these observed FCI pretest scores are significantly different from random guessing (i.e., significantly higher).

A histogram of *Activities*, the measure of instruction, is shown in Figure 2 (mean = .68 and SD = .20). Recall that students receive no direct credit for the majority of these activities, (only the indirect benefit of learning the material and then performing better on subsequent quizzes and exams). Hence, it is not surprising to see a wide variation in *Activities*.

A histogram of the *SCI*, the measure of final knowledge, is shown in Figure 3 (mean = .69 and SD = .18). Note that conceptual knowledge, as *SCI* seeks to measure, is only one component, although an important one, of all the knowledge and skills that a statics course, and the OLI web-based course in particular, seeks to impart.

Pearson correlations between *SCI* and *FCI* and between *SCI* and *Activities*, respectively, are shown in Table 3. While the correlation between *SCI* and *FCI* is significant, that between *SCI* and % *Activities* is barely significant. The significant correlation between *SCI* and *FCI* suggests that students' conceptual physics knowledge at the beginning of a statics course is predictive of their conceptual statics knowledge at the end of that course, consistent with the expectation proposed in the previous section. The relationship between *SCI* and *Activities* indicates that engagement in the online activities is predictive of their conceptual statics knowledge at the end of that course. However, this is a much weaker correlation that leaves plenty of room for improvement, as explored in the next section.

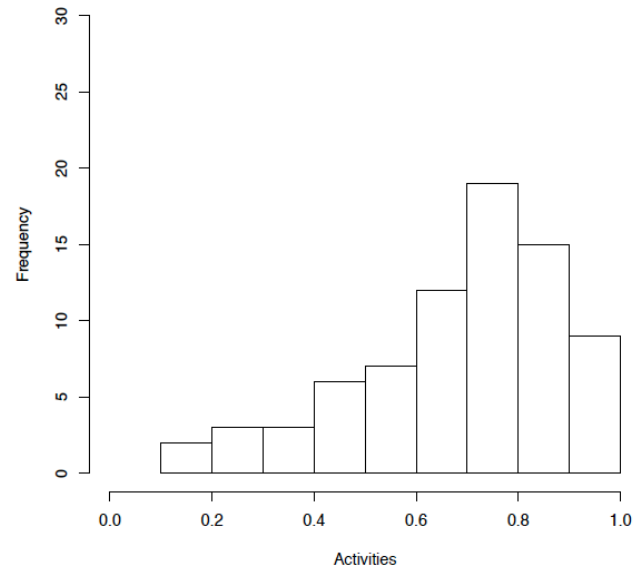


Figure 2. Histogram of fraction of activities undertaken in web-based statics course.

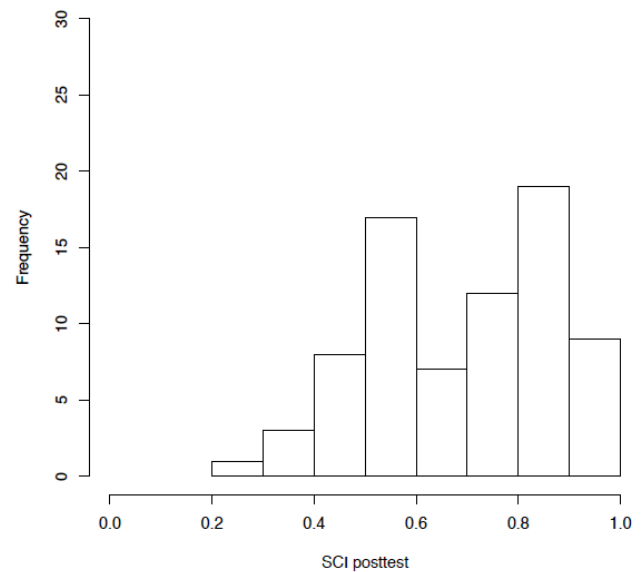


Figure 3. Histogram of Statics Concept Inventory posttest scores.

TABLE I. CORRELATIONS BETWEEN FINAL KNOWLEDGE (POSTTEST SCI) AND INITIAL KNOWLEDGE (PRETEST FCI) AND INSTRUCTION (PERCENT ACTIVITIES COMPLETED)

| <i>SCI vs. FCI</i> | | <i>SCI vs. Activities</i> | |
|------------------------|-------------------------|---------------------------|-------------------------|
| <i>Correlation (r)</i> | <i>Significance (p)</i> | <i>Correlation (r)</i> | <i>Significance (p)</i> |
| 0.38 | .0008 | 0.22 | 0.0506 |

B. Statistical Models of Dependence of Final Knowledge on Instruction

As our baseline regression model, we consider how well SCI scores are predicted if instruction, *Activities*, is the only variable; that is, if we had no useful measure of initial knowledge. The best-fit linear relation between these variables is found to be:

$$SCI = .55 + .21 \text{ Activities}$$

We find that this one-variable model captures only 5.1% of the statistical variation in SCI posttest scores, and the model is just barely statistically significant: for the coefficient of *Activities*, $t(74) = 1.99$, $p = .05$. This essentially repeats the earlier finding of a weak correlation between *SCI* and *Activities*.

Consider now a more complex model, in which *SCI* depends linearly on both *FCI* and *Activities*. In particular stepwise regression was used to include *FCI* in the model after including *Activities*. The resulting fit is of the form:

$$SCI = .07 + .29 \text{ Activities} + .56 \text{ FCI}$$

The fit of this two-variable model can be compared to that of the simpler model. First, the two-variable model captures 23.4% of the statistical variation in the data. Note the marked increase relative to the 5.1% variation captured by the one variable model. Second, the coefficients for *Activities* ($t(73) = 2.95$, $p < .01$) and for *FCI* ($t(73) = 4.17$, $p < .001$) are both much more significant statistically than with the .05 level, which found for the one-variable model based on *Activities* alone.

Thus, the two-variable model (*FCI* and *Activities* predicting *SCI*) is superior to the one-variable model in which initial knowledge is neglected (*Activities* alone predicting *SCI*). Moreover, the two-variable model also reveals a somewhat greater benefit to engaging in OLI activities than the one variable model (compare coefficients 0.29 and 0.21). While the *SCI* was not administered as a pretest, based on previous findings that it corresponds essentially to random guessing, one expects its inclusion as a variable would have provided little improvement over the one variable model, which accounted for only instruction.

V. SUMMARY AND CONCLUSIONS

Because scores on the Statics Concept Inventory at the start of statics correspond to random guessing, we argue that it is unlikely to be a useful measure of relevant knowledge at the start of statics. For the purpose of measuring the effect of instruction, we have instead used the Force Concept Inventory administered as a pretest to be the measure of initial knowledge. The posttest measure of knowledge was the Statics Concept Inventory. Based on statistical models we found that the instruction of interest, usage of a web-based statics course, had a beneficial effect, but that the effect became stronger and more significant statistically only after accounting for the initial knowledge in the form of *FCI* pretest scores. Ongoing efforts are devoted to identifying more clearly the sources of instructional benefit in using the web-based course.

The methodology applied here can be extended beyond the specific context. Many instructors seek to improve statics instruction and test the effects of aspects of the classroom context. The Force Concept Inventory, we propose, may provide a useful way of identifying the effect of initial knowledge. The particular statistical analysis of using a linear regression with two input variables is suitable when one can track a continuously varying amount of instruction, while alternative methods would be applied in other circumstances.

More broadly, with concept inventories being developed for other subjects, we need not necessarily use the same test for both the pretest and posttest. Instead, we should use tests that effectively reveal variation in students' relevant knowledge at the beginning and end of the course. As we have shown, scores on the two distinct tests can be used, with appropriate statistical methods, to weight the effectiveness of instruction.

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Accessibility Evaluation Improvement using Case Based Reasoning

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Abstract— Nowadays, many web content editors allow teachers to create web content as learning objects; however, most of these editors do not generate accessible web content. In many cases, the generated web content is not in accordance to the Web Content Accessibility Guidelines (WCAG). As a result, teachers and students with disabilities, e.g. people with visual impairment, people with hearing impairment, among others, could not properly use the web content in their learning or teaching processes. Moreover, some automatic tools for accessibility evaluation do not evaluate the web content using all the criteria from the guidelines; the rest are usually evaluated by humans (manual evaluation). In this paper, we introduce a tool to support accessibility evaluation in the generated web content when teachers use the TinyMCE web content editor. In this manner, we help them to identify web accessibility failures that can be improved. We also introduce a new approach for the web content accessibility manual evaluation process by applying the Case Based Reasoning technique. This work has been developed in the context of the European funded ALTER-NATIVA Project.

Keywords—component; Web Content Accessibility; Manual Evaluation; Automatic Evaluation; WCAG 2.0; Case Based Reasoning;

I. INTRODUCTION

Web content accessibility has been a topic of research for organizations interested on increasing the access for all people to web environments with special attention to their personal needs and preferences. As a main contributor of guidelines in order to make the web content more accessible, the World Wide Web Consortium [1] (W3C) published the Web Content Accessibility Guidelines (WCAG) and the most recent version is the WCAG 2.0 [2]. The WCAG 2.0 are used when the accessibility in a web page or a set of web pages have to be evaluated. According to the WAI (Web Accessibility Initiative), the recommendation is to use both automatic and manual evaluation [3] considering that even in an automatic evaluation some tools can omit data or show incorrect information.

In the manual evaluation, both the experts' opinion and the obtained results from using extra aids such as web browser plug-ins, color contrast analyzers, screen magnifiers and other additional tools are considered. Current tools for supporting manual evaluations of web content accessibility are useful for

the experts, because these tools allow them to detect problems that automatic validators do not.

The widespread use of educational environments through the web requires accessible web contents and, each time, teachers use more tools to generate those contents. However, teachers are not always familiarized with web accessibility. To overcome this situation and to generate accessible web content, aid from experts can be used in the web content accessibility evaluation process.

Taking into account the above context, we applied the Case Based Reasoning (CBR), which is a technique from Artificial Intelligence, that allow us to match the experience from experts who know about accessibility in web contents (using the success criteria of WCAG 2.0) with the design of educational web content. For instance, when a teacher designs their web pages in the TinyMCE web content editor [4], he/she needs an extra aid to know about how to do each element in web pages more accessible. The CBR has been applied in a wide variety of software applications in different fields such as games [5], health [6] [7], mathematics [8], theoretical research [9], economy [10], technology [11] [12], among others. An approximation in the application of CBR in web accessibility context is T-Orienta [13], which uses an Artificial Intelligence engine "to match the needs detected for each user with a set of recommendations about software and Assistive Technology devices" [14]. After reviewing literature of CBR applications, we do not have clear evidence that the CBR had been used in the domain of web content accessibility evaluation process.

One of the most important questions we need to answer in order to provide an additional support in web accessibility content evaluations is the following: How can the CBR technique support the web content accessibility evaluation process? To answer the question, in this paper a new approach in the evaluation of web content accessibility process is introduced. The abovementioned approach is supported by a web environment that uses the AChecker [15] validator as an automatic evaluation tool, the CBR-based component developed as an extra aid to manual evaluation (using the jCOLIBRI CBR framework [16]) and the TinyMCE [4] as the web content editor.

This document is structured as follows: section II describes concepts about web content accessibility; section III shows a

general description of the CBR technique and its cycle applied to the web content accessibility evaluation process; in section IV, a detailed description of the architecture for our CBR-based component is introduced; in section V, the implementation of the CBR-based component is depicted; section VI describes the workflow of the CBR-based component; section VII shows the context of ALTER-NATIVA [17] project and the main user requirements are identified; finally, in section VIII, some conclusions and future work are presented.

II. WEB CONTENT ACCESSIBILITY

A. What is the Web Content Accessibility Evaluation?

The web content accessibility evaluation can be described as the process in which experts (with different expertise levels) verify and determine if a web site meets several standards and guidelines [2]. There are case studies that show how the web accessibility evaluation process is applied. For instance, in [18], a set of web pages are analyzed by people who are learning about WCAG 2.0, i.e. beginners. In [19], the web accessibility of a set of web pages is evaluated by experts in WCAG 2.0. In both examples there is an agreement: a web content accessibility evaluation process has two ways of evaluation, a manual evaluation and automatic evaluation. In the manual evaluation, experts or beginners use different strategies to evaluate the web content accessibility. On the other hand, the automatic evaluation is supported by software that analyzes the HTML (HyperText Markup Language) on the web pages and delivers reports according to several characteristics selected by the user.

B. Reasons to evaluate the web accessibility

According to the WAI, the Web is a space that allows people to perform different activities in different fields, e.g. education, commerce, health, among others. When the web provides elements and alternatives to people with disabilities, they can easily develop those activities. For that reason, some benefits obtained from accessible web content are highlighted, e.g. to provide equal access and equal opportunity for all people [20]. Another benefit is when “the Web offers the possibility of unprecedented access to information and interaction for many people with disabilities. That is, the accessibility barriers to print, audio, and visual media can be much more easily overcome through Web technologies” [20].

C. WCAG 2.0

Web Content Accessibility Guidelines 2.0 or WCAG 2.0 is a W3C recommendation from 2008, and “covers a wide range of recommendations for making Web content more accessible” [2]. These guidelines have four layers of guidance:

- Principles: perceivable, operable, understandable and robust.
- Guidelines: “the 12 guidelines provide the basic goals that authors should work toward in order to make content more accessible to users with different disabilities.” [2]

- Success criteria: represented by three levels of conformance A, AA, and AAA being A the lowest level.
- Sufficient and Advisory Techniques: techniques that “go beyond what is required by the individual success criteria” [2] and “address accessibility barriers that are not covered by the testable success criteria,” [2] respectively.

D. Automatic Validators of WCAG 2.0

There are a set of automatic validators for web content accessibility evaluation that works under the WCAG 2.0 recommendation. In Table I, some of them are listed and analyzed. We compare the validators by asking if they are: a) online services b) standalone applications c) free tools and d) open source tools, and also if the validators allow: e) online demonstrations and f) file uploads to test local web pages.

TABLE I. ACCESSIBILITY VALIDATORS COMPARATIVE

| Validator | Comparative attributes | | | | | |
|---------------------|------------------------|-------------|------|-------------|-------------|-------------|
| | Online | Stand-alone | Free | Open Source | Online Demo | File upload |
| AChecker | X | | X | X | | X |
| TAW | X | | X | | X | X |
| eXaminator | X | | X | | | |
| TotalValidator tool | | X | X | | | X |
| SortSite | X | X | | | X | X |

According to the previous analysis, we decided to work with the AChecker validator because this service is available online, and both free and open source; besides, the AChecker validator can be integrated within the TinyMCE web content editor.

III. CASE BASED REASONING AND WEB CONTENT ACCESSIBILITY EVALUATION

Case Based Reasoning (CBR) is an Artificial Intelligence (AI) technique to solve problems using the knowledge of previous experiences or cases [8]. In the CBR, there is a cycle known as four R or R4 [21] because the process involved on the CBR can be represented as a cycle of four stages and R is the first letter in the name of each stage: Retrieve, Reuse, Review and Retain. The CBR cycle is detailed in the next subsection.

A. Web Accessibility and the CBR Cycle

In the CBR technique new problems represent new cases to be solved by using similar problems that have been previously solved [11] [22] [23]. This process involves four stages: retrieve, reuse, review and retain, as shown in Fig. 1. In the retrieve stage, a new problem (failure with some success criteria according to WCAG 2.0) is given, and a similar case or a set of similar cases are retrieved from the library case in which all solved cases are stored. Then, in the reuse stage,

these cases are selected to reuse the relevant information and knowledge for solving the problem. In the review stage, the reused cases are analyzed to decide if an adaptation is needed

to solve the new case. Once the new solution is given, in the retain stage, the case and its solution are stored in the library case as a learned case.

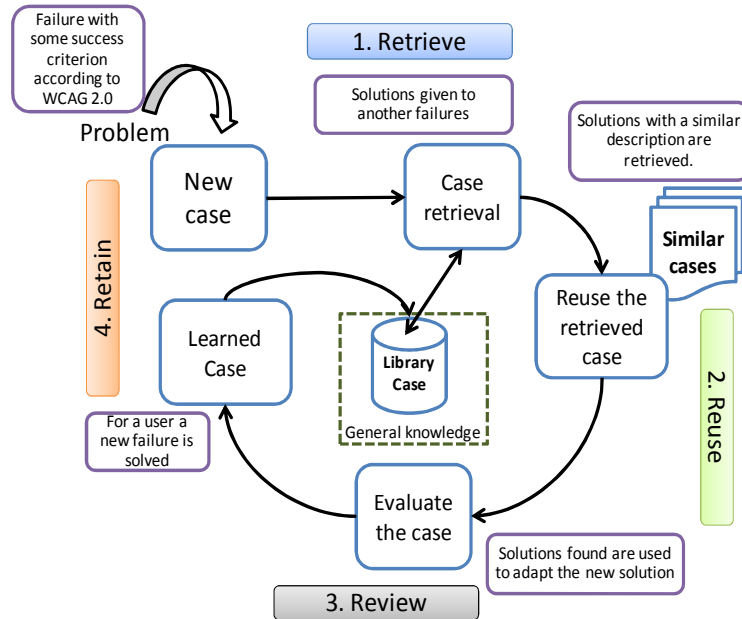


Figure 1. Process of Web content accessibility and the CBR cycle

In this work, we choose the CBR technique because it allows us to use the experiences of experts in web accessibility evaluation, which are stored as cases, for supporting the teachers in creating accessible web content. This process permits us to identify specific problems in web content accessibility, as well as the solutions given by experts for those problems.

B. Case Description

In the CBR, the cases can be described using attributes. All the cases in our work are described by a set of attributes used to find similarities between a new case and the stored cases. In this work, those attributes are defined in Table II.

TABLE II. CASE DESCRIPTION

| Attribute | Description |
|-----------------------|---|
| Case identifier | The unique identification number for each case. |
| Content type | The web content type of the web page. |
| Guideline | The guideline of the WCAG 2.0 according to the Content type. |
| Criterion | The success criterion according to the selected guideline. |
| Verification strategy | The strategy used by experts to identify failures in the web content. |
| Solution | The proposed solution for the found failure. |

One of the most important uses of the case description is the analysis of each case in the case retrieval stage in the CBR cycle. To retrieve a case, we developed a CBR-based

component (depicted in section V), which has to analyze each attribute in the stored cases in order to get the most similar cases to the new identified case.

IV. ARCHITECTURE FOR CBR-BASED COMPONENT

In this section, we describe the architecture that allows us to integrate the CBR-based component into an editing environment of accessible web content.

The architecture that supports the CBR-based component has four layers, as shown in Fig. 2. These layers are: users layer, interface layer, services layer and data access layer. In the next subsections those layers are described.

A. Users Layer

This layer is represented by two kinds of users. One type of user is the web page creator (in this work, teachers of ALTER-NATIVA project), who creates and edits web pages; the other type of user is the web content accessibility human validator (expert), who must have knowledge about web accessibility and, in particular, about the WCAG 2.0. Experts are responsible for reviewing web pages, identifying failures in web accessibility and providing comprehensible solutions for teachers.

B. Interface layer

In this layer, we consider two basic components, the user interface of the TinyMCE web content editor and the manual review of web content accessibility (manual evaluation). The last one represents the process that experts follow in order to find failures in web accessibility content and to recommend solutions to those failures.

C. Services layer

This layer represents the backend interface in which some services are used by the interface layer. Here, the CBR-based component, the AChecker validator, and the HTML structure of the web pages are represented.

D. Data access layer

The main goal of this layer is to store the HTML structure of web pages and cases generated from the CBR-based component. In our architecture, we have two storage systems. In the first one, corresponding to the repository, the web pages are stored as HTML objects; in the second one, corresponding to the database, the library cases of our CBR-based component are stored.

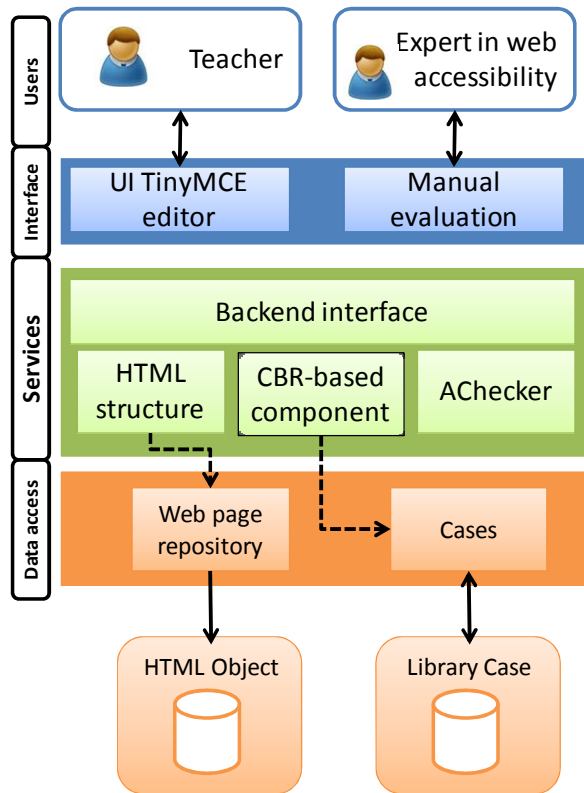


Figure 2. Architecture for CBR-based Component

V. IMPLEMENTATION OF THE CBR-BASED COMPONENT

In order to develop the CBR-based component we use the jCOLIBRI [16] framework. This framework was developed by the GAIA [24] group from the Universidad Complutense de Madrid. In Fig. 3, a screenshot of the software that supports the framework is shown. A class in the framework is implemented by using three main methods: PreCycle, Cycle and PostCycle. In the PreCycle method, the component and its connection to the library case is configured, in the Cycle method, each stage of the CBR cycle is performed and in the PostCycle method connections are closed.

Taking into account the CBR cycle, to retrieve the most similar cases in the retrieval stage, jCOLIBRI uses methods.

One of the most important retrieval methods is the Nearest Neighbour scoring (NNretrieval). This method “uses global similarity functions to compare compound attributes and local similarity functions in order to compare simple attributes” [16]. In fact, we decided to work with the NNretrieval function because, as explained in [5], each attribute is represented by a measure that allows us to sort the retrieved cases from the most similar case to the least similar case.

To integrate the CBR-based component and the TinyMCE editor, we developed two modules:

- The first module was modeled as a dynamic web application, which uses the jCOLIBRI framework. This application is connected with a library case (in a Postresql [25] database) where the expert’s experience about the failures in web content accessibility is stored. This module also supports the core services of the CBR-based component.
- The second module is a plug-in for the TinyMCE web editor developed in Javascript language, in which teachers can search for solutions about their web accessibility doubts, mainly when they need to know how to solve an accessibility problem in the web content they are editing.

Both of these modules were connected using the DWR (Direct Web Remoting) [26], a bridge to communicate the Javascript interface of the plug-in with the CBR-based component.

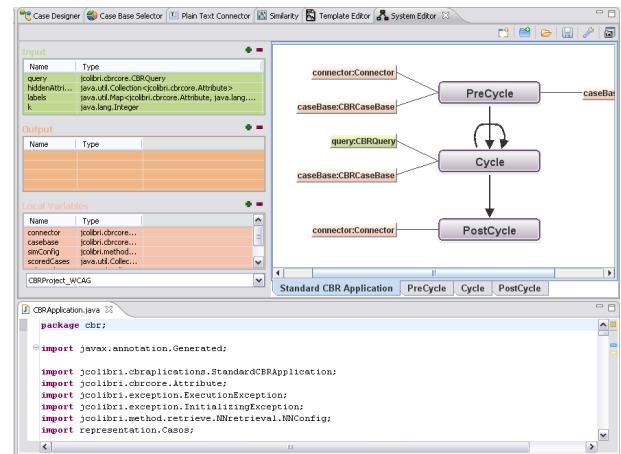


Figure 3. CBR-based component configuration at jCOLIBRI interface

VI. WORKFLOW OF THE CBR-BASED COMPONENT

This section explains each step followed by the CBR-based component. To understand how this component improves the web accessibility evaluation process, how a teacher gets information about web content accessibility is explained next.

When a teacher is interacting with the TinyMCE editor he/she adds different kinds of contents such as text, images, and videos, among others. The TinyMCE web editor includes functions that provide accessibility features for each type of

content. However, in some cases, when the content is added to the web pages, teachers can omit essential information.

Therefore, in the TinyMCE, the teacher can access to the service of the AChecker validator, but the information could not be clear for the teacher, considering that this information contains a list of results with technical definitions from an automatic evaluation. For this reason, teachers can use the CBR-based component to get extra information of the accessibility in a specific web content.

The workflow is performed as follows:

- The expert reviews the list of the available web pages in the system and then selects some pages to evaluate the web accessibility.
- Then, the expert reviews the web content of the selected page, selects the criteria that must be marked as failure (according to WCAG 2.0), and writes a solution to that failure. The solution should be written in a comprehensive way.
- Each failure and its solution are stored in the system as a new case that feeds the CBR-based component.
- When the teacher edits new web pages in the TinyMCE editor (see Fig. 4), he/she needs to know about the web accessibility of a specific content type. To search for specific doubts, the teacher uses the module integrated within the TinyMCE editor, which represents the graphical interface of our CBR-based component (see Fig. 5).
- Once the teacher sends the query, the CBR-based component runs the query searching in the library cases for one or more similarity cases. This similarity is calculated using the aforementioned attributes in each of the cases.
- A set of the most similar solutions to the current case are suggested to the teacher, who decides if he/she uses some of these suggestions to solve the case (doubt) or decides to create a new solution for the case (see Fig. 6).
- The suggestions allow teachers to improve the accessibility of the web page.

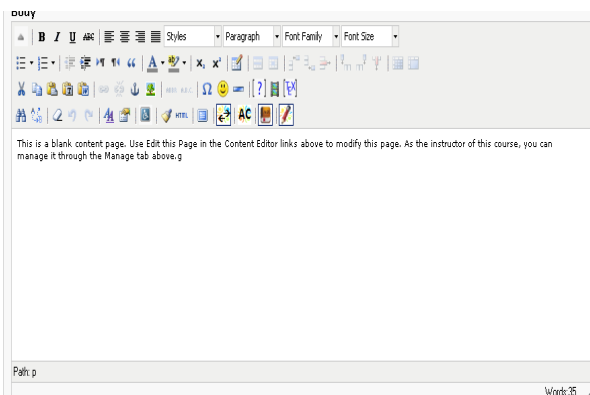


Figure 4. TinyMCE web content editor

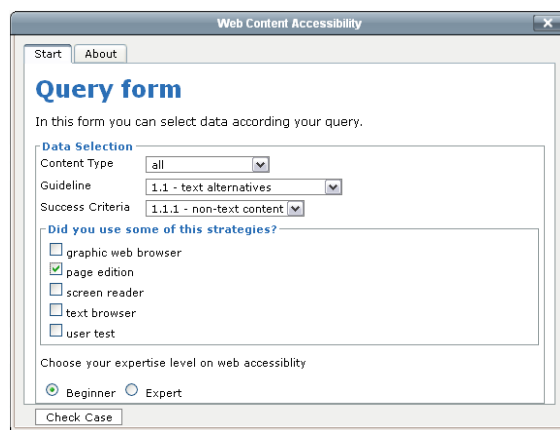


Figure 5. Web form to do the query

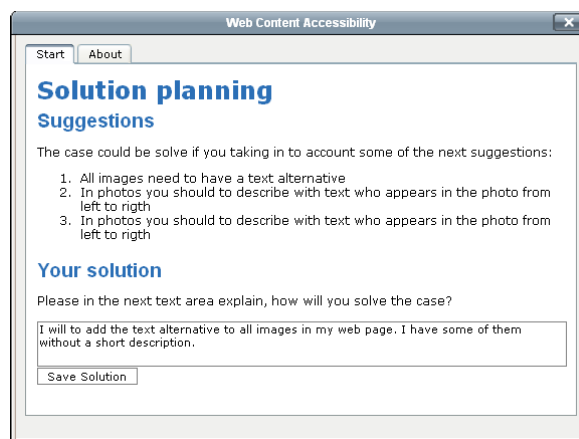


Figure 6. Suggestion from similar queries

VII. ALTER-NATIVA CHALLENGES TO SUPPORT ACCESSIBLE WEB CONTENT

ALTER-NATIVA is a European founded project whose main goal is to define curricular references with technological support for higher education in the areas of language, mathematics and science, for attending people in the context of diversity (such as people with visual impairment, people with hearing impairment and indigenous people). Taking into account the diversity covered by the project, there is a need to create accessible learning content so that all people, with different needs and preferences, can use the generated content in their learning process. In this context, we consider the following elements for a test validation scenario.

- **Actors:** There are two groups of actors in the test stage. On one hand, teachers that prepare future teachers and students that will be teachers in some of the ALTER-NATIVA project areas. On the other hand, experts in web content accessibility.
- **Technological requirements:** The introduced CBR-based component could be integrated in any instance of the TinyMCE web editor.
- **Procedure:** on one hand, the experts in web accessibility review one or more pages from a set of

web pages using the AChecker validator (or other tools), and write a solution to the identified web accessibility failures. On the other hand, the teachers create web pages with the TinyMCE editor, and use the graphic interface of the CBR-based component to use the recommendations of the experts in order to improve the web accessibility.

- Results: After using the CBR-component, teachers can learn about how to add web accessibility features to the content in their web pages.

VIII. CONCLUSION AND FUTURE WORK

The CBR-based component on this work does not intend to perform all the steps of the current manual web content accessibility evaluation. Instead, the component is defined as an aid, which is used by teachers and students to get solutions or recommendations about how to make the web content more accessible when they use the TinyMCE web editor.

This work was developed in an educational context; however, this work can be extended to other domains where users need to learn how to add web accessibility features to contents that are created using web content editors as the TinyMCE.

Using the CBR technique, we have observed that using the recommendations of the experts in the web content accessibility manual evaluation process permits us to obtain results that are easier for the teachers to understand than those obtained from the automatic validators.

As future work, we plan to integrate more algorithms to improve the case retrieval process and thus, to provide a better support to teachers in the process of editing web contents.

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Work in Progress: Evaluation of an Online Education Portal from the User's Perspective: An Empirical Investigation of a Photovoltaics (PV) Engineering Learning Portal, pveducation.org

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Abstract— In the last couple of decades, Photovoltaic (PV) solar systems have captured a lot of interest as a clean, renewable energy option. As a result, PV engineering has become an emerging field in engineering education. In order to meet increased learning requirements, new learning resources, an effective curriculum and proper assessment are needed. Pveducation.org is one of the discipline's oldest learning resources, providing PV content for photovoltaic professionals. The purpose of this paper is (1) evaluating the effectiveness of the pveducation.org learning portal from the user's perspective, and (2) find a relationship between the effectiveness of the website and user's learning gains. This study will conduct a systematic assessment of educational technology by using statistical techniques and data collected through a survey.

Keywords: *PV Engineering Education; survey development; learning portal effectiveness evaluation*

I. INTRODUCTION

With the increasing demand on new, sustainable technology in the world, the need for well-educated engineers in the solar cells sector is obvious, and ultimately escalating [1]. The green, sustainable economy is vastly dependent on highly-skilled and well-educated engineers, which in turn, requires rapid, effective, easy to use, and interdisciplinary learning portals [2]. In this context, pveducation.org fulfills a need by providing a resource to the solar cell manufacturing process with a curriculum designed to educate future PV engineers [1]. The creators of the website define pveducation.org as an online resource for educating the next generation of photovoltaic professionals [3]. It was developed in 2008 and has been serving the PV engineering community since. It is one of first comprehensive online resources in the PV engineering field. This website is designed like a textbook, where major sections are organized into chapters that are made up of individual webpages (or modules). These modules cover specific topics within each major chapter. The content of the website starts from fundamentals of PV, such as sun light, and solar energy to more complex phenomena such as the maintenance of PV (photovoltaic) systems, or design. Each topic is divided into modules and sub-chapters in a hierarchical flow which enables readers to find information easily on the website regardless of their pre-existing knowledge in PV.

II. ELEMENTS TO BE EVALUATED IN PVEDUCATION.ORG

The content of the website has been, and is currently being developed through repeated iterations by professors and experts in the PV field. During this content development period, small portions of the content are constructed at a time, allowing the developers to quality test it before it is released. Such quality testing involves criticism by other experts, or vocabulary and grammar testing. But this type of evaluation is not enough to determine the success of the delivered content. Therefore, the developers decided to evaluate it further, which involves collecting evidence from users about their perceived benefit from the content.

In addition to content development efforts, several different educational technologies have been embedded into the website to make it more user-friendly, interactive, and effective. These include simulations, animations, and metacognitive prompts - questions that allow the users to self-check their own understanding of the content covered in the modules. With the help of these technologies, pveducation.org has changed from an online textbook to an interactive website [2].

III. METHOD

This research involves administering a survey to collect data from learners who use pveducation.org. The research will assess the effectiveness of the pveducation.org website from the perspective of (1) content, and (2) the newly built educational technology tools. This study aims to examine the relationship between the quality of the website and the user's perceived value from it. Participants will be recruited from the pveducation.org website. Pveducation.org has approximately 3000 hits per day. Around one percent of users, 300, will be expected to participate in the survey. Participation is optional and the survey is delivered to participants through the website interface.

The survey used to collect data is reliable and valid for the purpose of this study. First, content validity was measured to ensure that the survey adequately measures, or represents, the constructs that the website developers wish to measure. Content validity can be defined as the extent to which the measurement reflects the specific intended domain of content [7]. For this purpose, two professors and two graduate students

in the field of engineering education were asked to assess the validity of the survey's sub-sections. The survey has been revised and developed iteratively according to the feedback gained from the content experts before it reached the stage to be used in this study.

The final version of the survey consists of two main parts. The first part is about the learner's website experience. It is divided into five sub-sections: (1) *System Quality*, (2) *Knowledge Building*, (3) *Endogenous Instrumentality*, (4) *Meta Cognitive Prompts*, and (5) *Overall Satisfaction*. The second part aims to gather demographic data about the learners.

Table 1 - Survey Scales, Number of Questions, and Pertinent Literature

| Survey Sub-Scale | Number of Questions | Pertinent Literature |
|-------------------------------------|---------------------|---------------------------|
| Learners' Website Experience | | |
| The System Quality | 12 | Ozkan et. al. , 2009 [4] |
| Knowledge Building | 9 | Shell et. al., 2008 [6] |
| Endogenous Instrumentality | 4 | Husman et. al. , 2004 [5] |
| Meta Cognitive Prompts | 3 | Conati et. al. 2008 [8] |
| Overall Satisfaction | 3 | Ozkan et. al. , 2009 [4] |
| Demographic Questions | | |

The System Quality items are related to attitudes toward technology, the usefulness of technology, and quality and reliability of the website. **The Content Quality** subscale is divided into two parts (1) knowledge building, and (2) endogenous instrumentality. *In the knowledge building subscale*, learners were asked to answer (1) whether the user set goals based on things they want to learn more about, (2) whether they will go beyond what they have learned in lectures, and (3) whether they find the topics of interest. The *endogenous instrumentality* subscale asks the user to respond to (1) do they use what they learn from pveducation.org (2) does the course content gain their attention, (3) is it easy to follow, (4) is it interactive, and (5) does the website cover an appropriate breadth of material.

The Metacognitive Prompts subscale includes three items. Participants will be asked to answer (1) whether metacognitive prompts are enhancing their academic performance (2) whether metacognitive prompts are helping them monitor their own understanding of the material, and (3) whether metacognitive prompts are improving their learning.

The last measure identifies overall satisfaction with pveducation.org. A 5 point Likert-type scale was used to collect data in all the sub-scales. The scale was anchored from 1 to 5, where 1 indicates strong disagreement and 5 indicates strong agreement. All responses are confidential and participants' IDs will be stripped from the data.

IV. EXPECTED RESULTS/FUTURE STUDIES

In addition to validating the measures used in the survey, the researchers will measure the reliability (internal

consistency) of the scale. It is expected that the subscales each have a Cronbach's alpha greater than 0.7 indicating that the items within the subscales are related.

Criterion-based predictive validity will be measured with effect size (R^2). This will be measured by regressing the survey's subscale on the learner's satisfaction value. A large R^2 value indicates a better prediction of the learner's satisfaction. The results will also inform us as to which subscales increase the user's overall satisfaction with the website and help inform future website design.

Confirmatory factor analysis will be used to determine the internal structure of the scales and ensure the dimensions have been correctly identified.

Future studies may include analyzing anonymous website transaction (log) information. Data mining, specifically clustering techniques can be used to understand the usage patterns of users. The findings will be valuable for future PV researchers who would like to create or improve online PV learning portals.

V. ACKNOWLEDGEMENTS

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Work in Progress: Multi-Faceted Penetration of Fast Fourier Transform by Interactively Analyzing Real-World Objects via Mobile Technology

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Abstract — Recent research shows that the engineering students have problems connecting the required computation to a conceptual understanding, as well as translating a graphical understanding of the process to a symbolic mathematical representation, especially when handling the multiple steps of the procedures. The students are usually able to perform sequences of the underlying calculations but cannot piece together the higher conceptual relationship that drives these procedures. This work-in-progress paper presents a viable approach and a new teaching and learning paradigm to enhance the effectiveness of teaching fast Fourier transform and significantly improve the learning outcomes. By integrating the mobile and cloud computing technologies, we are developing a handheld real-world relevance laboratory that includes an integrated learning module for Fourier transform and a shared intelligent project repository to host the module and real-world relevant data. This development is expected to overcome the intellectual inaccessibility of transform techniques and tackle the challenges in existing approaches: the prohibitive cost of project-based approach; limited access and real-world relevance data in simulation-based approach, and unreliable and unsustainable support.

Index Terms – Fast Fourier transform, mobile device, real-world relevance, interactive analysis.

I. MOTIVATION

The scientific principles and theories in electrical and computer are typically described mathematically and abstractly. One important aim in undergraduate electrical and computer engineering education is that students should understand theories and models and their relation to objects and events in the real world; they should also have the conceptual skills to apply these models and theories to formulate, develop, solve, evaluate and validate physical systems [1]. However, linking the mathematical symbols and abstract diagrams with the background concepts and their computational procedures has been proven to be not an easy task for students, especially when handling multi-step procedures. The students are usually able to perform sequences of the underlying calculations but cannot piece together the higher conceptual relationship that drives these procedures [2, 3]. In electrical or computer engineering, it has been found that the transform techniques such as

discrete Fourier transform and its efficient implementation algorithm, fast Fourier transform, dominate the list of difficult concepts although they are indispensable for follow-up courses such as communications, filter design, and digital signal processing [4]. Recent research [2, 4] (published in 2010 and 2011) showed that the intellectual inaccessibility of transform techniques is closely related to 1) the lack of connections between the concepts and real world applications, 2) the lack of reinforcement of the concepts when using them to solve problems (due to limited access to previous learning materials and labs), and 3) the lack of visualizations of each stage in the multiple-step processes.

Two approaches have been attempted to help the students better understand the concepts of transform techniques. One is to use project based exercises, where students learn through experiments [5]. The other one is to use a PC computer and/or other hardware (usually audio and video simulations) to help students to understand the concepts [6]. Unfortunately, despite existing efforts in teaching and learning transform techniques, none of them provide complete solutions to the above mentioned three problems related to the intellectual inaccessibility. Project-based approaches has been proven to be better since the students are motivated by solving real-world problems and learning-by-doing is the most effective way to learn. However, these approaches require significant investment in resources (labs and equipment) and more laboratory hours. Also, the students usually are not able to access to these experiments after learning the transform concepts in a particular course. They could not reinforce the concepts when they need to use them in the follow-up courses or when they need to solve real problems. The simulation-based approaches are cheaper, faster and can be rapidly adopted by students. However, virtually all of the simulations are performed with MATLAB [7], where the students have to work in a laboratory or purchase an expensive license. They are still constrained to a physical school building or a bulky computer. Moreover, there are few data related to the real world applications for students to simulate.

Currently, we are entering the mobile age. Today's learners have grown up with technologies and smart mobile devices have become an integral part of their daily lives [8]. They spend a considerable amount of time with these devices: talking, browsing the web, texting, social networking, and playing games. They increasingly associate computing technology with smart mobile devices rather than desktop computers. On the other hand, cloud computing has opened tremendous potential for improving cyber-based solutions to education with open and sharable; dynamic and expandable; reliable and sustainable; and affordable learning materials and environment. Integrating the mobile and cloud computing technologies enables a new model to overcome the intellectual inaccessibility of transform techniques and tackle the challenges in existing approaches: the prohibitive cost of project-based approach; limited access and real-world relevance data in simulation-based approach, and unreliable and unsustainable support.

II. HANDHELD REAL-WORLD RELEVANCE LABORATORY

To offer better learning experience and improve the understanding of the Fourier transform for electrical and computer engineering students This work-in-progress paper presents a viable approach and a new teaching and learning paradigm to enhance the effectiveness of teaching fast Fourier transform and significantly improve the learning outcomes. We are developing a handheld real-world relevance laboratory that integrates the anywhere anytime learning, authentic learning, collaborative learning, and cognitive learning. The laboratory includes an integrated learning module for Fourier transform and a shared intelligent project repository to host the module and real-world relevant data. The learning module improves learning through hands-on exercises related to real world applications and multiple facets penetration and visualization of the transform's implementation procedures. The repository supports data sharing collected from real world by geographically widespread users, collaborative learning, and intelligent counseling.

The learning module will include lecture notes for theoretical background, review questions and quizzes, assignments, and hands-on exercises with real world applications of Fourier transform technique. The hands-on exercises have multiple labs for applications in different areas and are organized at two difficulty levels: a basic level and an advanced level. The basic level hands-on labs that include image and speech signal processing and communication systems analysis do not require prior knowledge in transform technique and encourage the students to play with the mobile apps on the real world signals to learn, understand, and experience in the most interesting way. Step-by-step guideline and explanation will be provided for each lab and its implementation. These labs allow students to have instant practices on the real world signals collected by their own smart mobile device and to reinforce their knowledge Fourier transform at anywhere and anytime. The advanced level labs that include dual tone

multiple frequency detection, speech recognition, ECG signal processing and finger print identification challenge the students to learn more of the theory and develop comprehensive applications for more complicated cases. The sample results for advance level application will be demonstrated through multimedia flash so that the students could verify their results. Figure 1 shows examples of real-world image processing using fast Fourier transform.

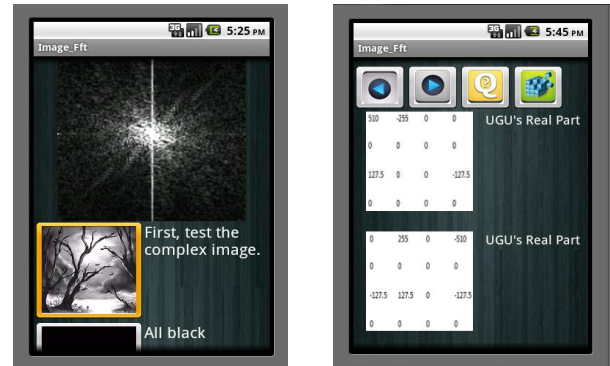


Figure 1. Fast Fourier transform for image processing. Left: Connection of the frequency and the variations in brightness across the image. Right: Visualization of the intermediate results in the fast Fourier transform

The handheld real-world relevance laboratory are designed to be cost-free, easy-to-adopt, and accessible at anywhere and anytime: they will be available online for download; the labs can be conducted real-time, anywhere and anytime without additional facility requirements; they can be used for in-classroom learning or online learning; they can also be used by the students to reinforce or review the transform technique after taking the theory class or before the application class.

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Work in Progress: Performing Signal Analysis Laboratories using Android Devices

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Abstract—In this paper, we present a graphical-programming application to support signal processing education on the Android operating system. This application features a simulation environment and a palette of DSP functions, which will allow students to perform laboratories using Android smartphones and tablets. In order to demonstrate the application of the software in a classroom setting, a number of laboratories which incorporate the proposed functionalities have been developed. A set of assessments designed to evaluate the effectiveness of the software is also presented.

Index Terms—Android, J-DSP, graphical programming, laboratories, DSP education.

I. INTRODUCTION

Presently, classroom teaching of digital signal processing is largely restricted to algorithms and their applications. Incorporating visual representations of algorithms can foster a better understanding of signal processing concepts as well as enhance student interest. In this paper, we describe a DSP simulation application for Android devices that will enable students to visualize algorithms and perform laboratories using interactive graphical programming.

Smartphone devices have witnessed rapid growth in the past decade. A study of usage of mobile phones in various classroom scenarios across the world has been discussed in [1], showing that the usage of mobile phones in classrooms enhanced student learning. It has also been demonstrated in [2] that the learning potential is enhanced when education tools possessing a higher degree of interactivity are employed. Applications providing visual representations of complex theoretical algorithms have been found to simplify the understanding of underlying concepts [3].

Android smartphones and tablets have a large user base, powerful processors, and memory capabilities. Though applications catering to elementary education have been developed, to the best of our knowledge, this is the first comprehensive DSP simulation application for Android devices. Though MATLAB and LabVIEW provide an extensive set of functions for algorithm implementation and application development, their mobile versions are quite limited in their capabilities. For example, the mobile version of the MATLAB application [5] requires a high speed internet connection to access a remote machine running a MATLAB instance. Hence, we propose to build a standalone Android application for simulating DSP algorithms using a visual programming interface.

The proposed application is based on J-DSP, a web-based graphical DSP simulation package that was developed as a non-commercial alternative for performing laboratories in undergraduate courses [4]. The underlying architecture of Android J-DSP (A-JDSP) is based on the Model-View-Controller (MVC) Paradigm. The models are used to store data and block parameters. The controller acts as an interface between the model and the view, handling events common to both. The view comprises of the user interfaces and the workspace. This is shown in Fig 1. The rest of this work in progress paper briefly describes the set of laboratory exercises developed for the A-JDSP application and presents the planned assessments.

II. LABORATORY EXERCISES

In this section we describe a set of laboratory exercises which demonstrate the application of A-JDSP in an undergraduate DSP course. These exercises are designed to demonstrate signal processing concepts like z-domain and frequency domain representation of signals, the Fast Fourier transform, and various aspects of multi-rate signal processing. The laboratory exercises are typically performed after students are introduced to the corresponding topics in their lecture sessions.

A. Z-Transform and Frequency Response

The objective of this lab is to instil an understanding of z-domain representations of signals among the students and to study its relationship with frequency domain representations. The functionalities of Pole-Zero (PZ) Placement, the Pole-Zero Plot, and the Frequency Response are demonstrated in this exercise. The PZ placement user interface is shown in Fig. 2. The laboratory is devoted to the study of frequency response of filters. The students set up a filter design simulation and exercises pertaining to the design of cascade and parallel filters are carried out. Finally, a set of exercises to construct filters and analyse z-domain plots is provided, enabling students to understand their relationship with the corresponding frequency responses.

B. The Fast Fourier Transform

This laboratory exercise demonstrates the application of the Fast Fourier Transform and examines various related concepts such as zero padding, resolution, and spectral leakage. The simulations in this exercise are realized using the FFT, windowing, and discrete signal generator functions in A-JDSP. As

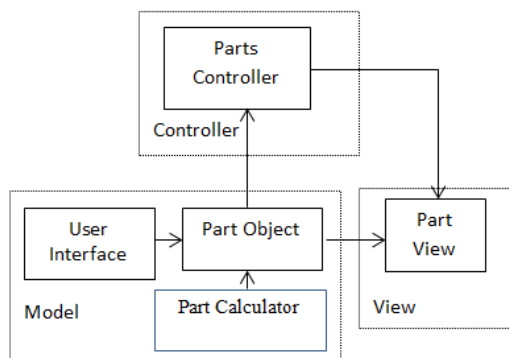


Fig. 1: Architecture of A-JDSP, based on the Model-View-Controller paradigm.

part of this exercise, the students examine the effect of signal symmetry and zero-padding on the FFT of a signal. A simple application of FFT in signal compression is also examined.

C. Multi-rate Signal Processing

The goal of this laboratory is to examine the effects and utility of sampling rate conversion. The Up-Sampler, Down-Sampler, Filter, Junction and Adder functions of A-JDSP are used here. The first exercise covers the principles of down-sampling and up-sampling of signals. The design of a 2-band Quadrature Mirror Filter (QMF), and a tree structured sub band filter are carried out. An example block diagram for designing a QMF filter is shown in Fig. 3.

III. ASSESSMENTS

In this section, we describe the planned assessment methodology to obtain evaluations for the proposed application. A-JDSP is being tested by the students of an undergraduate signal processing class at Arizona State University in Fall 2012. We will build assessments based on student evaluation at the end of the semester. The goal of this evaluation is to identify the impact of employing mobile devices to perform DSP simulations and laboratories. The evaluation will assess the interactive capabilities of the A-JDSP framework, and its ability to sustain student interest and understanding. The results of the assessments will be presented at the conference.

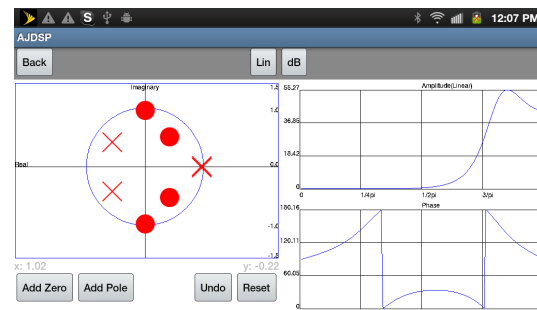


Fig. 2: Demonstration of filter design using PZ placement in A-JDSP.

The pedagogy adopted for the use of A- JDSP will include the following: (a) lecture on the pertinent signal processing concepts, (b) a pre-quiz on the concepts involved in the laboratory exercise, (c) simulation exercises and laboratories using A-JDSP, (d) a post-quiz to evaluate the effect of A-JDSP on student understanding. The results of these assessments will be used to address the issues in our software and thus enable us to provide prescriptive recommendations concerning its strengths, replication, and sustainability.

IV. CONCLUSIONS

In this paper we proposed an interactive and portable application for performing signal processing laboratories. The application is built for the mobile based Android operating system. With its architecture based on the Model View Controller Paradigm, Android-JDSP contains a comprehensive set of functions necessary to perform undergraduate signal processing laboratories on smartphone devices. Laboratories for the use of the proposed application in an undergraduate DSP course were described. Future work includes extensive testing of the application, and building functions to support interdisciplinary streams such as earth systems signal processing, sensor networks, speech, and image processing.

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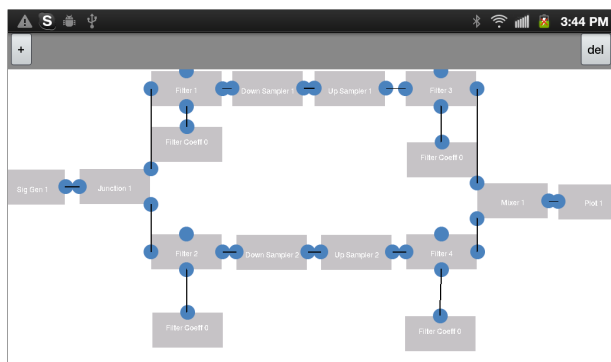


Fig. 3: A-JDSP block diagram for QMF design.

Exploring the Significance of Multi-touch Tables in Enhancing Collaborative Software Design Using UML

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Abstract—Encouraging collaborative software design through the use of multi-touch interfaces has become increasingly important, because such surfaces can accommodate more than one user concurrently, which is particularly useful for collaborative software design. In this paper, the potential of using multi-touch MT-CollabUML application for collaborative software design is explored. This exploration is done by looking at how students' collaboration might be enhanced in collaborative software design using Unified Modeling Language (UML) comparing the traditional paper-based environment with the contemporary multi-touch table environment.

Keywords—Multi-touch table; Software design; UML; Collaborative work.

I. INTRODUCTION

One promising learning technology that facilitates collaborative work among students is the multi-touch table. Several projects have introduced multi-touch surfaces to enhance collaborative learning. Collaborative learning has become increasingly important for several reasons. Multi-touch interfaces can accommodate more than one user concurrently, which is particularly useful for learning through large, shared display systems like tabletops [1, 2]. Using such systems encourages students to collaborate and create an environment wherein they can discuss their findings and integrate their ideas seamlessly with no technological hindrances. In addition, such systems can enhance students' interaction skills and promote teamwork.

Multi-touch environments offer new possibilities for interaction between humans and computers. Researchers from different educational backgrounds are exploring this area and indicate that multi-touch environments can be successful because interaction through touch is both intuitive and natural [3].

Many studies have shown the benefits of using multi-touch environments to enhance collaborative work. For instance, Rick and Rogers [4] built a system called DigiTile to enhance collaborative learning, which helped students design patchwork quilt blocks. In this study, students use multi-touch surfaces to drag pieces into a quilt block and change colors to design

mathematical shapes [4]. Further, multi-touch surfaces were used for collaborative information gathering. In this study, users were provided with a tool called WebSurface, which helped them browse the Web collaboratively to gather information from different websites. Using multi-touch surfaces allowed users to search for information, browse multiple pages at the same time, and easily gather the information they found [5].

The potential of multi-touch surfaces is to enable co-located collaboration activities, which allow small groups to work together collaboratively [6]. This potential might be a result of the ability of multi-touch tables to provide equal opportunities for collaboration in group work [7]. However, there has been little research to determine the potential of using multi-touch tables to enhance co-located collaboration in software design using Unified Modeling Language (UML). However, the level of collaboration in DigiTile [4] and WebSurface [5] is limited and restricted to simple actions performed by users, such as putting words in the right context, arranging items over tables, and simple click and drag actions. However, UML design involves advanced design issues that raise new collaboration needs, such as linking nodes and annotation. To this end, in this paper we explore the potential of using multi-touch technology for software design using UML by comparing it with traditional, paper-based collaborative software design.

In Section II, we briefly describe the related research work in multi-touch tables for collaborative work and in collaborative software design using UML. In Section III, we explain a comparative study between paper-based and multi-touch based environments in software design. In Section IV, we set forth and discuss the results and findings of the comparative study and how multi-touch tables have enhanced collaboration in software design using UML. Finally, in Section V, we draw conclusions from our research and discuss future work.

II. RELATED WORK

A. Multi-touch tables for collaborative work

In the literature on multi-touch tables, there is much interesting work reflecting the role of multi-touch in enhancing

collaborative activities. However, for the purposes of this paper, the use of multi-touch tables to enhance collaborative work is considered. Morris et al [8], conducted a research study to investigate the effectiveness of utilizing multi-touch tabletops to enhance cooperation during group functions and tasks. The finding was that multi-touch tabletops were particularly useful in enhancing team member awareness. This implies that multi-touch tabletops enhance information sharing among group members. In another study, Harris et al [9] examined the variation in group task performance between single and multi-touch tabletops. Multi-touch tabletops enhance task performance, unlike single-touch tabletops. Furthermore, another research study [10] examined the efficiency of multi-touch tabletops. Comparison between multi-mouse and multi-touch tabletops was performed. Results show that multi-mice are utilized more than multi-touch tabletops because of the following factors: (1) multi-mice enable users to interact with any part of the display when compared to the multi-touch; (2) users lack of familiarity with multi-touch tabletops; (3) variability in the usage of multi-touch tables. However, the authors note that users of multi-touch tabletops had fewer grammatical errors than those of multi-mouse users. In [11], multi-touch tabletops increase the awareness and common ground of group members working collaboratively to achieve a particular outcome. Moreover, multi-touch tabletops increase the effectiveness of group tasks and obligations [12]. According to the research studies described above, it is concluded that multi-touch tabletops increase group interaction and therefore increase attainment of group goals.

B. Technologies for collaborative software design using UML

There are many research efforts to facilitate collaboration among users in software design using UML, such as COLLECT-UML [13], CoLeMo [14], CAMEL [15], and AUTO-COLLEAGUE [16]. Unlike COLLECT-UML and CoLeMo, AUTO-COLLEAGUE does not support collaborative drawing for UML diagrams, but offers a chat system as its main collaboration tool. These systems, however, are designed to support distributed collaborative work, not a face-to-face collaboration style. With the exception of the Software Design Board [17], which is a shared whiteboard application, research has produced few outcomes supporting collaborative software design.

III. COMPARATIVE STUDY

As mentioned above, software collaborative design using multi-touch has not been widely explored; to the best of our knowledge there is no multi-touch collaborative UML design tool available. So, for purposes of this study, a multi-touch enabled tool called “MT-CollabUML” was developed to encourage students to co-locate collaborative software design using UML.

A. SynergyNet lab

This study was conducted in a specialized laboratory called SynergyNet at Durham University in the United Kingdom. The SynergyNet lab has a set of multi-touch tabletops, specially

designed furniture, and software that integrate physical components into a comprehensive environment to support collaboration (see “Fig. 1”).



Figure 1. SynergyNet lab

B. Participants

Twelve MSc program students volunteered to participate in the study. Participants, at the time of conducting this study, were studying a module called “Software Engineering for the Internet.” This module was chosen specifically because students were required to design software using UML collaboratively in groups. All participants had successfully completed the UML part of the “Software Engineering for the Internet” module before conducting this study. Involved students were asked to form four groups of three; each student joined his or her preferred group.

C. Experiment design

To investigate MT-CollabUML’s strengths and limitations in supporting collaborative design for UML diagram design, a within-subject experiment was conducted to compare how the participants used paper with how they used multi-touch surfaces in terms of collaboration. Similarities and differences were examined in terms of quantitative performance and qualitative behavior in the four groups of three students, who worked on creating UML-state diagrams. The goal was to identify differences in the level of collaborative design process across experimental conditions.

To ensure the validity of our investigation, we decided to compare the MT-CollabUML system with the traditional paper-based condition currently used for collaborative UML design. In both the MT-CollabUML and traditional paper-based conditions, we ensured that participants could work collaboratively; they had the same size work space and the same display orientation, and all group members could work at the same time. To maintain comparable conditions, we provided two similar tasks with the same difficulty and complexity.

The tasks were designed with clear and measurable learning outcomes and with the aim of integrating students’ reflections and discussions. We opted to use a collaborative group condition because the students involved were required to work in groups to perform software design using UML.

We provided two experimental tasks that required the participants to create UML-state diagrams. The course tutor was consulted to ensure that both tasks were of the same level of complexity. Each task consisted of several activities, including planning, discussion, decision making, drawing diagrams, and reflection.

Repeated measures design was followed in this study to help keep the variability low and make the experiment more efficient with a manageable number of participants. In this study, the four groups of students was arranged into group pairs; for every pair of groups, we gave one group a UML design task and asked them to complete it using pen and paper “Fig. 2”. We asked the other group to complete the same task using the multi-touch table. We then switched the groups and asked them to perform the second task using paper and multi-touch conditions “Fig. 3”.

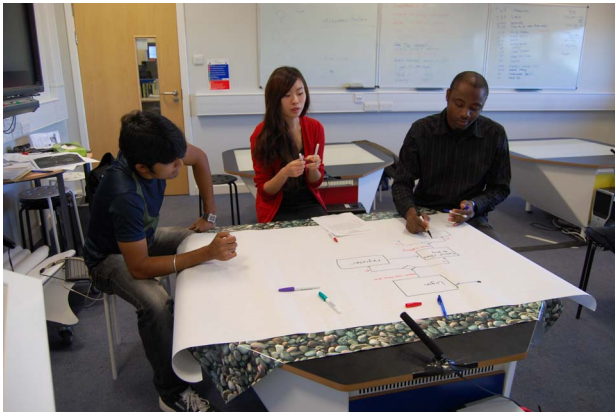


Figure 2. Paper-based collaborative software design



Figure 3. Multi-touch table based collaborative software design

D. Procedure

In the quiet SynergyNet lab, we used a within-subject study design in which we assigned all four groups both paper and multi-touch-based experiment conditions. Participants were given a 15-minute tutorial demonstration on how to use the multi-touch surface, and they were given as much time as they needed to complete the required tasks.

E. Data collection

All collaborative design activities were video recorded and transcribed for analysis. For the paper-based condition, we set up two cameras to focus on the table from two directions to ensure all group members could be seen. The multi-touch condition was conducted in the SynergyNet lab space shown in “Fig. 1”, where ceiling-mounted cameras recorded the multi-touch table from two angles and the screen capture was saved for future analysis.

F. Data analysis

Participants adopted different collaboration patterns as they designed UML diagrams in paper- and multi-touch table-based conditions. At times, they worked on the same problem, even adding nodes or annotations or using a digital keyboard; at other times, they separated work on different problems such as editing many nodes at the same time.

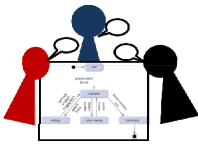
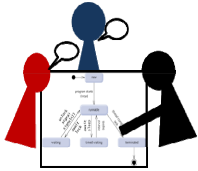

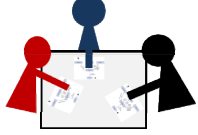

To investigate the similarities and differences between the conditions in terms of collaboration style, the collaboration style coding scheme of Isenberg [18] was adopted with modifications to fit with our study’s needs, as explained in Table I. For the purpose of this study, three collaboration styles were selected out of the proposed eight styles of collaborations by Isenberg [18]. The selected collaboration styles are: 1) Discussion (DISC), 2) View Engaged (VE), and 3) Disengaging (D).

The reason behind choosing these particular styles is that our participants performed them during the experiment. During the experiment, sometimes the participants stopped working and engaged in discussion (DISC) to explore different ways of solving the problem. At other times, some participants just engaged in watching (VE) what other participants were doing and gave them advice on how to proceed. Also, sometimes some participants were disengaged (D) during the experiment. These three collaboration styles (DISC), (VE), and (D) were common in our study and in Isenberg study [18].

Two new styles of collaboration were identified by the researcher, namely Shared Work (SW) and Working Individually (WI); these are not mentioned in Isenberg work [18]. It was observed that participants sometimes work together on the same diagram, but in different nodes or editing different areas; we call this Shared Work (SW) style. On the other hand, sometimes, especially in the paper-based condition, participants work individually (WI); each of them was creating different diagrams for the same task, so we consider WI as a style of loose collaboration. However, Isenberg mentions five other styles not relevant to our study, so we exclude them.

We calculated each collaboration style percentage for each group according to the total task time spent in both conditions. In the DISC, VE, and SW collaboration styles, participants collaborated closely by discussing and working together; some only watched, but they at least engaged in discussion. However, we considered the WI and D styles to be a loose collaboration, because one or more participants either worked separately or were completely disengaged during the task.

TABLE I. COLLABORATION STYLE CODING SCHEME (STYLES WITH DIFFERENT COLOR ADDED BY AUTHOR)

| Collab. Styles | Description | Example |
|----------------|---|---|
| DISC | Active discussion about the task. |  |
| VE | One person is actively working; the other watches and engages in conversation and comments on the observed activities but is not interacting with the table or paper. |  |
| SW | All persons share the work to solve the same specific problem. |  |
| WI | Working individually; each person is creating his/her diagram. |  |
| D | Disengaged. One person is actively working; the other is watching passively or is fully disengaged from the task. |  |

IV. STUDY FINDINGS AND DISCUSSION

This study explores the benefits of using a multi-touch table as a tool to encourage students to work collaboratively in software design using UML. In the case of multi-touch tables, students showed better and closer collaboration, and the use of multi-touch facilitated collaborative software design.

Qualitative analysis of the level of collaboration was performed as mentioned in Section III. The multi-touch finding showed that the percentages of task time that the participants spent in each collaboration style were: DISC (discussing), 26.31%; VE (view engaged), 30.82%; SW (shared work), 39.59%; WI (working individually), 0.00%; and D (disengaging time), 3.28%.

However, in the paper-based condition, the findings were: DISC, 41.86%; VE, 27.01%; SW, 5.35%; WI, 14.78%; and D, 11.00%. These findings are summarized in Table II.

There are two different levels of collaboration, namely close collaboration and loose collaboration, as explained in Section III. For example, DISC, VE, and SW are considered close collaboration, and WI and D are considered loose collaboration. In this research, we found that the total

percentages of task time spent in close collaboration styles were 96.72% in the multi-touch based condition and 74.22% in the paper-based condition. However, total percentages of task time spent in loose collaboration styles were 3.28% in the multi-touch based condition and 25.78% in the paper-based condition. Indeed, the multi-touch MT-CollabUML tool has played an important role in increasing the level of collaboration among students.

TABLE II. PERCENTAGE OF TIME SPENT IN EACH COLLABORATION STYLE IN MULTI-TOUCH AND PAPER-BASED CONDITIONS

| | Collaboration Style | Multi-touch based | Paper-based |
|---------------------|---------------------------|-------------------|-------------|
| Close Collaboration | DISC (discussing) | 26.31% | 41.86% |
| | VE (view engaged) | 30.82% | 27.01% |
| | SW (shared work) | 39.59% | 5.35% |
| Loose Collaboration | WI (working individually) | 0.00% | 14.78% |
| | D (disengaging) | 3.28% | 11.00% |

In the close collaboration styles, the participants engaged in active sharing of information and discussion regarding the task. They worked together as a team solving the same problems and pursued similar questions.

In the multi-touch based condition, the participants spent more time in close collaboration either by working actively on the same task (SW style) or by having one user actively drawing while the others contributed through discussion and comments on the ongoing design process (VE style).

In both multi-touch and paper-based tasks, participants spent a considerable amount of time in discussion prior to the actual design process (DISC style). Most of this discussion was conducted at early in the design process in order to agree on an initial design before committing to the design.

In the paper-based condition, it was difficult to revise the drawings on paper because the groups would have to redraw the whole design on a new sheet if the paper became messy. This explains why the participants in paper-based tasks spent more time in discussion before drawing. In contrast, the ability to easily revise and edit the UML design by using hand gestures in the multi-touch based condition made the participants probably feel more confident in contributing to the drawing process, because it was easy to redo and amend actions. This resulted in more active engagement by all group members in the multi-touch based condition.

In the paper-based condition, participants spent more than a quarter of the task time either working individually (WI) or disengaged (D). Participants sometimes worked individually, where each of them built different diagrams on a piece of paper and then showed their solutions to each other to decide which one was correct. As another strategy, one participant created a diagram while the others just watched, and then the active participant showed the diagram to them to discuss it. However, the results indicated that participants never worked individually in the multi-touch based condition, because the work space did not facilitate individual work. Therefore, the overall collaboration pattern results indicated that the multi-touch

based condition was better than the paper-based condition in terms of encouraging collaboration.

V. CONCLUSION

In this study, we investigated the differences in collaborative work in UML design among groups of students working in paper and multi-touch table based conditions to determine the potential of the multi-touch table. Results indicated the benefit of using the multi-touch MT-CollabUML tool in making a noticeable enhancement of the collaborative software design using UML.

The multi-touch MT-CollabUML tool allowed students to work collaboratively much more closely compared with the traditional paper-based work environment. The improvement in collaborative work between students in the multi-touch environment is a direct result of the facilities provided by the multi-touch MT-CollabUML tool in which students engage in active sharing of information and discussion of the task.

The multi-touch MT-CollabUML tool has played a role in minimizing working individually and encouraging group members to work collaboratively. On the other hand, the paper-based setting decreases the level of collaboration and encourages individual work due to the single person domination of the activity and practical difficulties in sharing the workspace and pens. Furthermore, in the paper-based condition, the correction of mistakes was to some extent difficult compared with the multi-touch table setting, and sometimes participants start the work from scratch after making mistakes. Indeed, the use of a multi-touch table helped students to better work together and enhanced and facilitated the collaborative software design of UML. More research should be done to compare between desktop-based collaborative software design and multi-touch based design to further explore the potential of multi-touch tables.

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Comparing the Mobile Novice Programming Environments: App Inventor for Android vs. GameSalad

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Abstract—Novice programming environments (NPEs) like Scratch and Alice witnessed tremendous growth in adoption and popularity in recent years. These NPEs have successfully lowered the barrier of initial entry to programming. They have also allowed novice computing students to exercise their creative freedom more meaningfully by enabling them to work on projects which have more real life context.

Recent trends in adoption of smartphone and other mobile devices among our youth points to a time in near future when majority of them will be mobile device users. Hence, if the NPEs want to remain relevant among youth, they need to adapt to and cater to a mobile-device centric audience. Google and MIT's App Inventor for Android is one of the early NPEs that is trying to achieve this by offering a Scratch-like environment for mobile apps development. GameSalad is another free software primarily for Mac platform that can also offers a drag-n-drop rule-based environment for creating apps. In this paper we compare these two environments' suitability for computing introduction. Our comparison is based on several logistical, instructional, and operational factors and points to the fact that both these mobile NPEs have their strong points as well as weaknesses. We believe the effectiveness and success of these mobile NPEs will vary depending on particular situations, and hence our work will aid someone looking for a mobile NPE in making a more judicious choice.

Index Terms—App Inventor for Android, GameSalad, Visual “blocks” programming, Novice programming environment.

I. INTRODUCTION

Programming is a difficult skill to learn. Many novice programmers constantly struggle to understand the computational concepts and syntactic details while learning programming. Traditionally, both in universities and high schools, programming was introduced using production/enterprise level languages like C, C++, and Java. The learning-curve for students learning programming for the first time using a language like Java is very steep. Introductory programs that students often write in a language like Java also often lack any meaningful real-life applications and contexts for those students.

Designing *Novice Programming Environments* (NPEs) to address some of these challenges is one solution that computer science education researchers have looked at. NPEs are

special purpose programming languages with the main goal of lowering the barrier of initial entry to programming. Some of the main features in most NPEs are hiding of syntactic complexities of programming languages, making it easier to understand and use the basic computational concepts, and enabling the students to create more meaningful programs and projects which are more relevant to their lives. Several NPEs were designed with these goals in mind and had varying degrees of success in terms of popularity and adoption. Refer to [5], [6] for detailed surveys of NPEs developed before 2005.

Two NPEs designed within the past few years that experienced widespread adoption are Scratch [8] and Alice [4]. Both Scratch and Alice are visual “block” programming environments where students create their programs by snapping together programming blocks that behave like puzzle pieces. There are many advantages of “blocks” languages. They eliminate the need for typing complete programming statements. Incompatible blocks would not snap together. These features reduce the chances of making a syntactic error. Additionally, the blocks visually depict computational concepts like a loop. Hence, it is easier for students to use the concepts. Both Scratch and Alice are very popular. The Scratch gallery currently has more than a million members and more than three hundred thousand project creators. A huge majority of these members and project creators are teenagers¹. Many high schools, universities, and other organizations leveraged NPEs including Scratch and Alice to design and offer novel programming introduction activities. These activities range from CS0/CS1 courses in universities [11], [12], [16], to summer camp and after school activities for school students as well as teachers [1], [7], [13], [17].

App Inventor for Android (AIA) is a relatively new NPE that was initially designed at Google [18]. Since January of 2012, the newly created Center for Mobile Learning at MIT has taken over the further development and maintenance of AIA. AIA shares the same program-design philosophy with Scratch. In AIA, just like Scratch, students also drag and snap puzzle-

¹<http://stats.scratch.mit.edu>

pieces like blocks to create their programs. The key difference between AIA and other NPEs like Scratch and Alice is that students create apps using AIA which runs on any Android device. AIA has witnessed rapid adoption among colleges and schools and has established itself as a major player among the “mobile” NPEs.

Android and iOS devices currently account for a huge majority of mobile devices in use. Hence, there is room for a mobile NPE targeting iOS devices as well. GameSalad is a software created mainly as a rapid iOS game-authoring tool for non-programmers. GameSalad is a rule-based system where the programmer creates rules for various components of the app being developed. GameSalad was not explicitly designed to be an NPE. However, it shares most of the main themes of NPEs, namely easy, visual, drag-n-drop program creation, support for easy expression of the main computational concepts, and ability to create programs that resonate with the students. Hence, it can be used in a programming introduction activity.

In this paper we compare App Inventor for Android and GameSalad for their suitability for introductory computer science classes using a set of metrics that encompass (a) logistical factors, such as the cost and complexity of the initial setup, and the difficulty involved in selecting and setting up suitable mobile devices for development and testing; (b) instructional factors, such as the availability of quality lessons and tutorials, and transitioning-in and transitioning-out features; (c) usability and operational issues, such as quality of the interfaces, the existence of embedded social features like app and code sharing, students’ ability to install the apps they created on a mobile device, and platform dependence.

In order to accomplish our analysis, we installed the software and connected mobile devices to a variety of platforms. We conducted web searches for existing instructional materials and peer help groups. We also designed a set of apps for introductory programming instruction, and created publicly available tutorials of our own for both GameSalad and AIA.

Rather than establishing a clear winner, our results suggest specific conditions upon which the choice of NPE should be contingent. Our study can therefore be a useful primer for educators planning introductory programming courses and activities. It will also be useful in guiding data collection for future quantitative analyses.

In the next section we provide backgrounds and motivations for our work. Section 3 contains our detailed analysis and comparison of AIA and GameSalad and Section 4 provides concluding remarks.

II. MOTIVATIONS

Today’s youth live in a mobile world. Personal computers are not their only computing devices any more. In fact many of them use a mobile device like a smartphone more frequently than a computer. Nielsen’s recently published Mobile Youth Around the World survey points to the fact that more than one third of 15-24 year old population in USA own a smartphone with females owning a majority of them by a small margin [15]. This survey did not specify the smartphone ownership

specifically among teens. However other indicators in the survey point to teen smartphone ownership being very high as well. That survey also pointed to the facts that almost all teens owning smartphones use them for advanced data services and that data consumption has grown many fold in recent years. Pew Research Center published a similar survey called Pew Internet and American Life Project [9] that shows similar trends.

Piper Jaffray’s biannual “Taking Stock with Teens” survey released in early April 2012 shows even broader adoption of mobile devices, especially iOS devices among teens. In their latest survey [10], they found that approximately 34% of teen respondents already owned an iPhone. 86% of the teens reported that they intend to buy a smartphone while making their next mobile device purchase. 51% of the teens reported that they are likely to buy an iOS device and 40% of the teens plan to purchase an iPhone within the next six months. Similar growth trends were reported in the tablet market as well. Most of the cellphone carriers in USA require smartphone owners to subscribe to advanced data plans. So the bottom line is, very soon a vast majority of the teens in USA will perpetually have an Internet connected computing device in their pocket.

One of the main goals of NPEs is to lower the barrier of initial entry to programming. This goal is becoming increasingly important in light of the fact that in recent years colleges and universities have failed to attract computing majors, especially females and under-represented minorities [2], [3]. The fact that females and minority students are poised to grow as a percentage of the total student population [14], magnifies the problem. Research has shown NPEs play an important role in attracting and retaining new programmers in computing related disciplines. Since the smartphone is one of the (if not the) main computing devices of today’s teens, NPEs for smartphones and other similar mobile devices are quickly becoming essential.

iOS and Android are currently the two main mobile operating systems. If one considers the general population’s mobile ownership, Android powers majority of the mobile devices. But as pointed out in the Piper Jaffray surveys, iOS is still the most desirous platform among the teens. Hence, NPEs for both these operating systems are needed. AIA is quickly becoming the de-facto NPE for Android domain. There is no consensus candidate for the iOS devices. Hence we wanted to research the suitability of one contender, GameSalad by comparing it to AIA. Our analysis is qualitative in nature and presents our opinions.

The main contribution of this paper is to present various factors that determine the efficacy of mobile NPEs and present our brief opinions about AIA and GameSalad pertaining to those factors. To the best of our knowledge, no prior research contrasting mobile NPEs exist. We expect this work to help anyone who is in the process of selecting a mobile NPE by directing them to the relevant issues so that they can make a more informed choice.

III. AIA VS. GAMESALAD: OUR ANALYSIS

In this section we present our analysis and comparison of AIA and GameSalad. We made the comparisons on several logistical, instructional, usability and operational factors. The following subsections detail the process we undertook to make the comparison as well as our impressions.

A. Logistical Factors

Cost: Both AIA and GameSalad are free software available for anyone to download. So upfront, the software itself costs the same². However, GameSalad, once downloaded and installed, requires no active Internet connection to be used whereas to use AIA, an active Internet connection, preferably a high-speed connection is required.

Complexity of initial setup: The initial setup for GameSalad is very simple. Installing it is just a matter of downloading the appropriate binary file from the GameSalad website. The setup for AIA is slightly more complicated. AIA uses Java, so before going through the steps to set up AIA, one needs to verify that Java is installed on the computer. After Java has been installed, installing AIA is fairly straightforward. Both AIA and GameSalad require additional drivers in order for devices to connect to the software. AIA installer comes with drivers for some of the more popular Android devices. AIA requires a driver called Advanced Debug Bridge (ADB) to interface with any device. Since there is a plethora of Android devices that are currently available, finding the ADB driver (especially for relatively newer devices) can be difficult. In our experience the websites like AIA Repository³ maintains a list of ADB drivers for various devices with download links.

In order to test apps developed in GameSalad, a software called GameSalad Viewer must be installed in the iOS device. GameSalad's website lists YouTube tutorial⁴ about this process. But this process is quite complicated, requires a Mac, and in our opinion is more complex than the corresponding step in AIA. Additionally, the recently released Windows version of the GameSalad creator software cannot communicate with the GameSalad Viewer. Hence, GameSalad apps developed in Windows can't be directly tested on an iOS device (an app developed in Windows can be transferred to a Mac computer and then tested).

Selecting a target mobile device and associated cost:

AIA is platform dependent. Only Android devices are available for testing. Till recently, GameSalad was platform dependent as well and needed Apple products for testing. However, recently GameSalad has started incorporating Android support for testing. Their pro version has Android publishing. Even their free version has support for an Android viewer that can be installed on Android devices.

As far as available devices for GameSalad and AIA are concerned, an unlocked contract-free iPhone 4S 16GB will cost \$649.00 and the newest generation iPod touch will cost \$199.00 from the Apple store. For Apple tablets, the iPad 2 starts at \$399.00.

There are many Android products on the market. The two major categories are hand held phones and tablets. It is difficult to acquire an Android phone without signing a contract. Most tablets do not require a contract and can be found anywhere from \$55 to \$500.

Apple products certainly have more "desirability" among teens. Additionally, the popularity of a sub \$200 device, iPod touch makes device selection for GameSalad easier. The only sub \$200 Android device that has witnessed broad adoption so far is Amazon's Kindle Fire. There are numerous Android devices available with new ones introduced every day. Hence selecting a device becomes more challenging.

B. Instructional Factors

Availability of instructional resources: GameSalad and AIA both have tutorials available on their respective websites^{5,6}. Both the AIA and GameSalad tutorials are aimed towards an audience with little programming experience, however the tutorials go different ways about familiarizing the user with the environment. The GameSalad tutorial show the different features and functions of GameSalad while the AIA tutorial both demonstrate features of AIA and teach you how to use the features to interact with your device simultaneously.

The tutorials offered by GameSalad and AIA are in a text format with images interspersed throughout. For video tutorials, YouTube, the popular video sharing website, has hundreds of tutorial videos for both GameSalad and AIA. For additional support, both GameSalad and AIA have dedicated forums where users can ask questions to the online community^{7,8}.

To the best of our knowledge, there are four books on App Inventor, which are currently available. We have reviewed two of them. Both of them take a project-based approach and introduce various programming ideas through hands on projects. Recently a couple of books on GameSalad were released as well, which we have not had a chance to review yet. AIA has seen more adoption in college classes. Hence materials used in college courses are more readily available for AIA⁹.

Ease of creation of instructional resources: We created and made publicly available several elementary tutorials to guide novice students through the creation of a few simple games in both GameSalad¹⁰ and AIA¹¹. These included a pong like game, and a baby catch game. The creation of such simple applications is not particularly more difficult in one

²GameSalad has recently launched a pro version which costs \$299/year. This comes with advanced features like Android publishing, Twitter integration, ability for in-app purchase etc. The basic version used for all our analysis is still free.

³<http://www.tair.info/faqs-and-how-tos/troubleshooting/gray-button/>

⁴<http://www.youtube.com/watch?v=fBXdUFDjNtY>

⁵<http://cookbook.gamesalad.com/tutorials>

⁶<http://beta.appinventor.mit.edu/learn/tutorials/index.html>

⁷<http://forums.gamesalad.com/>

⁸<http://beta.appinventor.mit.edu/forum/>

⁹<http://www.appinventor.org/course-in-a-box>

¹⁰<http://www.youtube.com/playlist?list=PL12561857EAD47904&>

¹¹<http://www.youtube.com/playlist?list=PL2D27126F35E50A1B&>

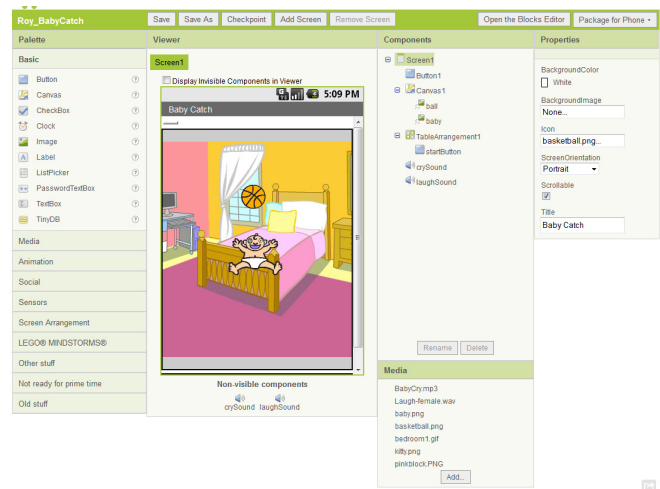
environment than the other. However, construction of lessons on loops, variables, functions, is more straightforward in AIA, which provides ready-made blocks to represent such constructs, than it is for GameSalad, which obscures these things to a great degree. While it is certainly possible to demonstrate the relevance of these concepts to GameSalad projects, doing so requires care and finesse. What is more, GameSalad's abstraction away from such basic computing concepts might present an impediment to student understanding.

Transitioning-in and transitioning-out: AIA shares its look and feel with Scratch, which has a substantial pool of current users. Hence, a student transitioning-in to AIA from an environment like Scratch will find it very seamless. Even then, the barriers to entry are lower for GameSalad. GameSalad users are able to create simple but slick looking games without having to learn anything about lists, loops, event listeners and the like. On the other hand, from early on AIA has been envisioned, at least in part, as teaching software. Consequently some thought and energy has been invested in facilitating the graduation of its users to more complete programming environments. Not only is the block syntax somewhat reminiscent of the Java programming language upon which it is built, with its “Java Bridge”, AIA provides a platform that allows users to incorporate AIA components into Java and Android SDK applications. GameSalad was designed without pedagogical motivations. Rather than providing a gentler introduction to programming, its aim is to obviate programming altogether, to allow professional app development without the use of a programming language. While experience with GameSalad will no doubt benefit students going on to learn computer science, students for whom experience in app development has been limited to GameSalad will be starting over when learning a first professional programming language to a much greater extent than will students with commensurate experience with AIA.

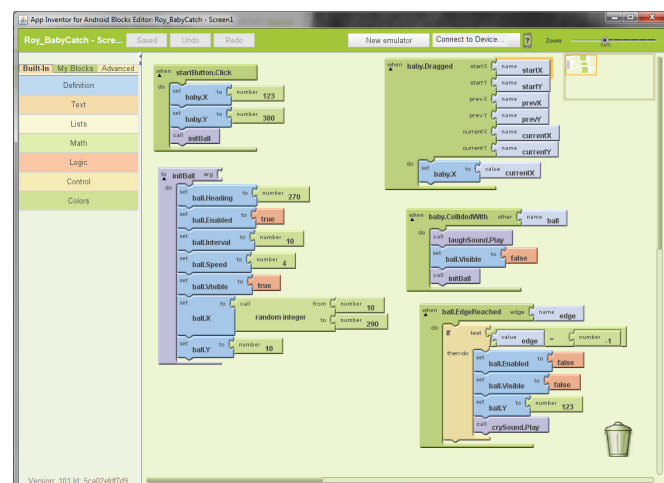
Suitableness for introducing basic computing concepts: Several factors make AIA more attractive as a platform for teaching elementary computing concepts. AIA is more general than GameSalad, which as the name implies, was designed specifically to facilitate game development. While GameSalad can be used to create non game applications, doing so can be pretty awkward. AIA provides ready-made blocks that allow students to use loops, incorporate simple data-structures (such as lists), and define variables and procedures without learning complicated syntax. While introducing OO concepts, objects and classes, is fairly straightforward, GameSalad does not provide support for data structures or loops, and is less extensible than AIA.

C. Usability and Operational Factors

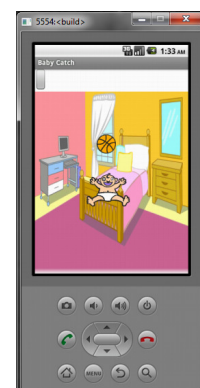
Quality of the software interface: Figure 1 shows the various components of AIA interface while Figure 2 depicts that of GameSalad for the same app. The AIA software interface has three main components, the browser based designer where the layout of the app is created (Figure 1(a)), the blocks editor which creates the programs for all the objects of the app



(a) AIA app designer

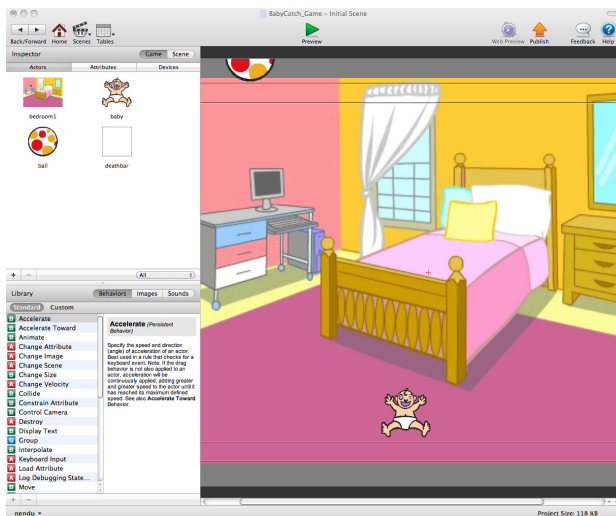


(b) Blocks editor

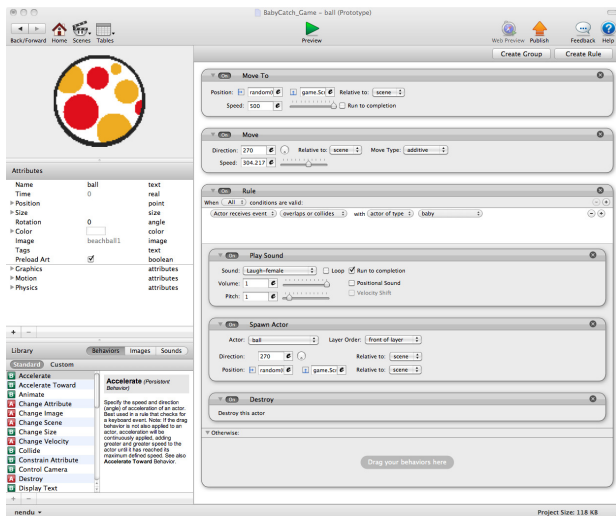


(c) Emulator

Fig. 1. The AIA interface



(a) GameSalad layout window



(b) Rules window



(c) Emulator

Fig. 2. The GameSalad interface

(Figure 1(b)), and the emulator (Figure 1(c)). When a student is creating an app, they have to move between these three components.

GameSalad also has three similar components, however they are integrated in a single window. Figure 2(a) shows the GameSalad layout window, Figure 2(b) the “rules” window with all the rules controlling the ball in this game and Figure 2(c) shows the working app running in the emulator.

In our opinion, GameSalad has a sleeker and more refined interface. Additionally, in GameSalad, rules for each object are separate unlike AIA where the single blocks editor window shows all the blocks for all the objects. This effects the readability of the code. In GameSalad it is very trivial to figure out what code corresponds to what object. Code object mapping is not as obvious in AIA.

Embedded social features: One of Scratch’s main strengths is its popular project gallery where thousands of users share their projects and codes. Neither the AIA website, nor the software has any support for an app gallery. However, researchers at University of Massachusetts at Lowell are currently creating such a gallery for AIA app and code sharing (it is under beta testing). GameSalad has better code and project sharing feature. GameSalad has a gallery on their website called Arcade and any user can publish their projects from within the GameSalad software to the Arcade.

App installation: It is easy to install apps created in AIA to a device. As long as the device is capable of installing apps from unknown sources, the AIA software itself can install the app to the connected device.

It is much harder to install an app created using GameSalad on an iOS device. This is not a limitation of GameSalad however. This has more to do with the fact that iOS does not allow the installation of any app unless it is through the app store. We feel students creating basic apps would not be able to navigate the app-store app submission and review process which will enable them to install their apps on their devices.

Platform dependence: AIA works both on PCs and Macs. Until recently, GameSalad was Mac specific software. GameSalad launched a windows version of their creator software in May of 2012. However, apps created using the Windows version of GameSalad cannot be directly tested or installed on an iOS device. A Mac is still needed to achieve this step. We believe this will be a major impediment in broader adoption of GameSalad as not many schools have a lab with Mac computers.

IV. CONCLUSION

To summarize, in this paper we compared AIA and GameSalad, two mobile NPEs based on various logistical, instructional, and operational factors. Mobile novice programming environments are relatively new, but they hold tremendous potential in attracting students to computing as they can appeal to the mobile-computing-centric mindset of today’s youth. Hence, our work and results will serve as a starting point for any educator who is making a decision about selecting a mobile NPE.

In our view, there is no one clear winner among AIA and GameSalad. Both the NPEs have their strengths and weaknesses. GameSalad might be more suitable in schools that have labs with Mac computers and in programs where there are no expectations for students to work on their own computers outside of class and for programs in which the primary goal is to get students excited about development rather than more serious introductions to computer science. AIA on the other hand might be more suited for a more formal CS setting where the ultimate goal is programming proficiency. In this paper we detailed various factors that will affect the decision of selecting one NPE over the other. In the future we plan to broaden this work to cover more mobile NPEs and more relevant factors based on which a comparison can be made. We also plan to conduct a quantitative study on the effectiveness of different features of the mobile NPEs in teaching computational concepts to novice programmers.

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Work in Progress: Using Mobile Phones to Accomplish an Audience Response System with iGoogle Home Page

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Abstract—Audience Response Systems can benefit the normal course of the classes. Dedicated Audience Response Systems can be quite expensive to purchase and maintain. Additionally, the question types supported are somewhat limited, usually only choice questions are available. In our previous works we have developed a set of OpenSocial gadgets that can be included in a personal iGoogle page. Our future work is centred in providing a electronic voting system based on gadgets with iGoogle using mobile devices as smartphones and laptops for voting.

Keywords: Audience Response System; iGoogle; OpenSocial; gadget;

I. INTRODUCTION

An Audience Response System (ARS) allows teachers to ask questions to an entire class that can answer electronically [1]. The teacher displays a question on a screen and the students send their responses to a receiver using their remote devices. The results are collected, summarized and presented to the class. The participation can be made anonymously or identifying the participants by increasing the teachers' efforts and the complexity of the devices. The system is usually composed by a receiver, responsible of storing the answers and dispatching the result statistics, and a set of remote devices used by the students. Many devices support simple choice questions and some of them numeric text entry, so teachers cannot make complex questions to the class.

New technologies are involved in our everyday life; this concerns both teachers and students. It is not uncommon for students to bring smartphones or laptop to class. We must consider that mobile devices have more computing and communication capabilities. Current smartphones can use a Wi-Fi connection or a data plan from any cell operator to get access to Internet. For these reasons, an ARS using these technologies can be developed and maintained at lower cost than normal systems.

In previous experiences we have developed a set of OpenSocial gadgets to provide e-learning specific features over iGoogle. As part of the testing we realize that although iGoogle

offers a complex presentation in a normal Web browser, it has a simpler layout for small devices. Our works are centred in modifying the students' gadget Edu-GAL (Educational – Gadget Activity List) [2] and create a new gadget called Edu-GAR (Educational – Gadget Audience Response) in charge of displaying in-class questions and let students to answer them.

II. RELATED AND PREVIOUS WORK

Existing ARSs are composed by remote control devices that are specifically developed for this purpose. In this way, they must be purchased and maintained in good conditions. Other problems with the use of these devices in the class are that students can damage or loss them. Some remote devices use infrared (IR) to communicate remote devices with the receiver. This type of communication needs to have direct vision between transmitter and receiver, which can be difficult to obtain in a crowded class.

On the other hand, the current trend in mobile phones is to create more advance devices. Our last survey to our students revealed that the 40% of them have a smartphone with Internet access or Wi-Fi connection and the 87% have a laptop. These devices are used by the students in their everyday life, so students will take more care about them than other casual devices.

There are cheaper approaches in the development of an ARS using Web-based solutions (compatible with mobile devices); but they usually provide support only for a restricted amount of participants and as the teacher needs more features (i.e. multiple users, identify participants, etc.) the price increases significantly.

In previous works, we make a set of OpenSocial gadgets focused on providing e-learning functionalities to iGoogle: learning paths, activity creation/completion/monitoring and resources manipulation [3]. These gadgets provide a Graphic User Interface (GUI) to a sub-set of the Web service functionalities. Gadgets are not linked to a particular Web service and support different types of activities. One of the

activity types supported is centred in the answer of a questionnaire composed by IMS QTI [4] based questions (currently only simple and text-based) to evaluate the students' knowledge. We created one gadget for each of the following learning roles: authors, teachers and students.

Our gadgets can make use of existing Web service to create and display information to the users. The communication can be made anonymously or identifying the user to provide personal information. Users can do some actions according with the Web service limitations. This approach allows users to take advantage of existing gadgets to compose their personal learning environment and help themselves:

- creating activities as authors using Edu-GAAT (Educational - Gadget Activity Authoring Tool),
- managing activities and checking students' results as teachers using Edu-GAM (Educational - Gadget Activity Manager)
- attempting activities and completing learning paths as students using Edu-GAL (Educational - Gadget Activity List)

III. PROPOSAL

The developed gadgets are small applications that ask for information to the Web service when needed (e.g. when a user selects one resource the gadget asks the Web service for its content). There isn't any synchronization method. We are planning to modify Edu-GAL to create a new gadget called Edu-GAR (Educational - Gadget Audience Response) that will periodically poll the Web service searching for new questionnaires. This new gadget will display one questionnaire composed by one or several questions at a time, if there is any published. Users will be able to select between two operation modes: automatic polling or manual polling. The former polls the Web service periodically and the latter let users decide when to poll for information. Manual polling reduces the amount of traffic generated during the class.

To provide a complete ARS, teachers should use Edu-GAAT to create activities before the class starts setting it as unavailable. When the class begins the students can prepare themselves accessing their iGoogle page with Edu-GAR selected. During the class, the teacher will enable an activity using Edu-GAM. Edu-GAR will display the questionnaire with a small delay, depending on the gadget's configuration (if there are more than one activity at a time, it is the Web service duty to decide which activity is shown). At this point students can answer the questions and submit the results. Once the time is over, the teacher can stop the poll by setting the activity as completed and check the result statistics using Edu-GAM.

IV. CONCLUSIONS

The gadgets can be used by any smartphone with a Web browser regardless of the operating system (i.e. iOS, Android,

Windows Mobile or BlackBerry OS). The creation and the maintenance of a specific application for each operating system may be time consuming and overtake the developers' workload.

This approach can decrease the price of the creation of a new ARS, and its maintenance is simple. The only need is to create/find a Web service to store and process the information. There is not necessary to purchase any remote device for voting; the cost of an ARS using this approach is independent of the number of participants.

The iGoogle page is related to the personal account of each student and gadgets can use OAuth protocol to make signed requests to the Web service. This fact eases the participant identification because every student will be logged with her/him personal account; students don't need to log an additional account in order to participate. For this reason, a student can use different devices along the course without being tied to a single remote device; moreover, devices can be also shared to give support to different students.

Our proposal is not suitable of making first-to-answer questions because students won't be using the same cell operator neither a device of identically specifications. Another drawback can appear when a student outside the class has her/his iGoogle page open during the poll. In this case, s/he may be able to answer to the questions. At this point the teacher should check the amount of responses and the identity of the participants if only in-class answers are allowed.

Using this gadget the teacher may be able to create more complex questions than choice interactions and make questionnaires of more than one question.

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Special Session: What do student-generated diagrams say about their understanding?: Developmental trajectories of model-based reasoning in engineering students

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Abstract—The main goal of this special session is to foster a continuing conversation within the FIE community about model-based reasoning in general and the essential role of diagrams in engineering education in particular. During this session, small groups of participants will develop categorization schemes using a collection of student diagrams. Groups will share their categorization schemes and ideas through a gallery walk.

Index Terms— Diagrams, Expert – Novice, Model-based reasoning, Think aloud protocols

THE main goal of this session is to foster a continuing conversation within the FIE community about model-based reasoning generally and the essential role of diagrams in engineering education specifically.

It is our hypothesis that experts solve problems in CSTEM disciplines by using a complex series of cognitive moves in a non-linear and iterative fashion, in contrast to the linear problem solving described in textbooks and often modeled in classrooms. More specifically, the expert must navigate three semiotic systems as she transforms a textual/linguistic account of a problem to a diagrammatic representation and finally to a symbolic mathematical representation. At each stage, salient elements are extracted and re-presented in a new semiotic form. Such cognitive transformations are grounded in model-based reasoning, or the ability to represent a system with its interactive parts or dependencies, which is a form of reasoning fundamental to engineering problem-solving.

Motivated by the importance experts place on diagramming, cognitive scientists have conducted numerous studies to understand the role of diagrams in problem-solving. These studies have shown that it is a complex phenomenon with multiple facets and that not all diagrams are helpful for

solving problems. Despite the complexities, it is clear that drawing diagrams can facilitate multiple aspects of the problem solving process.

This session turns the lens around and asks what we can learn about student understanding from the diagrams they produce. How do a student's choices about which features to include from the text and which to ignore indicate their conceptual understanding? How does their decision to abstract a particular part into a black box with inputs and outputs reveal the knowledge they bring to the solution process? If a student draws a more realistic depiction of a process, does it indicate a lack of abstraction of thought?

During the session, participants will solve a problem which requires a diagram and then work in small groups to categorize the types of diagrams produced by students. The goal is to discover what a diagram might say about the students' model-based reasoning and conceptual understanding. The small groups will produce bulletin boards for a gallery walk, followed by a period of reflection and integration of ideas.

The session agenda includes:

- Introductions of people and session
- Example problem
- Mini-lecture on Representational transformation
- Small group work: Creating a categorization scheme for the diagrams. Goal of scheme is to identify how well students understand diagrammatic reasoning
- Gallery walk
- Small groups reflection and wrap-up

Since diagrammatic reasoning is important in all STEM disciplines, we expect this session to appeal to a wide variety of FIE participants. Faculty who teach courses requiring diagrammatic reasoning should find the session very useful. Since there has been very little rigorous research on the text to diagram translation, education researchers interested in cognition, representation, problem solving, and design will find the session thought-provoking. In addition, attendees who are interested in community and identity formation will find the session relevant as different disciplines have different community-sanctioned diagrams and diagramming standards.

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Finally, since the topic is truly at the frontiers of current research, graduate students who participate will be introduced to an area ripe for research.

This session will introduce the FIE community to a frontier area of research which is rich with questions and opportunities. We expect that it will start new lines of conversation and collaboration across STEM disciplines, resulting in new research projects. Participants will benefit from the opportunity to think deeply about diagrams and what they reveal about students' understanding.

Finally, this session is the beginning of a planned series of Special Sessions and research papers by the facilitators to be presented at FIE conferences over the next several years.

Challenges and Issues in the Development of a Software Engineering Simulation Game

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Abstract— In Software Engineering courses, students are introduced to important theories and concepts. However, these courses lack a practical opportunity for students to experience them more effectively. Even with the team-based project approach it is not possible to train students in all the real situations of a software development organization, due to the very nature of software applications and the large variety of organizational cultures. Simulation games are an appropriate complementary approach to the traditional educational techniques. Students' preparation can be improved by allowing them to practice, through a simulator, activities that are infeasible to practice during a Software Engineering course, due to restrictions of time and resources. Unfortunately, the creation of a simulation game is not a straightforward activity; it involves many different skills and addresses different viewpoints. In this work, we discuss the issues and challenges associated with the creation process of a Software Engineering simulation game. We adopted an incremental and iterative approach, where each step involves different knowledge, allowing us to point out a set of important aspects that should be taken into account during the development. These aspects can guide new developers and instructors in the design and selection of educational simulation games.

Keywords- *software engineering; simulation game; software process improvement*

I. INTRODUCTION

Simulation in education can be an effective tool for enhancing complex subjects learning and understanding. By using a simulator, several aspects of difficulties can be planned and experienced without great risk, with low cost and without logistics restrictions [1]. A Software Engineering simulation game provides an environment where development processes are practiced by “playing” them [2]. In this environment, a common situation is for the players to receive a task that should be completed during the simulation game.

The development of simulation games with the aim to improve students' learning experience is gaining increasing attention [3]. A number of simulation games have been developed [2], [3], [4], [5], [6], [7], [8], and [9]. Most of these simulation games make use of a software development project that drives the game play [10]. Typically, they have a graphical user interface which simulates a software development organization, creating a game-like environment. The main goal is to create an enjoyable atmosphere that will make the learning process more effective.

The design process is at the heart of the simulation games development [11]. Despite the design process importance for attaining students' learning, we have noticed that it is not

receiving much attention in the literature. The steps that should be taken into account during the simulation game design are (i) Software Engineering concepts addressed by the game; (ii) the game-like elements used to enhance motivation and the effectiveness of learning; and (iii) the modeled real world phenomena.

In this article, we address the design decisions took during the development of SPIAL, a graphical and interactive Software Engineering simulation game, highlighting the faced challenges and issues. The aim of SPIAL is to improve Software Engineering education in dealing with the complexity of what happens in a real software development organization. Using SPIAL, we evaluated how a Software Process Improvement (SPI) simulation game can teach to students the best practices of Software Engineering. The results of this research can guide new developers and instructors during the design and selection of educational simulation games. Our study confirms the high level complexity of this subject and the missing process support for Software Engineering simulation games development.

The remainder of this paper is structured as follows. Section 2 outlines the related work on Software Engineering simulation games and a brief description of SPIAL. Section 3 presents an overview of the steps carried out during the simulation game design and development. Section 4 discusses the issues and challenges of our development approach and Section 5 presents the final considerations and future work.

II. BACKGROUND

Most of the simulation games have as their goal to develop a software project within a certain set of constraints, and their rules are based on Software Engineering lessons (e.g. SimSE [2], SESAM [5], SimJavaSP [6], and MO-SEProcess [7]). Typically, they present a metaphor of a software development office, where the player assumes a project manager role. The experimental evaluations of using these tools have shown a restricted number of new concepts that students have learned after playing them [2], [12]. This can be a result of a not straightforward performance feedback that is presented to the students, or the way that the virtual world was designed. In order to address these aspects, we changed the context from Project Management to SPI and we integrated feedback during the whole simulation game playing.

SPIAL (*Software Process Improvement Animated Learning Environment*) is a graphical, interactive, simulation game, which emphasizes SPI concepts. Despite its focus on SPI, it is a teaching tool that reinforces Software Engineering concepts to students.

SPIAL is a single-player game in which players take on the role of a manager of an SPI group in a software development organization. The player is given a process improvement task and he/she can interact with other stakeholders (high level management, project manager, team member, consultant, or customer) represented as non-player characters, i.e. a character controlled by the computer (see Figure 1). In order to complete the task, the player can make investments for improving specific process areas of a software development project (which can be considered a pilot project). A good investment strategy will result in improvement of process areas and a bigger budget for further investments. SPIAL incorporates some of the concepts defined in CMMI-DEV version 1.3 [13] (*Capability Maturity Model Integration for Development*). In the first SPIAL version, we considered an organization with maturity levels 1, 2 and 3, with capability levels of process areas varying between 0 and 3.

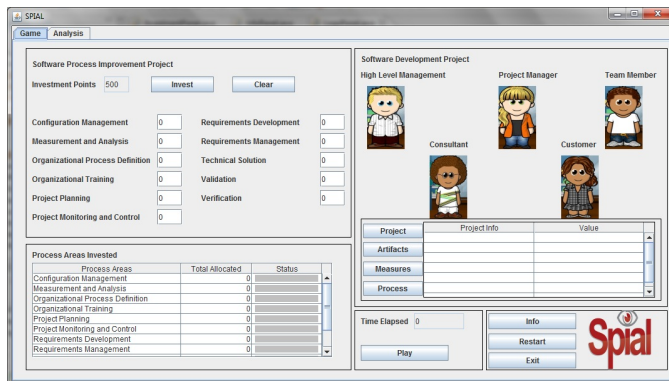


Figure 1. SPIAL Graphical User Interface.

The player can visualize project estimations, indications of process areas capability level and decide in which process area to invest. During project execution, the player can visualize the effects of his/her selections on the outcomes (productivity, defect, cost, and time-to-market measures) and if needed, change his/her investments. The occurrence of events follows some probability distribution, for example, the software development team can have resistance to adopt the changes, and the player can overcome it with specific actions, such as promoting training. The final outcome is a score that represents how close the results are to the initial proposed target. During the game, the non-player characters communicate the effects of the player's actions through bubbles over their heads, for example, "Since there is dependency among process areas some of your investments may not be effective", or "Poor investment decisions result in a reduction of business value, and a reduction in the number of investment points."

The analysis tab sheet (see Figure 2) was designed with the aim to give players a better insight of the correctness of their decisions, specifically providing graphical information about the measures, the description of the rules used in the game, information about the achievement or not of their improvement targets and the final score. All events occurring during the game are recorded in the events log table.

For illustrative purpose, we elaborate the following initial scenario, which is a narrative description [14] of what the user

(in our case, the player) will perform and experience as he/she makes use of the application:

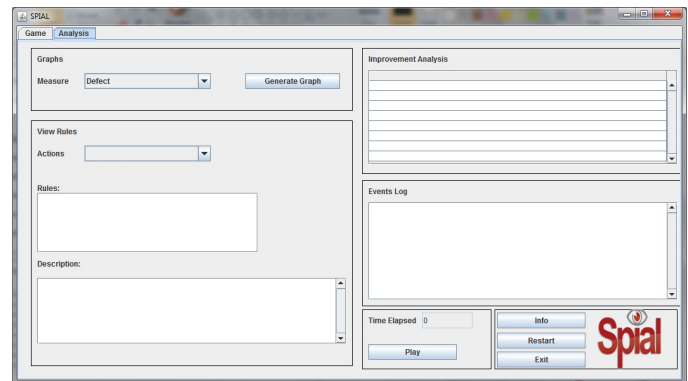


Figure 2. SPIAL analysis tab sheet.

"You are a student of a Software Engineering course and you already know some concepts of Software Engineering. Now, you want to learn more about Software Engineering, with emphasis in software process improvement, using a simulation game. You need an intuitive game to help you learn how software process improvement works in the industry, the software process improvement techniques and the best practices of Software Engineering [motivation]. In this game, you will play as a manager of an SPI group [player role] and your responsibility is the coordination of a process improvement in a specific project. You need to analyze the current situation of the project and select in which process areas to invest. The type of improvement that is required [improvement task] will be stated at the beginning of the game and it can include, for example, reduce defects, improve the productivity and/or reduce costs [goals]. After making investments, you can verify their effects on the process areas capability level (status column) and on the defect, productivity, cost or time-to-market measures. Right investments will increase the budget of investment points and wrong investment will decrease it. Other possible functionalities are: you can stop your game, you can see the Software Engineering rules applied in the game and you can receive information from the team. During the whole game you can see your performance and some tips about the available functionalities. At the end you receive a final score."

III. AN OVERVIEW OF THE SPIAL DESIGN AND DEVELOPMENT STEPS

In the course of SPIAL development we adopted an incremental and iterative process, comprising the following steps:

A. Identification of students' mistakes

We investigated the common problems incurred by students in a Software Engineering course [15]. The most striking observations are the difficulty that students have to bridge the gap between the theoretical lectures and the team project, the limited range of skills that they apply during the project development, and, usually, they do not follow the prescribed software development process during the team project development. They first elaborate the technical artifacts and then they complete the baseline with the managerial artifacts.

In SPIAL, students can reinforce and learn concepts related to the best practices of Software Engineering and SPI. Specifically, students can practice concepts related to technical and managerial aspects of software development (CMMI Levels 2 and 3); follow the stages of a development process in an organization; learn the events that can occur during an SPI project (e.g. resistance to change and high-level management commitment); and observe the results of improvement actions changing an immature software development process to a more mature process (e.g. the reduction of defects).

B. Analysis of other simulation games

We identified and compared the main Software Engineering simulation games [10]. Based on this analysis, we defined the essential design aspects for the development of our simulator. The assessment of the simulation games revealed that, although they are, in some cases, developed with different aims, they have a considerable number of common aspects, for example, "trial and error" strategy, goals, rules and some game features. They also have different features mainly regarding the feedback instant and type, and the adaptability characteristics. Five important design characteristics that we took into account during the SPIAL design are: clear goal/rules, feedback, realistic virtual world, adaptability and game features. Regarding the feedback, it is important to have informative and performance feedback during the whole game. This provides challenge for the players and motivates them [16].

C. Investigation of the SPI and Software Engineering domains

We investigated the domain of our simulation game. Since a simulation game should reflect what happens in the real world, we analyzed the main results reported by organizations in research papers regarding their SPI initiatives. Through a systematic literature review [17], we gained an up-to-date view of the SPI area, allowing us to identify and characterize the actual results of SPI initiatives. In the SPIAL context, the results of this study provided the bases for the simulation model and requirements definition. We observed that SPI initiatives do not bring "dramatic" changes (the improvements in measure values are between 5 and 35%); the main common reason for launching SPI efforts is the reduction of the defect rates detected during development and after delivery; and the companies did not describe the context where the initiatives happened, preventing us a better assessment.

In addition, we collected 123 Software Engineering rules from text books and other Software Engineering simulation games. These rules are used to teach the best practices of Software Engineering to students, rewarding or penalizing their actions. This set includes rules that are imprecise (do not specify values) and rules beyond the Software Engineering area, including a wider range of business processes. From this set, we selected the ones related to the SPIAL process areas, resulting in 57 Software Engineering rules. For example: "Requirements deficiencies are the prime source of project failures." [18], and "A combination of different V & V methods outperforms any single method alone." [19]

D. Development of SPIAL

Based on the steps carried out previously we identified

important requirements for our simulation game, which were used in the definition of the SPIAL behavior.

We evaluated the available components for simulation games development. Since we did not find components that were generic enough to be reused, we decided to develop our own framework, FASENG [20]. FASENG has three main components: simulation model, simulator, and simulation engine. The simulation model is used to represent the structure and behavior of the simulated process. Instructors can tailor a simulation model according to their course. The simulator takes the simulation model as input and interprets it, calculating the behavior of each element. The simulation engine is a component which the player interacts with, receiving visual feedback of the simulation results and being able to change the model parameters.

FASENG was developed based on a set of selected requirements related to the application of learning theories. Specifically, requirements specifying (i) main focus on students and their learning process; (ii) learning acquisition by students; (iii) interactivity; (iv) complexity of real world problems; (v) reflection about the learning subject; (vi) teamwork skills; and (vii) different learning styles. Since there is a clear structural and conceptual separation among these components, they can be reused in new developments. Nevertheless, FASENG and SPIAL requirements had some interplay not discussed here.

E. Evaluation of SPIAL

Finally, we evaluated SPIAL from two viewpoints: specialist and player.

An inspection using the Semiotic Inspection Method [21] was conducted by a specialist and communicability breakdowns were identified¹. According to the specialist, despite feedbacks given during the whole game, such as measurement charts and improvement analyses, important aspects to understand the core behavior were missing, such as the reason why sometimes investments do not produce any improvement.

We evaluated the game carrying out a pilot experiment with undergraduate students of a Computer Science Software Engineering course as players. We selected (i) questions to evaluate whether students enjoyed the game; (ii) questions that evaluate the students' perceptions about the appropriateness of the game; these were organized in eight dimensions [12]: duration, difficulty, content relevancy, correctness, sufficiency, sequence, teaching method, and adoption in a Software Engineering course; and (iii) questions about the learning perspective. The first two categories of question are related indirectly with the learning, showing how effective is the educational environment. The students' answers were mapped to a value range $R = [0,1]$, where a "strong negative" is encoded as "0", a "weak negative" as "0.25", undecided as "0.5", "positive" as "0.75", and a "strong positive" as "1". We recruited 12 undergraduate computer science students to participate in this pilot experiment (one student gave up, leaving us with 11 students). Table I presents the average results for each question (some questions depend on material not presented here). On average, students found the game quite enjoyable and they had fun during the game play. They also felt

¹ We have used this information in order to enhance SPIAL.

that the game duration is appropriate and it is relatively easy to play. They agreed about adopting this game in a Software Engineering course as a complementary approach. They moderately learned new concepts; however, they felt this game more successful in reinforcing concepts taught in Software Engineering course than teaching new concepts.

TABLE I. ANSWERS FOR PILOT EXPERIMENT.

| Question | Avg |
|---|------|
| Did you enjoy playing this game? | 0,84 |
| Did you have fun during the game play? | 0,75 |
| Is the game duration adequate? | 0,70 |
| Is the game difficult to play? | 0,59 |
| Are the Software Engineering concepts covered by the game adequate considering the classes? | 0,68 |
| Did you feel that the game reflects a real SPI initiative? | 0,64 |
| Is the game sufficient for its purpose? | 0,70 |
| Is the play sequence satisfactory? | 0,73 |
| Is the game an adequate complementary teaching method? | 0,91 |
| Do you agree with this game adoption in a Software Engineering class? | 0,91 |
| Did you learn a lot about new Software Engineering concepts playing this game? | 0,40 |
| Did you learn a lot about practical application of an SPI program in an organization? | 0,47 |
| Is the game useful to reinforce Software Engineering concepts that were presented in class? | 0,62 |

IV. DISCUSSION

The primary purpose of educational simulation games development is to match the learning objectives tightly with a suitable solution. The design and development is an iterative process, involving a number of different skills and activities. During this process, designers select the conceptual content to be addressed, model the real world processes, and employ suitable game-like elements to represent these processes and concepts. The final goal is to create an environment that can motivate and engage students. These steps are illustrated in Figure 3 and described in the following subsections.

A. Conceptual content

The conceptual content of SPIAL was designed around the Software Process Improvement, Software Engineering rules, and Software Engineering process concepts. Our first challenge was to define the reference model that would work as the subjacent theoretical background. In the analyzed SPI initiatives, the most widely adopted models are the ones from SEI, CMM and CMMI. Therefore, we decided to use the latest version of the CMMI model (CMMI-DEV version 1.3 [13]), which guided the definition and validation of the mathematical framework represented in our simulation model. Typically, other simulation games employed some abstraction of a software development process, rewarding or penalizing students according to a selection of Software Engineering rules (e.g. SimSE [2], SimJavaSP [6], and MO-SEProcess [7]). They lack a basic reference which can guide designers in the simulation model definition and validation.

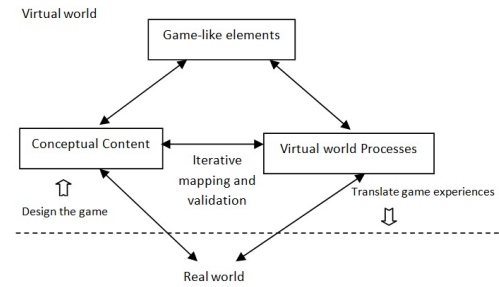


Figure 3. Educational simulation games design. (adapted from Martin [11])

SPIAL was designed to be used as a complementary tool in an introductory Software Engineering course. As a research work, it was not our purpose to cover all the SPI body of knowledge. In this way, we restricted the process improvement concepts to the basic ones of CMMI Level 2 and 3, not covering tools or specific methodologies (e.g. adoption of a requirement tool or execution of a perspective-based reading review), only process issues. Since our simulation system can be extended for more advanced classes, this restriction can be overcome by including into the simulation model high-maturity levels concepts.

The selection of the rules was a task that took us a considerable effort. The reason is that we were interested in rules that can be applied in a simple waterfall development project, covering some concepts of CMMI. In most of the cases, either these rules are too generic or they are from other domains (e.g. agile software development). We restricted the set of the rules to be applied in this simulation game (57 of 123 rules). We mapped each rule to a specific process area of the model (e.g. Requirements development) and the corresponding measurements that they can impact (e.g. defects and productivity). This helped us in the calibration activity of the simulation model.

The set of concepts to be covered by the game should be defined according to the students' needs and the instructors' teaching objectives. It is not possible to address all the content of an introductory Software Engineering course, so designers and instructors have a non-trivial task to select which concepts would be covered by the simulation game. In our case, we conducted a case study to identify the recurrent problems detected in the artifacts produced by students. The lack of students' preparation for dealing with real world Software Engineering projects has also been recognized by the industry [22], [23]. This was an assurance with respect to the main problems that we have identified [15]. Example of these problems are students not following a prescribed process, not being able to make the connections between theoretical lectures and their practical applications, and lacking of skills, mainly managerial ones. With SPIAL we tried to overcome the students' deficiencies, focusing on basic concepts of Software Engineering such as: process, project, product, artifact, stakeholders, Waterfall development process, requirements, design, implementation, test, and software measures (defects, cost, productivity and time-to-market). In addition, we focused on the following software process improvement concepts: pilot project, process areas, improvement investments, motivators and de-motivators factors, and capability levels.

B. Virtual world processes

The simulation game is anchored in a particular reality where players play roles of characters in a particular situation following a set of rules and interacting with other characters. The settings, players' role, and players' activities are important design aspects related to the virtual world where the game occurs [10]. In respect of the virtual world processes, we can, for instance, think of flows of information or resources, and interactions between actors [24]. Since the simulation model is a simplified representation of the reference system, it is not feasible to depict all elements and relations on it.

In SPIAL, we identify the core virtual world processes from the analysis of SPI initiatives reported by organizations in research papers. In most of the research studies, the context where the improvement happens was not defined. This brought some difficulties during the reuse of information and restricted the number of phenomena represented into the simulation game. We observed this problem when we conducted the validations. Five students (45%) were undecided regarding the real aspects of an SPI initiative presented in SPIAL, five students (45%) felt that they learned only basic new concepts (i.e. not advanced concepts) of SPI, and also six students (55%) reported that they only learned the basics about the real world of SPI initiatives in organizations. Examples of the represented phenomena in SPIAL are:

- When the organization is immature, players have no access to the measurements that can help them to monitor the development project improvement and progress. In the real world, this corresponds to an organization where the measurement processes are not defined.
- When players have doubt about which process areas to invest, they can meet the (virtual) team members responsible for each area (e.g. the non-player characters requirements manager or test manager) in order to collect more information about the main process problems. In addition, they have to make the connection between the problem description and the corresponding process area, for instance, the problem: "Baselines of identified work products aren't established" is related to the Configuration Management process area and the problem: "The inspections are not carried out for every artifact", is related to the Verification process area.
- The team can be resistant to some improvements. In order to avoid the impact on the investments, the game has features allowing players to pay for team training/mentoring, or improvement feedback.

Another important issue in the simulation development is the simulation model calibration. One first barrier for the calibration of our model was the lack of specific values of the Software Engineering rules. Since most of these rules are quite imprecise, it is not possible to map them directly into the simulation model. In addition, most of the SPI studies reported only qualitative evaluations. When the quantitative evaluations were available, the information was limited, or it had validation problems, preventing their application in our model. We incorporated rules and SPI results by experimenting them with different values and we selected the values that were most suitable for an educational environment. We made sure that the

real system is approximate sufficiently well by the simulation model and students can check the effects of their actions.

C. Game-like elements

Educational games incorporate some features that do not exist in the real world, for example score or fantasy, mainly to enhance challenge, motivation, and in consequence, improve the learning process. The game features can be used to represent the concepts and processes of the simulation game. The designer should evaluate the trade-offs of representing these concepts and processes in a graphical or in a textual way.

In SPIAL, we considered essential the following game features which can also be found in other Software Engineering simulation games: not too easy nor too difficult life-like challenges (e.g. constraints on the investment budget, and the target of defects and cost reduction); interaction (player can stop the simulation at any moment to make investments or to access measurements information); feedback from other stakeholders represented as non-player characters (we use bubbles over the stakeholders' head and also a table that informs players whether they have achieved the measurements targets); random events (during the improvement some team motivators and de-motivators factors can occur, e.g. the senior management is committed with the improvement or the team is resistant to improvement changes); graphical representation (players can check the measurement charts evolution during the whole project); and performance indication (at the end players receive a score).

V. CONCLUSION

This work presented an analysis of the steps carried out during a Software Engineering simulation game development, named SPIAL. The development process comprised five steps: (1) Identification of students' mistakes; (2) Analysis of other simulation games; (3) Investigation of the SPI and Software Engineering domains; (4) Development of SPIAL; and (5) Evaluation of SPIAL.

Our experience with SPIAL has highlighted some important aspects that can be used to enhance the field of Software Engineering education and simulation game development. The most concrete result is the simulation game itself, along with its SPI simulation model. SPIAL was developed using a reusable framework, which allows its adjustment to distinct learning environments. This can assist students with different learning styles, different levels of initial knowledge and instructors with different expectations and objectives.

Another important result corresponds to a set of issues that emerged during the simulation game design and development. These issues can guide new developers and instructors in the design and selection of educational simulation games. It was identified:

- The importance of having a core theoretical reference model, in order to assist the simulation model definition and validation. During the preparation of experiments, this model can assist in the questions definition.
- The considerable effort needed to filter the Software Engineering rules. They should be selected for each specific simulation game domain.

- The importance of concepts definition scope to be covered by the simulation game. This should be done according to the students' needs and the instructors' teaching objectives.
- The influence of the virtual world processes addressed by the simulation game on the students' learning. It is interesting to include activities that trace back concepts, processes and game-like elements during the design step.
- The considerable effort needed to calibrate the simulation. In the Software Engineering area, it is difficult to find enough data in the literature (or with appropriate quality level). Beyond the instructor, as discussed in Section III.D, we can appeal, for example, to specialists to help in the model calibration. However, we need to verify whether the results approximate the real world and whether they are suitable for an educational environment.
- The game-like elements assist the students' learning process, enhancing challenge and motivation. The designer needs to select which concepts and processes will be represented as game-like elements.

As a future work, we plan to address important issues detected during the first evaluations, mainly incorporating other phenomena that happen in the real world. This will make the simulation closer to the real software development organizations. We will also carry out additional experiments in order to assess other aspects of SPIAL, as for example its relationship with the instructor.

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FASENG: A Framework for Development of Software Engineering Simulation Games

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Abstract— Simulation games can help teaching and learning in several areas of Software Engineering. One important research issue is providing support for simulation games development, making the results of their adoption successful in Software Engineering courses. In this work, we identify a set of requirements focusing on some of the Constructivist learning theories. These requirements were used to evaluate Software Engineering simulation games. Based on these requirements, we created FASENG, a framework for development of Software Engineering simulation games. FASENG has three main components: simulation model, simulator, and simulation engine. Since there is a clear structural and conceptual separation among them, they can be reused in other development environments. In order to check the framework flexibility, we developed two distinct Software Engineering simulation games. The two main results of this research are a better understanding of Software Engineering simulation games requirements and the development of FASENG.

Keywords— software engineering; simulation games; requirements; framework; software engineering education

I. INTRODUCTION

In the Software Engineering field, one of the greatest challenges is to provide practical experience to students in order to handle a number of situations intrinsic to the software development [1]. Students should be able to identify practices and techniques that can be applied in a real software development project. This is a complex issue due to the very nature of software applications and the large variety of organizational cultures [2].

Besides the traditional teaching methods, alternative approaches have been created to attempt to be more close to what happens in real organizations. This includes executing programs that resemble the medical residency programs [3], requiring students to apply software quality engineering concepts in an industrial representative real-world project [4], and using simulation games [5].

Simulation games¹ seem to be an appropriate complementary approach to traditional lectures [6], [7]. One reason is that they are quite natural for students who grew up using computers, cell phones and other gadgets, i.e. “Digital Natives” [8]. Unfortunately, there is no agreement regarding the main simulation game aspects that support learning, the process for engaging students and the type of learning results [9]. This is essentially related to the difficulty of designing an effective educational simulation game.

In this work, our main motivation is to support simulation game designers and instructors during the creation and selection of simulation games for educational purposes. In this

context, one important research issue is to identify which requirements make the results of the simulation games adoption successful in Software Engineering courses. We present a study of requirements in terms of Constructivist learning theories. These requirements were used to evaluate eight Software Engineering simulation games. The results of the study show that some learning theories, even having potential to be applied, are rarely addressed by the analyzed simulation games. In order to have some support during the development of simulation games, we created FASENG, a framework of reusable components that addresses the identified requirements. In order to check the framework flexibility, we developed two distinct Software Engineering simulation games.

The remainder of this paper is structured as follows. Section 2 outlines the background of our work. Section 3 presents the requirements considered for FASENG development. Section 4 describes the framework architecture. Section 5 depicts FASENG initial applications. Section 6 discusses some of the research limitations and Section 7 presents the final considerations and future work.

II. BACKGROUND

In contemporary history of pedagogy, we can find several approaches for learning processes, such as [10]: Behaviorism, Cognitivism, and Constructivism. Considering software development characteristics and these approaches, one suitable complementary paradigm for Software Engineering courses is the constructivism [1]. Constructivism focuses on learning instead of teaching, encourages the information construction and discovery-oriented approaches [10].

When discussing educational approaches, it is essential to connect this discussion to the theories that describe how people learn, i.e. learning theories. In our work, we evaluated the following learning theories related to constructivism²: **Learning by Doing** (individuals learn actually doing a task, not only hearing about it), **Discovery Learning** (individuals learn by discovering the knowledge on their own), **Situated Learning** (individuals learning are situated, being in large part a product of the activity, context and culture in which the knowledge is developed and used), **Anchored Instruction** (individuals learn in a context similar to the real world), **Constructionism** (individuals learn by constructing or doing something), **Learning through Reflection** (individuals learn when they reflect on their learning experience), **Cooperative and Collaborative Learning** (individuals learn when they help each other to achieve a goal or learning about something), **Elaboration Theory** (individuals learning is facilitated when the information is organized in order of complexity, from least

¹ In this work, simulation games are defined as simulation tools with some game features (e.g. fantasy, mystery, or challenge).

² <http://www.instructionaldesign.org/theories/index.html> presents some theories of learning and instruction, retrieved March 22, 2012.

complex to most complex), and **Aptitude Treatment Interaction** (individuals learn when the learning environment is tailored to their aptitude).

III. REQUIREMENTS

The creation of the simulation framework started with the identification of common requirements found in the Software Engineering simulation games. In order to obtain these requirements, we conducted a Systematic Literature Review (SLR) [11] with the aim to evaluate the following aspects of existing Software Engineering simulation games:

- Characteristics that promote the application of the learning theories associated with Constructivism.
- Design decisions adopted to deploy each identified characteristic.

Our SLR research procedures are the same carried out in Peixoto et al. [2]. The identified simulation games are: SESAM [12], SimSE [13], The Incredible Manager [14], SimJavaSP [15], MO-SEProcess [16], SimVBSE [17], qGame [18], TREG [19]. When we conducted our evaluation, we not only read the related articles, but whenever possible we also played the simulation games.

The identified characteristics were organized as a catalog of requirements, similar to the one used by Hoffmann et al. [20]. They are important for the following roles:

- **Instructors** who adopt a simulation game as a complementary approach to the traditional educational methods. These requirements can assist them during the simulation game selection process.
- **Designers** who need to know which requirements are more effective for the learning process and the way they are implemented.
- **Players** who play the game to complement their knowledge in specific Software Engineering subjects.

Table I shows the requirements traced back to learning theories and Table II shows whether the simulation games implemented them.

The requirements are presented next.

REQ1 - A simulation game should give support to the transfer of learning: It is important for players to understand the lessons of a simulation game and develop their own mental model [10]. In consequence, they will be able to transfer this knowledge to a real situation. Transfer of learning happens when the knowledge, skills, or information is transferred from one situation to another [10]. A good transfer of learning occurs when the performance in real situation is improved [10].

Two common characteristics were found in the evaluated simulation games that can enhance the transfer of learning. The first one is the players' active role during the whole game, e.g. as a project manager, they can hire or fire employees. The second one is to allocate players to a hypothetical work or to a problematic situation, where they need to develop solutions. The most common scenario in the evaluated simulation games is students acting as project managers in a project with time, quality and budget constraints.

REQ2 - A simulation game should be interactive: One of the most beneficial aspects of simulation games is their ability to engage learners in meaningful activities through various forms of interactivity [10]. These include actions such as: making choices and decisions, manipulating objects, reacting to events, and collecting information [10]. Interactivity gives the player a sense of control over the game, improving motivation during the learning process.

The interactivity characteristic is presented in all the analyzed games with different levels of implementation. For example, SimSE implements all the actions listed above, in contrast, in qGame, players can only make choices.

REQ3 - A simulation game should reflect the complexity of the problems found in the real world: Besides simplifying the environment, it is important to support learners working in complex situations [10]. Fast and flexible simulations allow repeated experiences and different situations can be introduced and practiced [10]. The goal is that players act in specific roles, solve the problems, and observe the effects of their decisions. Simulation games can take different paths depending on the players' actions and reactions. Therefore, a simulation is a case study involving a specific reality where players play roles with responsibilities and restrictions.

All the simulation games implementation fully satisfied this requirement. For instance, the task allocation follows some of the complex aspects of the real world such as the allocated person should have the abilities required for the corresponding task.

REQ4 - A simulation game should facilitate the reflection about the learning subject: Some studies have shown that students who are encouraged to reflect on what they are doing, learn better both the declarative and procedural types of tasks [21]. Therefore, active reflection on experiences during activities carried out in a Software Engineering course (e.g. team project) promotes the acquisition of more meaningful and persistent learning [21].

In a simulation game, one example of an element with great potential for reflection support is the revisiting session, which is generally referred to as the debriefing sessions [22]. In this session, it is possible to analyze the decisions taken during the game, draw conclusions and make the connection with the real-life situation. Unfortunately, none of the assessed simulation games provided any guidance for carrying out the debriefing sessions. Another element that can promote partial reflection is the explanatory tool or a feedback mechanism, allowing individual performance assessment.

REQ5 - A simulation game should support teamwork skills development: It is well-known that computer science students need to learn communication and collaboration skills [23]. Although many programs today make team projects fundamental elements of their curricula, students receive almost no orientation about how to work effectively in a team [23]. One way to meet this requirement is to build multiplayer simulation games. In these games, players can collaborate among themselves, allowing students to develop teamwork

TABLE I. LEARNING THEORIES AND REQUIREMENTS.

| Theories vs. Requirements | REQ1 | REQ2 | REQ3 | REQ4 | REQ5 | REQ6 |
|--|------|------|------|------|------|----------------|
| Learning by Doing | √ | √ | - | - | - | - |
| Discovery Learning | - | √ | √ | - | - | - |
| Situated Learning | √ | - | - | - | - | - |
| Anchored Instruction | √ | - | - | - | - | - |
| Constructionism | C | - | - | - | - | - |
| Learning through Reflection | - | - | - | √ | - | - |
| Cooperative and Collaborative Learning | - | - | - | - | √ | - |
| Elaboration Theory | - | - | - | - | - | C ^b |
| Aptitude Treatment Interaction | - | - | - | - | - | √ |

a. “√” indicates that this requirement facilitates the application of the specific theory. “C” indicates that theory application is conditioned by the way that the requirement was implemented. “-” indicates that we did not identified a relationship.

b. This requirement tracks to the theory where the difficulty level increases gradually.

TABLE II. SIMULATION GAMES AND REQUIREMENTS IMPLEMENTATION.

| Simulation Games vs. Requirements | REQ1 | REQ2 | REQ3 | REQ4 | REQ5 | REQ6 |
|-----------------------------------|------|------|------|------|------|------|
| MO-SEProcess | √ | √ | √ | P | √ | - |
| qGame | P | P | √ | P | P | P |
| SESAM | √ | √ | √ | P | P | P |
| SimJavaSP | √ | √ | √ | P | P | - |
| SimSE | √ | √ | √ | P | P | P |
| The Incredible Manager | √ | √ | √ | P | P | P |
| TREG | P | P | √ | P | P | - |
| SimVBSE | √ | √ | √ | P | P | - |

a. A simulation game can address the requirement completely “√”, partially “P”, or not “-”.

skills (e.g. MO-SEProcess). In contrast, single-player simulation games, where players can interact with other Non-Player Characters (NPC), i.e. a character controlled by the computer, can address partially the teamwork skill (e.g. qGame, SESAM, SimJavaSP, SimSE, The Incredible Manager, TREG, and SimVBSE). These games have some restrictions in representing real work situations, as communication breakdowns and conflicts between team members.

REQ6 - A simulation game should support different learning environments: The learning process may vary among students. Some students may learn better by watching and listening, others by reading, and others by doing and moving or using a hands-on environment [24]. Adaptation of the learning environments can assist students with different learning styles, different levels of initial knowledge and different expectations and objectives [25]. Adaptation can be static, for example, increasing the complexity in the course of the game, allowing students to choose different simulation models, or instructors to change the simulation model. Adaptation can be dynamic, for example, if players have some difficulties during the simulation game, a hint can be presented to them or the difficulty level of a task can be decreased gradually [26].

Among all simulation games that we found, no one presented dynamic adaptation features. Three of them support different simulation models: SESAM, SimSE and The Incredible Manager; and only qGame has different levels of difficulty.

IV. FRAMEWORK

The knowledge of Software Engineering simulation games and their common requirements, and the lack of support to simulation games development led us to the decision to create our own framework, FASENG (*Framework for Software Engineering Simulation Games*). FASENG is composed of three components (simulation model, simulator, and simulation engine) that can be reused in new simulation games creation (see Fig. 1). These components can also be found in other Software Engineering simulation games [12], [14], however, in our case, they can be reused in new developments. In the first version of this framework, we developed components that support requirements REQ1, REQ2, and REQ3, and partially requirements REQ4, REQ5, and REQ6.

A. Simulation model

The simulation model represents aspects of the world to be simulated (REQ3) and it is defined externally in a XML file. The applicability of a simulation model depends on the model builder’s ability to capture these aspects [14]. In essence, the Software Engineering processes are difficult to model, mainly because of their intrinsic characteristics, mostly involving human behavior, such as, non-linear relation of cause and effect, feedback cycles, dynamic behavior and socio-cultural issues that can affect them.

In the XML file, instructors can tailor a simulation model according to their course (REQ6). This model allows the

representation of an active role to players (REQ1), reaction to events (REQ2), feedback (REQ4) and different participants to actions (REQ 5). We used some modeling constructs similar to those defined by SimSE [13]. These elements are shown below followed by a corresponding XML excerpt.

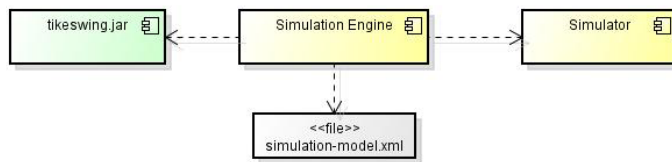


Figure 1. FASENG architecture.

Object types: The object types define the templates for all the objects. The object type consists of a name, a boolean value indicating whether a log will be generated for each object and a set of attributes. For each attribute, its name, type, and two boolean values can be defined. The boolean values indicate the visibility of the object (i) during the game and (ii) at the end of the game. Unlike SimSE, there is no object type creation restriction.

```
<type name="ImprovementProject" log="false">
  <attribute name="InvestmentPoints" type="integer" visible="true"
    visible-end="true"/>
</type>
```

Initial state: The initial state contains a set of objects that are active at the beginning of the simulation. Each object is an instantiation of a given object type, containing initial values for their attributes.

```
<object name="IProject" type="ImprovementProject">
  <attribute-value name="InvestmentPoints">500</attribute-value>
</object>
```

Analysis: The analysis represents types of rules that are created specifically to provide some performance feedback to the players. It contains the name of the analysis and a reference to their implementation.

```
<analysis-result>
  <analysis-result name="Improvement_Analysis" class="br.ufmg.dcc.
    engsoft.spial.analysisrule.RuleImprovementAnalysis"/>
</analysis-result>
```

Actions: The actions represent a set of activities presented in the simulated process, for example, give training to the team or invest in some process area. Each action has a name, description, one or more rules, one or more participants, a trigger and one or more destroyers. Triggers, rules, and destroyers behavior is implemented in Java language. The advantage of this approach is a greater power of expression.

```
<action name="investment" description="Investing in Process Areas" >
```

Participant(s): The participant restricts the types of objects that can participate in the action, as well as their minimum and maximum amount.

```
<participant name="ProcArea" type="ProcessArea" minimum-occurrence="1"
  maximum-occurrence="2"/>
```

Trigger: The trigger represents a condition to start the execution of an action. There are three distinct types [13]: autonomous, player, or random. Autonomous triggers cause the action to begin automatically, without player interaction. Player

triggers start actions when players carry out some operation, for example, selection of a menu item. Random triggers specify the likelihood of the action to be executed. Triggers can cause the end of the game and the calculation of a score; this is represented by the “game-ending” parameter.

```
<trigger name="investmentTrigger" type="player" user-operation="Invest"
  description="Investment in Process Area" class="br.ufmg.dcc.engsoft.
  spial.trigger.TriggerPlayerInvestment" game-ending="false"/>
```

Rule(s): Rules specify the effects of the execution of an action. They modify the objects attributes that participated in the action. Each rule identifies the time of its execution, which can be: trigger, destroyer, or continuous. Trigger rules will be executed at the time the action is triggered. Destroyer rules will be executed when the action is destroyed. Continuous rules, on the other hand, will be fired every clock tick, representing continuous behaviors of the model. Rules also specify the order they will be executed through the “priority” parameter.

```
<rule name="investmentRule" description="Investment made in some
  process area" timing="trigger" priority="3" class="br.ufmg.dcc.engsoft.
  spial.rule.RuleDiscretInvest"/>
```

Destroyer(s): Opposite to the triggers, destroyers represent a condition to ending the execution of an action. It has four types: three like the triggers (autonomous, random, or player), and an additional one: timed. The timed destroyer specifies the duration of an action (time-to-live).

```
<destroyer name="investmentDestroyer" type="timed" time-to-live="3"
  class="br.ufmg.dcc.engsoft.spial.destroyer.DestroyerTimedStandard"
  game-ending="false"/>
```

B. Simulator

A great number of simulators are either continuous or discrete. Since in software projects both mechanisms are presented, we decided for a hybrid approach in which [27]:

- At a higher level of abstraction, the structure of the software process, activities, interactions and artifacts are best modeled by a discrete event approach;
- At a lower level of abstraction, the behavior of the activities and the factors that influence the simulated project are best modeled by a continuous approach.

In the simulator component, aspects of discrete events are used to represent individual objects (e.g. process areas, and artifacts), actions (“give training or mentoring”, “make an investment”), conditions of triggers and destroyers, and the rules executed at the start or at the end of an action. The continuous characteristics are represented through continuous rules, which are performed at each step of the simulation, whether the actions that define them are currently active.

The simulator runs in a loop. For each time step, it looks whether the conditions of triggers and destroyers were satisfied, executes continuous rules, generates log, and gives feedback to the players. If triggers or destroyers conditions are satisfied, the rules associated to the actions are checked. Continuous rules are fired every clock tick, whether their respective action is active. The log is generated for the object types defined in the XML file. The calculations of performance feedback are defined by the instructor. The detailed communication between the simulation engine and the simulator is shown in Fig. 2, using a simplified UML diagram.

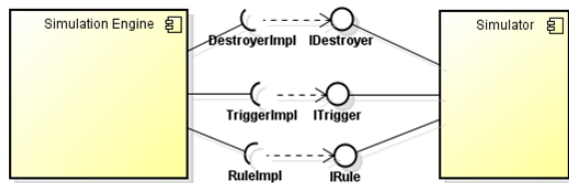


Figure 2. Communication details between simulation engine and simulator.

The simulator has several component interfaces, representing the start (triggers) and end (destroyers) conditions for each action, as well as rules to be executed. Since there are several types of triggers, rules, and destroyers, a hierarchy of interfaces was created in the simulator component. For each condition or rule to be created in the simulator engine, an interface of the simulator should be implemented in a Java class. Then the rule class must be referenced in the XML file of the simulation model. When the simulator encounters this class name in the simulation model, it learns which class should be instantiated. The simulator was designed to handle the simulation model, defined externally in an XML file, and to generate the internal representation of it.

C. Simulation engine

The simulation engine is a component with which the player interacts, receiving visual feedback from the simulation results and through which the player changes the model parameters. This component uses the MVC (Model-View-Control) design pattern, which allows the separation of domain logic from the user interface. TikeSwing³ was used in the implementation of this design pattern. During the tailoring phase, instructors can change the interface according to their needs, without worrying about other aspects of the application (model and control). Since the Software Engineering simulation games can have different scopes, we did not restrict the interface design to fixed graphical elements.

V. SIMULATION GAMES DEVELOPMENT

We created two simulation games using this framework in order to make initial validations of its flexibility. In both of these games, it is required basic Software Engineering knowledge. The first one was a simplified version of the waterfall SimSE model⁴. This simulation model consists of employees, artifacts, tools, project, and customer object types. A participant plays the role of a project manager of a team of developers. The player's goal is to develop a software project within a certain set of constraints.

The second simulation game is called SPIAL [28] (see Fig. 3). SPIAL simulation model contains initial game description, process areas, improvement project, development project, motivators and de-motivators SPI factors, development process, artifacts, stakeholders, control measurements, and analysis. A participant plays the role of an SPI group manager in a software development organization. The player is given a process improvement task, and he/she can interact with other stakeholders. The goal is to achieve the established improvement targets of defect, cost, time-to-market and productivity. This simulation game has 16 rules and 12 actions. The validations demonstrated that SPIAL can be

beneficial to reinforce and teach new Software Engineering concepts. Students mentioned having fun during the game play.

Using this framework it was possible to represent distinct simulation models. The instructor's work was restricted to the definition of the simulation model, rules implementation, and GUI design.

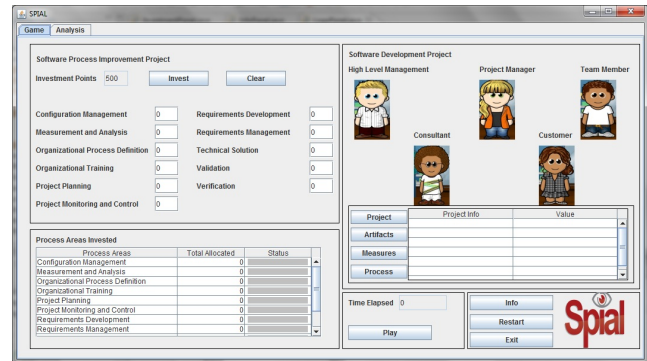


Figure 3. SPIAL Graphical User Interface.

VI. LIMITATIONS

Regarding the limitations of this study, one could argue that we did not identify all requirements that can be traced back to the described learning theories. Although this is a valid criticism, we believe that for the evaluated Software Engineering simulation games they are appropriate, mainly considering an initial development of a reusable framework.

As one of the aims of this research was to develop a reusable framework, a broad validation mechanism should be carried out. We did not create validation mechanisms to verify requirements from different stakeholders' viewpoints (instructors and other developers). We only carried out a systematic literature review and an experiment with students using SPIAL. We obtained more positive than negative results. We expect that these initial results will help the investigation of further research questions.

We cannot *a priori* assume that the results of this study generalize beyond the specific environment of Software Engineering simulation games. We identified requirements exclusively from simulation games of the Software Engineering field. However, we believe that many considerations can be applied to the whole educational simulation game field.

VII. CONCLUSION

This paper described a study of simulation games requirements that can help instructors and designers during selection and creation of Software Engineering simulation games. The research took into account the best practices of simulation games development, their main characteristics and the learning theories related to Constructivism. Based on these requirements, we analyzed eight simulation games and we defined a framework, with three main components, that can be reused in new developments.

We observed that some learning theories, such as Learning through reflection, Elaboration Theory and Aptitude Treatment Interaction, were not completely addressed by the analyzed

³ TikeSwing is a framework for Java Swing development providing high-level MVC architecture.

⁴ <http://www.ics.uci.edu/~emilyo/SimSE/downloads.html>

simulation games. The identified requirements and the corresponding framework can support designers of new simulation games to address important learning theories during the initial development phases.

As a future work, we plan to enhance the framework evaluation considering, for example, other learning theories, and the interplay between requirements, implementation and validation. During FASENG development, we identified three roles: simulation game developer (who adapts the interface and creates the Java classes), simulation model designer (who specifies the behavior), and developer (who creates the XML file). We are planning to create guidelines for each of these roles and supporting tools, for instance, a tool to help simulation model tailoring and XML file creation.

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A web tool to create educational content with gaming visualization

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Abstract— Students usually love games. They captivate their attention and hold it for lengthy periods of time. Educational systems have taken advantage of this fact and have used games in education for many years. However, teachers cannot create their own games as easily as they create other learning objects. A tool to assist this labor would be very useful for them. In this paper, we present NICE-Game, an innovative game-like educational content creation tool. It is divided into two modules, the builder to create the games and the viewer to play them. With NICE-Game, different kinds of educational contents (i.e. images, videos, texts) can be easily integrated into a game. Using personal handheld devices is a growing trend among students, hence multi-platform and multi-device issues have been also considered in this implementation. Details about the design, development and the tool itself are explained in this paper as well as an example of an educational game available online.

Keywords; *Games in education, NICE-Game, games and mobile—learning.*

I. INTRODUCTION

Teachers always try to increase students' motivation and the quality of the learning experience. With this same purpose, learning tools and methodologies are improved every day. They can benefit from the increasing popularity of video games and the spreading of personal devices such as smartphones and tablets, introducing video games in learning in order to motivate students and train specific competences.

Educational video games can be really improved with the introduction of new technologies. But the development costs are very high (even higher if we consider the opportunity costs of developing another kind of video game) and teachers or learning centers usually cannot afford it. Therefore, teachers usually have to resort to existing games. However, most of them are focused on specific topics that cannot be reused to explain in other academic subjects. The type of educational content used in the game (e.g. video, images or audios) or the content's language are important parts of the game that need to be adequate for students bearing in mind their context (e.g. age, gender, etc.).

This is the main problem that we found when started to create an educational game for the GLOBAL excursion

(Extended Curriculum for Science Infrastructure Online) European project (<http://www.globalexursion-project.eu/>).

GLOBAL excursion [1] is a supporting action funded by the European Commission under the Research and Innovation Infrastructures programme of FP7. The project will develop a common understanding, teaching use cases, as well as pedagogical and technical artifacts. The aim of this project is to provide young citizens and their educators (teachers, parents, etc.) across Europe with a range of e-Infrastructures and access to expert knowledge on its usage for a joyful exploration of e-Science through e-Infrastructure.

The main purpose of the GLOBAL excursion project is to enable students and teachers access to the experimental laboratories and resources of selected e-Infrastructures in order to improve science curricula by enriching school's existing teaching and learning materials.

In this paper we explain how this problem was tackled in GLOBAL excursion. With details about the design, architecture and development issues of the solution proposed. The rest of the paper is organized as follows. The next section reviews the state of the art in educational games. Section 3 explains our solution. Section 4 presents the results showing some captures of a game. In section 5 we discuss the issues that arose and section 6 finishes with some conclusions and future work.

II. RELATED WORK

The usage of games in education is a growing trend in recent years. Educational games have potential to improve students' motivation [2] [3], promote self-directed learning [4] and develop social and cognitive skills [5] [6].

The potential for educators to become involved in the development of educational games is substantial [6]. Interesting initiatives are providing frameworks to develop adaptive educational games, where teachers can create and evaluate their own games and simulations from scratch. Like those provided by e-ucm (www.e-ucm.es), a research group from Complutense University of Madrid, with several related projects and research lines like Game-Tel [7] and e-Training DS [8].

There are other commercial software packages available that make it easier to create computer games, replacing part of the programming by mechanism in which games are constructed from simple building blocks. Examples are StageCast (www.stagecast.com) that is particularly aimed at young kids or the products by ClickTeam (www.clickteam.com) or Game Maker [9].

On the other hand, mobile learning or m-learning is another interesting approach in Technology-Enhanced Learning (TEL). M-learning is defined as the provision of education and training on mobile devices [10]. The combination of m-learning and game-based learning can improve the attractiveness of the educational activities, promoting collaboration and competition between students or improving the immersion in games. As a result that combination offers new opportunities and scenarios for learning [11].

As smartphones and tablets come into play, m-learning and game-based learning have a great opportunity to reach a wider audience. Smartphones penetration rates are already very high in some countries and they are a growing trend in some others [12], [13]. Tablets penetrations are lower, but growth is promising [14].

With all these issues in mind, we have designed a web tool to introduce educational contents into games. Our main goal is to allow educators to choose the design of the game, introduce the educational content and customize the game story. The created game will have also to run on multiple devices such as smartphones or tablets.

III. NICE-GAME: NATURAL INTEGRATION OF CONTENT AND EDUCATION IN A GAME

A. Scenario and Architecture

NICE-Game is a web tool to integrate educational content into simple games. It can be divided into two sub-tools: one to create the game (i.e. Game Builder) and one to visualize the generated games (i.e. Game Viewer).

The content types that can be integrated in the game are texts, images and videos. Considering the combination of these types of contents, like with classroom presentations, the teacher (or game creator) will be able to generate very interesting and amusing lessons. Different games can be created for different targets depending on the pupils' age, the topic to be addressed or the time that the teacher wants to dedicate to create the game.

Teachers will be able to choose the content from a pool of educational contents available in the NICE-Game platform. They will also be able to upload their own content or indicate the content URL in case it is hosted in another site. So with the combination of the three kinds of content, they can create enhanced educational games.

In the initial phase of our scenario related to the GLOBAL excursion European project, the available content will be provided by the scientific infrastructures participating in the project. But as more teachers join the platform, this content will be increased.

Once the game has been created it can be accessed from any kind of modern device, either tablet, smartphone or laptop/desktop computer. Even televisions when they have web browsers will be able to execute these games (although maybe we will have to change the interaction mode to adapt it to the television interface). In addition, the game viewer can be easily integrated in any kind of learning management system (LMS) such as Moodle or Blackboard, as it is visualized in a browser.

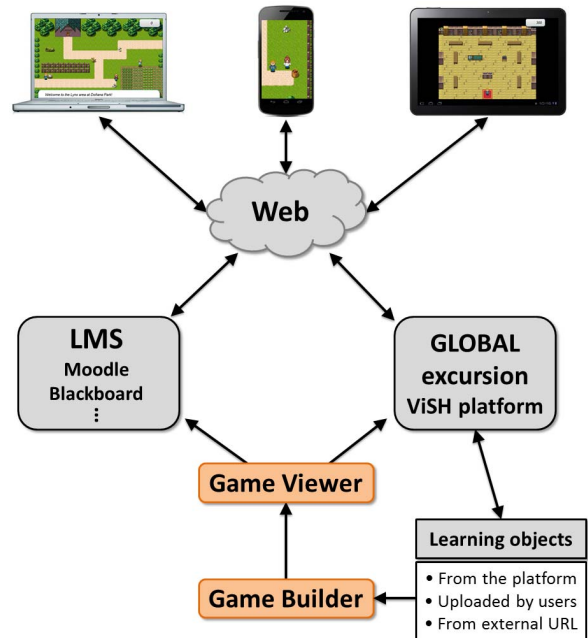


Figure 1. NICE-Game architecture

Figure 1 illustrates the NICE-Game architecture composed by several modules that are going to be described in detail in the next sections.

B. Game Builder

Once a user (usually a teacher) registers and logs into the platform, she/he will be able to create a game. The process of game creation is divided into three phases. In the first phase the user have to select the game levels and in the second and third phase she/he can customize the points of interest (POIs) and non-playing characters (NPCs) of each level.

1) Selection of the game levels

The first phase consists of selecting the game levels. The builder currently offers several screenshots to choose, each of them with a different design (e.g. library, laboratory, nature, etc.). The selected levels have to be dragged to the final positions. In every level the player starts in the left side and enters the next level in the right side (see figure 2).

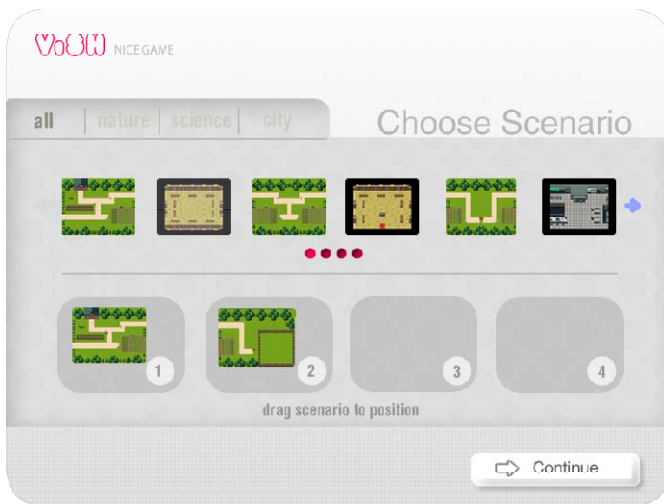


Figure 1. Level selection

The way we achieve this phase is one of the main differences between our solution and another solutions presented in the related work section. In some frameworks, teachers have to upload the background images and the characters with all the movements. The resulting game is usually very poor or requires a lot of work and design knowledge from the teacher side.

Game design is a very complex task [15], [16] and with this phase we try to avoid teachers to worry about it. They only have to select a scenario among a growing number of them.

2) Adding POIs and NPCs

In the second phase the user will be able to add interactive objects (POIs or NPCs) to the game and place them where desired. Some scenarios have more default decorations and more free space than others (see figure 3).

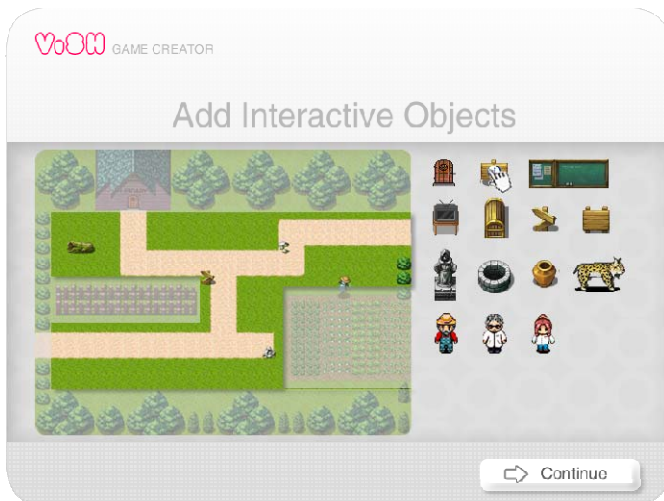


Figure 2. Add interactive Object

3) *Add educational content*

The final phase is focused on adding the educational content and write dialogues and multiple choice questions.

Three possibilities exist to add content:

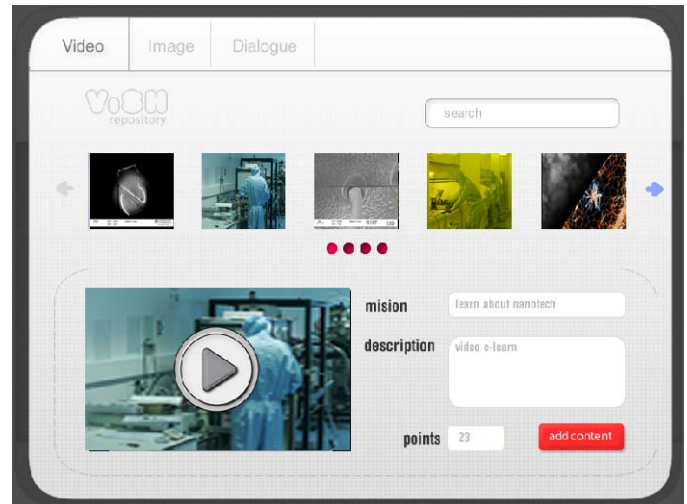


Figure 3. Add educational content

For the NPCs the user can add any dialogue and/or multiple choice questions. The limitation (at least in this first version) is the lack of interactivity. There is no workflow definition and no conditions, the NPC tells the player all the dialogue with the only possibility of answering a multiple choice question if any.

Together with the educational content a mission can be defined as an educational objective that has to be consumed by the student (e.g. study the presentation at the blackboard to learn things about the biology of the lynx). These missions will give points to the student and unlock new scenarios (if they exist) so as to motivate her/him to complete the whole game. As a result, the teacher has to define not only the mission itself, but also the score related to every mission in this phase (see figure 4).

C. Game Viewer

The game viewer is a component that allows the integration of the educational game in any modern device browser. It works offline, as there is no interaction with the server during game playing time.

The main difference here is about the player controls. In the laptop or desktop computer, the character is controlled with the keyboard, whereas in touch screens there is a virtual pad.

As the game viewer works in the device browser and there is no need to install anything on the user's device, it can be integrated in any LMS or web page as any other external web resource.

After loading the game, the user gets some welcome screens that explain how it works, how to move the character (depending on the device used) and how to interact with other objects (POIs) and characters (NPCs).

Then, while playing the game, the user gets points when progressing with the educational contents related to the missions defined. By using this scoring method, we try to increase the user motivation and amusement. There is also available a missions' panel that indicates what the user has done/viewed, and what remains undone to guide her/him through the game.

D. Implementation: Technological Decisions

The technology that we have used to develop this solution is HTML5 (HyperText Markup Language, version 5 [17]). HTML5 is the standard for the web. This new version allows many new possibilities like game developing based on the canvas, geolocation or device multimedia access between many others.

The main advantage of HTML5 is that it is standard and any modern browser runs it. So what is developed in HTML5 can be executed in any device with a browser in it (even new televisions and car entertainment systems are starting to include a browser in them). Any server technology is compatible with HTML5. In our case we have used Ruby on Rails. The server hosts the game builder, the generated games and the game viewer.

For the game builder, the server has a pool of educational resources stored in the GLOBAL excursion platform. It also allows the user to upload new objects (that will be automatically stored in the platform) or reference them via their URL. Once the game is created, the server stores the game generated, which definition is now based on JSON (JavaScript Object Notation). This JSON object contains all the information about the game levels, the POIs and NPCs and has references to the educational objects as absolute URLs.

For the viewer, the server will only have to send the files related to the game to the user to be shown in the user's device browser. As we have commented above, the game viewer can be integrated in any educational platform as web content in order to allow reusability in different contexts.

IV. RESULTS

NICE-Game has been developed in relation with the GLOBAL excursion European project. GLOBAL excursion has developed a platform called Virtual Science Hub (ViSH) to host all the activities carried out by the teachers and researchers in the project and to foster collaboration between them.

The initial fields covered in the project are nanoscience, biology, biotechnology, volunteer computing and grid computing. To enhance the students' interests and make this topics enjoyable and amusing for them, a new kind of complex

learning objects called virtual excursions have been defined. These virtual excursions are created by the teachers and consumed by their students, and NICE-Game is one of the possible types.

As a result, the architecture depicted in Figure 1 has been implemented and deployed inside the GLOBAL excursion project. Therefore, to create a virtual excursion the teachers have to follow the steps described in section 3 and select among educational contents hosted in ViSH.

An example (available at [18]) of a generated game can be seen in the figures 5 and 6. The scenario is related to a biology use case in which the students will learn about the Iberian lynx that lives in the Spanish Doñana Park. Doñana Biological Station [19] is one of the selected e-Infrasstructures that collaborates in the GLOBAL project providing information about the activities, fauna and flora related to the park.

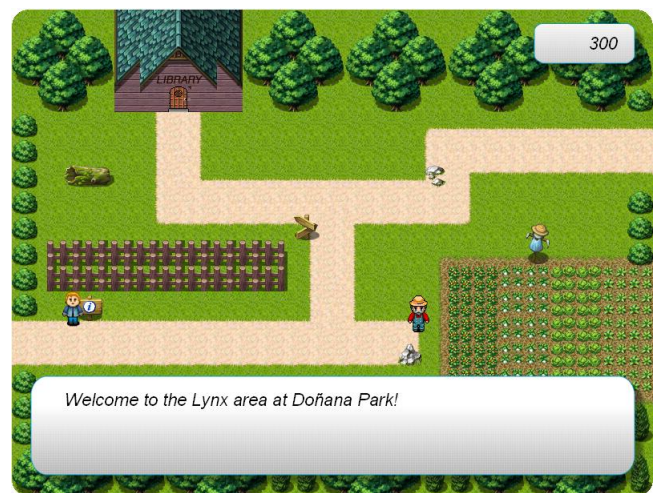


Figure 5. Player starting game

In Figure 5, we can see the nature scenario of a very simple generated game in which the player is interacting with a POI (i.e. an information point). There is also one NPC (a farmer in the middle) and a path to a next phase in the right.



Figure 6. Multiple choice question

In figure 6 there is another NPC that is making a question to the player related to the knowledge acquired in the previous phase.

Furthermore, as we can see in all the figures, there is a scoreboard in the upper right corner informing about the points that the student has won by completing the game missions.

V. DISCUSSION

Designing a new model to create educational games in a proper and easy way considering aforementioned issues was our first priority. It has been based on taking important decisions related to the design and the technologies used.

The first one was about letting users upload images to be used as scenario maps or providing pre-designed scenarios. We decided to keep it simple by providing these pre-designed scenarios, allowing the teachers to concentrate their efforts on choosing the most suitable educational contents. This way, we eliminated a usability barrier and the resulting games look more professional as we avoid teachers from designing their own characters, elements and scenarios.

On the other hand, the way to add dialogues was also very controversial. Some existing tools allow the user to create a workflow with the possible dialogues. This way they create interactive dialogues with conditions where the player can choose options. From these complex workflows we only took the possibility of making multiple choice questions, as we consider them enough to assess what the students have learned in the majority of cases.

Finally, the technology chosen (i.e. HTML5) has numerous advantages as we have summarized above, but it also has some objections. The most important related to our use case is that we cannot integrate any flash object (e.g. videos) with it. Hopefully the number of HTML5 videos and educational objects are growing day by day in the Internet, and it is becoming a less important issue.

VI. CONCLUSION AND FUTURE WORK

In this paper we have presented NICE-Game, an innovative model to generate educational games based on integrating learning objects inside a game scenario that is built in an easy way by teachers. We have shown an innovative way of doing it using current web technologies like HTML5 or JSON, so as to make possible running both, the game builder and the viewer, in different platforms (e.g. Windows, Linux, etc.) and devices (e.g. desktop computers, smartphones, tablets, etc.).

This tool is being used now in the GLOBAL excursion project by its integration in the ViSH web platform. It is being evaluated now by teachers involved in the project and after that it will be released as open source tool and opened to the teaching community.

We have presented in this paper the first version of NICE-Game so there any many future works that we have considered.

The first functionality that we would like to add is about allowing teachers to get the students' results of the questions in the game. This way they can use the game as an assessment

method to check if the pupils have read the contents and viewed the videos and images.

Another interesting functionality to consider would be letting students to customize their characters (clothes, hair and skin colors, etc.) or involve them even more in the story in order to increase their motivation.

Exporting the game to educational standard formats such as SCORM and LOM will also be considered to facilitate the teachers the integration with their LMS corresponding to their specific institution.

An additional open issue to study is related to the number of resources hosted in the platform since it can be very high, and become higher with time (because when new researchers and teachers join ViSH, they will upload new resources from their institution). Recommendation of suitable learning objects to build the virtual excursions will be very important here to increase personalization and accuracy. This will make easier for teachers to select the most suitable learning objects depending on the context and subject they want to teach. The final aim of this task would be to recommend directly a finished game to the teacher to use it with his/her students if it is related, for example, to the teacher's subjects.

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Work in Progress: Integrating Game Design and Development into Undergraduate Biology Education

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Abstract— While research has investigated the application of computational methodologies in undergraduate biology education, those approaches require students certain backgrounds from multiple disciplines. Recently, game design and development for education has moved into different fields of science, including biology. Several multi-media interactive products have been developed to simulate biological mechanisms and can be used by undergraduate students. However these approaches focus on students as game users and, not as game developers. Here, we propose an innovative approach to involve game design and development into undergraduate biology classroom. The approach assumes no additional background, and aims to increase engagement in the complexities of the course material through the process of game design and development. We initialized a case study that systematically combines a game application-driven project into genetics teaching. In the pedagogical experiment, undergraduate biology and computer science students designed educational games to enhance the speed and depth of comprehension of both biological and software engineering concepts. The result of this study shows that the reinforcement effects of biological education games apply differently on students with or without biology backgrounds.

Index Terms - Game Design, Game Development, Biology Undergraduate Education, Genetics, Software Engineering

INTRODUCTION

The computational components of undergraduate biology education have hardly changed in the last several decades, even though advances in computing have forever changed the practice of biological research. Some recent studies [1, 2] advocate the idea of applying computational methodologies into biology education. However, the strategy requires students to have significant prerequisite knowledge of algorithms, mathematical and statistical concepts, which could lead to a large amount of extensions and revisions of current biology curriculums. Moreover, principles and practices of software engineering and quality assurance are rarely introduced and adopted by biology major students. Recently, game design and development has become a fast growing major in computer science education [3, 4]. A few practices [3, 5-6] have been established to improve the learning curve of undergraduate biology major students. However, biology major student involvement in the phases of application design and development is not sufficient in most of those approaches because students are usually only considered as users.

Our innovative approach is to directly involve biology major students into game design and development. Students from biology, computer science, even bioinformatics, work

together on game application-driven projects, which are derived from college-level biology concepts. During the pedagogical experiments, we focused on research around three main questions: (a) Does the approach help biology major students reinforce their learning in biology? (b) Does the approach help biology major students better understanding the principles in software engineering? (c) Does the biological education games help general college students understand biology better?

OUR CASE STUDY

A. Game Design and Development

Gene expression, the Central Dogma of genetics, is proposed to serve as the biology context of the hybrid approach. During the game design and development, students are expected to answer the following questions. A) How to design a game story that fits the educational context? B) How to make it more intriguing and easier to use? C) What application architecture style or model is appropriate to demonstrate the biology concept? D) How to decompose and manage the system?

Three students majoring in biology and two students majoring in computer science volunteered to work on the project. The biology major students designed the games and prepared the project requirements. The computer science students develop two prototype applications. All five students met monthly over one semester. Google Project Hosting (<http://code.google.com/hosting/>) was used for project management. Monymoon, a social productivity platform, was used for team communications and collaborations.

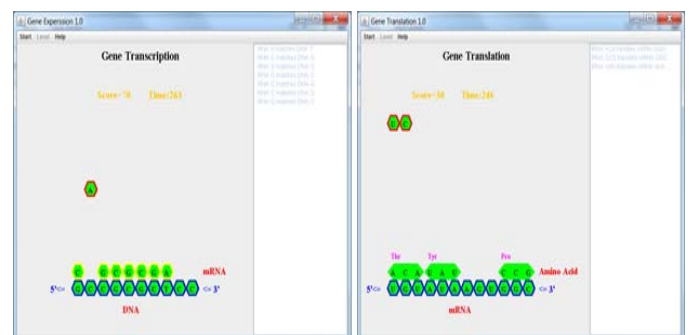


Figure 1. Tetris games for gene transcription and gene translation

The team developed two Tetris-like games (see Figure 1) to describe two phases of gene expression: *gene transcription* and *gene translation*. The applications were developed using Java.

The biology major students served as the content experts, and referred back to their textbook for the details of the genetic concepts. Moreover, creative biological questions, such as “what is the color of DNA nucleotides”, were derived during the game design. Due to the systematical collaboration, both biology major and computer science major students had better understanding of the principles and practices of software engineering, such as objected-oriented, standards and reusability. These prototype games, as developed by students for students, were then used for educational and usability testing.

B. Educational and Usability Testing

We obtained IRB approval to conduct a pre- and post-game study comprising of three focus group sessions. A total of 74 junior students from either biology major or computer science major participated in the focus groups. 25 of students are NOT or only A LITTLE familiar with the content before playing the games, 28 students are SOMEWHAT familiar with the content, and 21 students are familiar with the content.

We self-designed two quizzes to evaluate content performance of students before and after playing the two games. Both quizzes contain the same content-evaluation questions related to gene expression. In the pre-quiz, we inquired the background of each student and their familiarity with the content. In the post-quiz, we also inquired a) their completion status of games, b) entertainment worthiness, and c) educational achievement. Extra questionnaire are provided for students on improving the games. Most items used a 5-point Likert scale with response options from “1 = Strongly Disagree” to “5 = Strongly Agree”. Students have 30 minutes to complete the pre-quiz, two games and the post-quiz.

In our initial results, majority of students finished the games (91% for gene-transcription game and 76% for gene-translation game) on time. The average grade of pre-quiz is 62; and the average grade of post-quiz is 79. 89% of students think the games are worth their time (entertaining); and 81% of students think the games could enhance biology learning in college-level (educational).

We are analyzing the focus group sessions to determine how biological education games affect populations with different science backgrounds. The comparisons of feedback on different groups are showed in Figure 2. Those who are not familiar with genetics (group 1) improved 26 point after playing the games; while those who are already familiar with the topic (group 3) only improved 7 points. The t-test of the average improvement also shows the difference between group 1 and group 3 is statistically significant (p-value is 0.0016).

Preliminary observations from the focus groups suggest that: a) games have better effect on those who are not familiar with the content than those who already knew them, and b) that students who are more familiar with the content think the games are more entertaining and less educational.

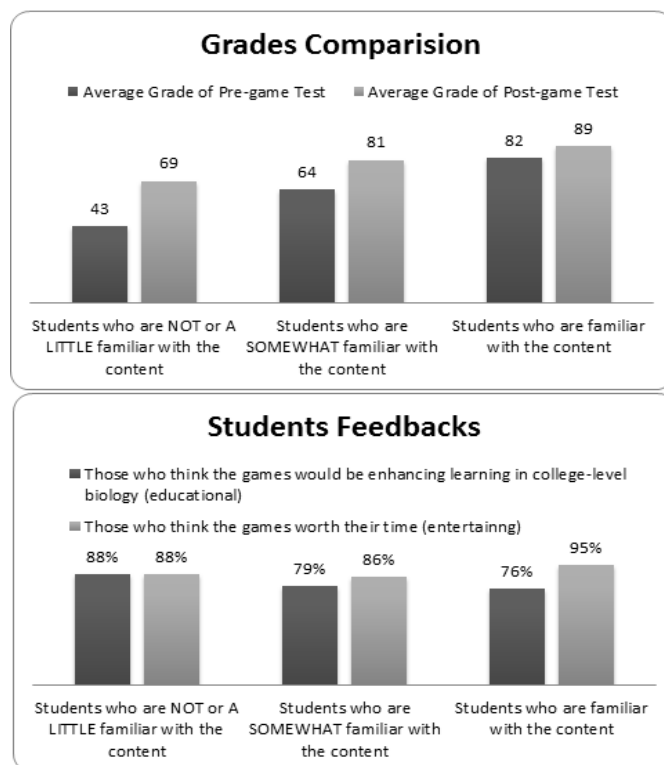


Figure 2. The average grade and feedback comparisons among three groups.

FUTURE WORK

We will complete the analysis of the focus group sessions. We also intend to repeat the process in a wider group of students or broader topics in the coming semester. In addition, we will conduct further statistical analysis by using mixed measurement item response theory (MM-IRT) to model the actual response patterns, rather than relying on the observed variable of backgrounds [7].

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Work in Progress : Learning flow-of-control with FlipLogic:A game-based approach

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Abstract— We present FlipLogic, a puzzle game that we developed to help children (ages 10-12) become familiar with conditional logic statements in programming. We designed the game to be embedded in an existing after-school curriculum on computer programming fundamentals. Our broader goal is to create a series of games to help students learn a variety of programming concepts including control statements, conditional branches, logic expressions, loops, and variables. We plan to study the effectiveness and motivational appeal of our design in after-school settings, comparing this game-based approach with a more traditional instructional approach.

Keywords - Children, programming languages, learning games

I. INTRODUCTION

Computer programming has long been a focus of study in the field of educational technology. Many researchers have argued that programming is an empowering tool that provides a creative and fertile medium for children's activities and learning [1–3]. However, learning to program isn't easy, and novices of all ages face a number of conceptual barriers. One area of difficulty relates to how language is used to express problems [4], [5]. Pane et al. [5] examined the language and that novices use to solve programming problems before being exposed to programming. They found that participants rarely used explicit looping and always used one-sided conditionals (*if* with no *else* statement). Their results also show that participants tended not to use complex Boolean conditionals, and instead write a series of mutually exclusive simple rules. Here, we present a puzzle game that we designed to help children better understand the meaning of conditional terms.

II. BACKGROUND AND RELATED WORK

A. Computer Programming for Novices

Since the 1970s a large number of programming languages have been built to make programming more accessible to novice learners and children (see [6]). However, despite the fact that computers have become pervasive in many children's lives, few learn to program. Previous research suggests two main reasons for children's discouragement and low engagement in programming [3], [6]. First, for beginners, programming can be very difficult because of the challenges with learning a rigid syntax. And, second, the programming activities are often not exciting and not aligned with children's experiences in the world [3].



Figure 1. A screen shot of the FlipLogic game.

In recent years, many new languages have been developed to make programming easier for younger learners by offering alternatives to text-based programming. Some examples of these systems are Scratch [3], where children construct programs using graphical object, and Tern [7], which uses a tangible programming interface. Following these examples, we are attempting to familiarize children with fundamentals of programming without the emphasis on learning syntax. FlipLogic has a blocks-based programming environment, where children can create conditional rules to control the game, using a set of visual blocks (Fig. 1).

B. Game-based Learning

Today, computer games occupy a central role in the lives of many children. Recently, there has been increasing interest in the role of computer games as a powerful new resource to support children's learning [8–10]. Researchers argue that computer games can be effective educational tools by motivating children to learn and by supporting them through direct experience. Further, with highly interactive games players can become involved in complex reasoning tasks and can develop the understandings that are difficult to achieve otherwise [11]. However, despite these promises and the recent effort in developing game-based learning, there has been little success in designing effective educational games [9], [10]. Many factors determine the effectiveness of an educational game. For example, among other things, Gee [8] argues that good games introduce well-ordered problems; are challenging, yet doable; and provide links between skills and strategies for playing the game. Other researchers have argued that to achieve both motivation and learning outcomes, good educational games should *intrinsically integrate* target learning objectives with the mechanics of game play [9]. In

other words, the best (most fun) parts of the game should be where the learning happens. In designing FlipLogic, we were careful to apply these principles by closely aligning our learning objectives with the mechanisms of the gameplay. Additionally, despite its simple rules, we attempted to make the game challenging enough to encourage children develop computational strategies while solving the puzzle.

III. GAME DESIGN

FlipLogic is a rule-based puzzle game with a short play-time of 15 to 20 minutes. Our design was inspired by a number of computational puzzle games, where the players “program the behavior of game”, such as Escape Machine [12]. We implemented the game using HTML5 and JavaScript to ease its access in classroom settings as the game could simply run in a web browser on a computer.

In FlipLogic, the player has to complete the puzzle by creating a set of rules (or codes) for flipping puzzle pieces to control the game. These rules take the form of conditional statements. The puzzle pieces (tiles) are arranged in a 5 x 4 grid, which have to be flipped one at each turn. The goal is to create a successful board arrangement that meets a number of predefined criteria, like to connect the two houses with a stone road. In order to achieve these goals, the player controls the pieces, before flipping them, by making certain rules: *if the tile is a stone then keep it, else replace it with a stone* (Fig. 1). When the created rules are evaluated, the actions are performed according to the *true* rule.

The player can switch between different modes of conditional statements: *If-Then* mode (for mutually exclusive conditionals), *If-Then-Else* mode, and *If-Anything-Then* mode (for making general rules). By playing the game, children will ideally become familiar with various conditional logic terms and concepts such as mutually exclusive conditionals (represented as *if-then* structures), and conditional statements with *else* branching (represented as *if-then-else* structures).

One important feature of the game is a *code window* that shows the equivalent code of the rules in the language that is used in the curriculum (Fig. 2). By incorporating this feature in the game we hope to make it easier for children to adapt their intuitive sense of how conditionals work to the particular syntax used in their programming codes.

IV. STUDY DESIGN

We will investigate the learning outcomes of our games by integrating them into an existing curriculum designed to help middle-school students learn fundamental concepts of computation. In this 9-week after-school program, students create their own videogames using DrRacket language in a web browser. We will compare three different scenarios on introducing the programming concept: (1) the existing approach, which will be an instruction lacking the gaming aspect, (2) a game-based approach, and (3) a hybrid approach, which will be an instruction followed by a computational game. We will assess the effectiveness of each approach, by evaluating the students’ performances and their abilities in implementing the new concepts in their videogame programs.

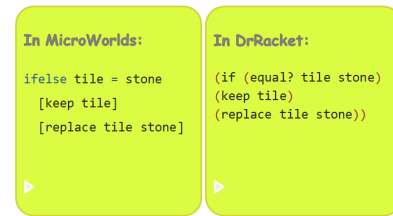


Figure 2. code windows showing the equivalent code of the rule created in Fig. 1 in two Microworlds EX (left) and DrRacket (right).

V. CONCLUSIONS AND FUTURE WORK

This paper reports our design of an educational game with the goal of introducing the concept of conditional statements in programming, to children ages 10-12. Our broader goal is to design a series of games focusing on different aspects of programming fundamentals including logic expression, control statements, and variables. We will then assess the effectiveness of game-based instructions in promoting students’ understanding of computation, comparing it to a non-gaming approach. We believe that incorporating the game-based approach in existing curricula will help children succeed in their first experiences with programming.

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Intensive International Summer Schools in Global Distributed Software Development

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Abstract—Computer science graduates face unprecedented opportunities and unforeseen challenges in today's highly global economy. These students will have to work and to think with international perspectives and cultural awareness.

In this paper, we report on our experiences organizing and teaching the *Pacific Rim Summer Schools in Global Distributed Software Development*. We describe the motivation for our focus, our summer school curricula and programs, provide information on the costs of organizing and running the summer schools, and examine the sustainability of our program. We conclude with a discussion of the role of such experiences in computer science curricula and in the education of American and international computer science professionals.

I. INTRODUCTION

Computer science students face unprecedented opportunities and unforeseen challenges in today's global economy after graduation. These students will pursue careers as software developers, managers, scientists, and policy makers. As the software industry increasingly deploys globally distributed teams for software development, there is commensurate demand for computer science graduates with the software engineering skills needed to manage the technical problems of Distributed Software Development (DSD), as well as the human skills required to address the issues of managing or working in project teams that span languages, cultures, and time zones. All of these positions will require our graduates to work and to think with international perspectives and cultural awareness. Why not introduce them to this challenge while they are still students? How can this be done effectively?

With the support of two NSF CPATH grants, the authors have engaged in a five-year effort to internationalize computer science education through the creation of an international community of computer science departments, development of relevant curricula, and the realization of effective, international experiences for undergraduate majors. The two NSF grants are: *CPATHi18n*,¹ *Internationalization of Computer Science Education: the Pacific Rim Community Model* (NSF-CISE-0722341) and *Globally Distributed Software Development: an Instructional Community Model* (NSF-CISE-0939198).

As the names of these projects indicate, the geographic focus of the projects has been the Pacific Rim, while the professional concentration has been on issues in distributed software development. These efforts have been previously

reported at SIGCSE [3] and [12], at ICSE [5] and in [4]. More information can be found at www.cpathi18n.org.

During the summers 2010 and 2011, we organized two-week summer schools, first at Peking University in Beijing and then at the University of Oregon in Eugene. The events brought together students from computer science programs around the Pacific Northwest and East Asia for an immersive experience in which students were organized into small cross-cultural software teams to learn techniques and tools for global software development, and to acquire skills and knowledge in cross-cultural communication, team dynamics, and international computer ethics issues. Students also attended classes on cutting-edge industry-led topics and special topics symposia, and participated in team-building and social activities.

The motivation for our two-week summer program is to expose our students to the multicultural and ethical issues that can arise in an international setting while placing them in the software engineering context of distributed software development. The main technical thread was software engineering methods and tools and how these must be adapted to a distributed development situation. In separate short courses we discussed the multicultural and ethical issues.

Both the content and the format for the summer schools were based on lengthy deliberations among computer science faculty from our Pacific Rim partner institutions and industry partners from Google, Intel, IBM, Microsoft, and Avaya Research. In this paper, we describe our curriculum and compare it with regular academic-year courses that we currently teach on these topics. We also present the positive student, faculty, and industry reactions to their summer school experience, and discuss impacts on the participants. We provide information on the costs of organizing and running the summer schools and consider the sustainability of our program. We conclude with a discussion of the role of such experiences in computer science curricula and in the education of American and international computer science professionals.

II. BACKGROUND

This project set out to build a Pacific Rim Community of universities and industry in the Pacific Northwest and Asia focused on internationalization of computer science education. Our goal was to identify curricula and activities which would help to infuse with international aspects the education of computer science majors which to date remains largely parochial in both course content and student experiences.

¹The term i18n is a well-known industry abbreviation for the word *internationalization*, which starts with i, ends with n, and has 18 letters in between.

We built this community “from scratch” through personal contacts, an Asian Friendship Tour, and a series of international workshops and ancillary activities that took place during 2007-2011. During the four community-wide workshops we conducted during 2007-2009 we identified the following items of priority to our Pacific Rim academic and industrial partners:

(i) Need for *international experiences* for North American and Asian computer science students. Computer science majors on both sides of the Pacific Rim rarely participate in Study Abroad programs and software engineering project courses are limited to face-to-face interactions with classmates. In Asia, students have few opportunities for team-based projects.

(ii) Need for *new curricula* in global distributed software development that introduce geographic, temporal, and cultural differences as these give rise to software engineering coordination and control problems that differ both qualitatively and quantitatively from those of co-located developments.

(iii) Need for *soft skills* in the areas of cross-cultural communication and teamwork, with sensitivity to East-West differences in management and teamwork styles as well as social cues and conventions.

(iv) Need for an *efficient way* to provide international experiences and education in global distributed software development. Given the high credit hours and sequential nature of the computer science major, a year or semester abroad is difficult to coordinate with programs at one’s home institution; a full summer program competes with summer employment.

After much discussion, the CPATHi18n community decided to focus on curriculum development in three related areas: global distributed software development, cross-cultural communication, and international computer ethics; and delivery of this curriculum in a two-week international summer school.

III. GLOBAL DISTRIBUTED SOFTWARE DEVELOPMENT

The core course in our Pacific Rim Summer Schools is the 32 hour course on Global Distributed Software Development. This course is an abbreviated version of our greater efforts to develop term or semester-based courses on DSD. We first describe the general principles and challenges of DSD and then describe the course taught in our summer schools.

A. Principles and Challenges of DSD

Most students are introduced to software development, project management, and teamwork in software engineering project courses where the teams are formed from their classmates and development proceeds by face-to-face interactions among peers. In contrast, industrial experience shows that “distance matters” in the sense that geographic, temporal, and cultural differences result in software engineering coordination and control problems that differ both qualitatively and quantitatively from those of co-located developments. When students work in co-located teams, many of these problems simply do not arise. Moreover, informal communication tends to fill the gaps left by problems like unclear requirements, ambiguous specification, or poor planning. As a result, few students have the opportunity to encounter the kinds of problems that arise

in DSD or apply their skills to development issues beyond programming.

A pedagogical model that can provide a more globally relevant experience is one in which student teams are actually geographically distributed. Under this model, development teams are formed of students from different schools who must collaborate to complete a common software project. However, this pedagogical model requires significant pedagogical resources and collaboration infrastructure. Institutionalizing such courses also requires compatible and reliable teaching partners.

Our work under the NSF CPATH grant seeks to address these problems by using an “open source community” approach. This includes: developing a core set of reusable instructional material and establishing a common web-based infrastructure supporting distributed collaboration. Community members then partner with one another to teach instances of a DSD course tailored from community resources. The materials are available on our community web site [6].

The skill-sets identified under the NSF’s CPATH initiative, the substantial body of literature on the software engineering of distributed development, and our own experience developing software engineering courses for industrial practitioners [7] helped identify topics critical to addressing the problems of distributed development:

Project. A good project must be motivating for students, scoped appropriately to require teamwork for success, but not so ambitious that failure is common. International collaborations make selection and preparation of an appropriate project even more challenging. Local resources including the types of available computing platforms, compilers, etc. will vary as does access to the Internet or particular web sites. The students’ background in programming languages and tools likewise vary. Issues can also arise where projects that may be current and interesting to students in one locale are either unfamiliar or old hat to those in another. Finding a project that is interesting and equally challenging to all participants requires active collaboration among sites.

Tools. Distributed development requires common (typically web-based) tools. These include a version control system, project management tools, task tracking, synchronous and asynchronous communication tools, and programming tools. Tools that are widely and freely available, with minimum dependence on a particular environment are more appropriate than tools that require a substantial investment in time or money or that require a uniform computing environment across participating sites. Finally, the infrastructure should provide appropriate support for teaching (e.g., maintaining developer logs and tracking contributions of individual team members) as well as instrumentation for evaluation of the course.

Distributed Team via Community. We have been developing a community of computer science educators around the Pacific Rim (CPATHi18n) over the past several years. We followed this with a workshop at ICSE 2011 focused on understanding the issues around DSD course delivery and initiating the effort to teach a pilot course. One result has been the creation of a small web-based community of educators interested in

| Topic | Learning Objectives |
|--|--|
| Difficulties in DSD and the role of SE | Understand the kinds of project coordination and control problems that arise in distributed development and the kinds of Software Engineering methods used to address them. Coordinating the work of distributed teams by developing a common project plan (roles, schedule, milestones, deliverables, etc.) |
| Software Requirements | Understand the issues in negotiating and converging on a common set of requirements when stakeholders are distributed. Understand how to check understanding, write, and validate common requirements. |
| Principles of Software Architecture | Understand how required system qualities are achieved in the software architecture. How architectural decomposition (into components) can be used to manage the goals and constraints of distributed development. |
| Architectural Design | Understand principles and methods for achieving specific design goals that support distributed development. These include decomposition into modules for concurrent development and design for incremental delivery. Understand how to specify module interfaces as contracts. |
| Verification and Validation | Understand how to conduct effective reviews of development artifacts. Understand how to plan and implement effective test suites to check assumptions. |
| Lessons Learned | Conduct project postmortem to understand the whole development picture, issues that occurred, how and where Software Engineering principles and methods have facilitated distributed development. |

TABLE I
DSD CURRICULUM TOPICS AND LEARNING OBJECTIVES

DSD courses. Our class materials and project specifications materials have been validated through several collaborative teaching experiences between the University of Oregon and Peking University (2010-2012) as well as between Iowa State University, Jilin University, and the Federal University of Bahia in Brazil.

B. DSD in the Two-week Intensive Summer School Format

We have tailored the DSD curriculum to support a two-week summer session. While students in the summer session come from universities all around the Pacific Rim, the pedagogical experience differs in that the students are co-located. Thus, while student teams continue to have issues with language and culture, the effects of geographic distribution must be simulated. This is accomplished by using two computer labs to physically separate student teams for all project activities. This has proven effective if less challenging than separation by both distance and time zones. In other respects, the course content is the same if a somewhat abbreviated version of our core DSD content. Table I summarizes the curriculum content.

IV. SUMMER SCHOOL STRUCTURE

A. Pacific Rim Partners and Management Team

The institutional participants in the Summer Schools are listed in Table II. This group evolved naturally from the partners most committed to realizing the project goals. The management team from the University of Oregon (the authors), took the leadership role in all aspects of curriculum development and summer school organization. They were supported by an administrative assistant and a web design student employee. Faculty and industry partners provided teaching faculty, guest lecturers, and faculty advisors at their home institutions. Dean Zhong Chen from Peking University hosted and helped to organize the 2010 Summer School as well as the second CPATHi18n workshop in 2008.

The faculty advisor from each participating computer science department was responsible for recruiting and screening students, deciding whether or not to award academic credit. The Summer School Advisory Committee includes both academic and industry members. The Advisory Committee was

| Institution | Country | Students | Faculty Advisor |
|--------------------|---------|----------|---|
| Beihang | China | 5 + 4 | Prof. Zhang Xiong |
| Peking | China | 10 + 4 | Dean Zhong Chen Prof. Ming Zhang |
| Tsinghua | China | 6 + 2 | Prof. Bin Xu |
| Tohoku | Japan | 2 + 3 | Prof. Takeshi Tokuyama |
| KAIST | Korea | 2 + 1 | Prof. Key-Sun Choi Prof. Doo-Hwan Bae |
| Yonsei | Korea | 1 + 1 | Prof. Bernd Burgstaller |
| British Columbia | Canada | 3 + 4 | Dr. Ed Knorr |
| Simon Fraser | Canada | 2 + 0 | Prof. Ted Kirkpatrick |
| Victoria | Canada | 2 + 0 | Dr. Mike Zastre |
| Oregon State | USA | 1 + 0 | Dr. Molly Shor |
| Portland State | USA | 2 + 0 | Prof. Cindy Brown |
| Oregon | USA | 9 + 4 | Prof. Andrzej Proskurowski Prof. Virginia Lo |
| Seattle University | USA | 1 + 1 | Prof. Rich LeBlanc |
| Washington | USA | 2 + 0 | Prof. Steve Tanimoto |

TABLE II
PARTICIPANTS IN THE PACIFIC RIM SUMMER SCHOOLS 2010 AND 2011

instrumental in setting curriculum goals and topics, coordinating the summer term schedules of multiple international universities, and deciding on locations for the summer schools.

B. Curriculum and Schedule

The centerpiece of the Summer School consisted of the lab-based course on Global Distributed Software Development and the lecture classes on Cross Cultural Communication and International Computer Ethics. The following are brief descriptions of the course modules delivered in our 2010 and 2011 Pacific Rim Summer Schools. Course syllabi, assignments, and reading lists are available on the web at [1].

Global Distributed Software Development: Increasingly, industrial software is being developed using teams that are distributed around the world. While offering the potential of increased productivity, distributed software development (DSD) also introduces new risks. Coordinating distributed teams requires overcoming a range of software engineering issues that arise where sites are separated by time zones, languages, and cultures. In this course students develop an understanding of the problems inherent in distributed development and are introduced to software engineering methods and

| Day/Time | Activity |
|---------------------|--|
| Day 0 | Arrival and Check-in |
| Day 1 All Day | Orientation and Campus Tour Welcome Banquet |
| Days 2-5 Morning | Global Distributed Software Development |
| Days 2-5, Afternoon | Cross Cultural Communication International Computer Ethics |
| Days 2-5 Evening | Team Project or Special Events |
| Day 7, All day | Cross-cultural Team-based Activity |
| Day 8, All day | Field Trips, Shopping, etc. |
| Days 9-12 Morning | Global Distributed Software Development |
| Days 9-12 Afternoon | Writing Computer Science Research Industry Courses and Hack-a-thons |
| Days 9-12 Evening | Team Project or Special Events |
| Day 12 Evening | Farewell Banquet |
| Day 13 Morning | Departure |

TABLE III
SUMMER SCHOOL SCHEDULE

principles that help address these issues. Students apply these methods and principles to small problems simulating some of the characteristics of distributed development.

Cross-cultural Communication for Software Teams: The course looks at definitions of “culture” and articulates “cross-cultural communication”. In particular, the course concentrates on the role of culture in distributed teams, as related to the dichotomy of individualistic vs. social societies, tendencies in the workplace, and handling conflict. Other concepts discussed are: sending and receiving “messages”, perceptions, redundancy and convention, and the role of language (written and conversational) and non-verbal communication. The course presents several case studies. Students get involved in cross-cultural interaction exercises.

International Computer Ethics: This course addresses a wide range of ethical issues that have arisen from the creation of the global Internet and related information technology. In particular, we discuss issues that are due to differences in cultural perspectives. We review the history of information technology, including a look into the future, and discuss differing ethical reasoning systems. Ethical topics discussed are privacy, intellectual property, freedom of speech and information access, and issues that arise in the creation and application of software globally. Finally, we review a code of professional ethics for software engineers and discuss international dimensions to the code.

Writing Computer Science Research: This mini-course in writing computer science research papers (in English) provides students with important guidelines for writing publication quality scientific research papers. The course is targeted to native and non-native speakers of English. We developed this course module in response to requests from our Asian partners.

Industry Courses: Our industry partners offered a variety of hands-on courses for our summer school audience. They included Kinect Hack-a-thon (Microsoft), Mobile Apps (Intel), and Web Apps (Google), Cloud Computing (Microsoft), and Parallel Programming (Intel).

Table III shows the general format of the Summer School.

C. Academics

The two-week schedule involved team-based project work and classroom lectures during the day, with evenings dedicated to team-work or special events. Students were given a pre-arrival Reading List that included papers on DSD [9], Cross Cultural Communication [8], [10], and International Computer Ethics [2]. After the summer school, all students completed a final exam and graduate students wrote a research paper on a DSD topic. Grades and course credit were administered in consultation with the students’ home institutions.

Below we describe the details of the 2010 and 2011 Pacific Rim Summer Schools in Global Distributed Software Development. In 2009 a pilot Summer School was offered in partnership with UO’s Network Resource Startup Center that included students from Africa, South Asia, China, and the University of Oregon.

D. 2010 Peking University, Beijing China

In July 2010 we organized the Pacific Rim Summer School in Beijing. The CPATH grant-supported activities included: curriculum development, soliciting and supporting instructors, defining the audience and recruiting students, soliciting local support (Peking and Tsinghua Universities), managing and supporting logistics: stipends for the participants, academic credits, classrooms and labs, lodging and meals. The UO Office of International Affairs provided logistic support to students.

The Summer School brought together 52 students from 14 universities from the U.S./Canadian Pacific Northwest and from Asia (China, Japan, and Korea). To qualify for the Summer School, computer science students had to be at the level of junior through second year graduate, and have completed an upper level software engineering course. Students had the option of earning 6 credits in computer science. The Summer School faculty team were from the University of Oregon, Peking University, Beihang University, Tsinghua University and industry partners Microsoft, Intel, and Avaya Research. Students lived together with cross-cultural roommates and faculty on the campus of Peking University, and participated in team-building and cultural activities around Beijing.

The core curriculum was augmented by lectures on topics in software engineering, industry lectures on software measurement (Avaya Research) cloud computing (Microsoft) and parallel computing (Intel), as well as on-the-street cross-cultural and team building exercises. Dean Zhong Chen gave a distinguished lecture entitled “A Dragon Awakes: How China Handles Data Security.” Team-building activities included a bridge-building exercise involving newspaper and masking tape. On the weekend, teams of students were also sent around Beijing with the assignment to develop requirements analysis for a mobile application to aid western tourists visiting China. Social activities included excursions to the Great Wall, Forbidden City, and free time for shopping, eating out, and exploring Beijing nightlife.

E. 2011 University of Oregon, Eugene, Oregon

In August 2011, we organized the Pacific Rim Summer School back at the University of Oregon, in keeping with our plan to alternate locations between North America and Asia. In addition, we organized a campus-wide symposium on International Computer Ethics, securing additional funding from the UO Center for Asian and Pacific Studies.

The Summer School brought together 22 students from 9 universities from the U.S./Canadian Pacific Northwest and from Asia (China, Japan, and Korea). Eligibility criteria and grading arrangements were the same as in the previous year. The Summer School faculty team were from the UO, Peking U., Beihang U., and industry partners Microsoft, Intel, and Google. Students lived on the UO campus, and participated in team-building and cultural activities around Eugene with the assistance of faculty from the UO School of Business and the UO Center for Asian and Pacific Studies. The smaller group size of 22 students (versus 50 in 2010) was due to inadvertent scheduling that made it inconvenient for more Oregon students to attend. The ratio of Asians to North Americans was 2:1. However, the smaller group size and intense curriculum resulted in the formation of strong friendships and excellent classroom and lab experiences.

That year, we introduced a course in Writing Computer Science Research Papers in response to requests from our Asian partners. Stanford Law Professor Mei Gechlik taught a one-day seminar in computer ethics on a case study of Google's Presence in China. The campus-wide symposium on *China's Revolution in Information Technology: Ethical Issues* had as guest speakers Mei Gechlik, Eric Priest, UO School of Law, and Denis Simon, UO International Affairs. Industry courses included Web Apps (Google), Kinect Hack-a-thon (Microsoft), and Mobile Apps (Intel). Intel donated a HP tablet PC to each participant. Academic activities were complemented by a trip to the Oregon coast, and movies, music, sports, and shopping.

V. EVALUATION

A. Faculty and Student Feedback

Feedback on the Summer Schools was solicited through student exit surveys and a survey of the faculty advisors from the partner institutions. Overall, the student exit survey shows the Summer School to be very successful in raising students interest and awareness of the value of global distributed software development and cross-cultural experiences. The students value the opportunity to learn and work together with students from another culture as much or more than the actual course content. The full survey results, including answers broken down by country, can be obtained by contacting the authors. Some typical student quotes:

Student from UBC: "This workshop was one of the most amazing experiences in my university career. Not only did it help change my outlook on cross cultural communication in regards to computer science, it helped me appreciate and understand other cultures in more ways than one can list."

Student from USA: "Impressive (curriculum). This workshop is a great introduction to issues we will face working for the big companies."

Student from KAIST: "It was a really good chance to realize how difficult a software development in a globally distributed environment is. The most impressive thing was a variety of teaching methods I've never experienced in South Korea."

Student from PKU: "In this summer workshop, I learned a lot, both professional and personal."

Feedback from our faculty survey indicated that the partners value the new ties among the Pacific Rim Partner institutions and are committed and enthusiastic about future summer schools. The Asian partners were very eager for engagement with colleagues in North America, sending their Deans and department heads to the workshops and offering to host. The North American partners were interested and supportive, but tended to delegate duties to instructional faculty, rather than research faculty. All partners used a rigorous process to screen and select the student participants. Departments on both sides of the Pacific Rim committed financial support to their students to defray high costs of travel.

The summer school was deemed an invaluable experience for most if not all of the student participants. The majority of students had never traveled abroad nor lived and worked closely with students from another country. The small group size and intense team-based curriculum resulted in the formation of friendships that have continued beyond the short two weeks. The synergy and collaborative spirit by all (students and faculty) exceeded expectations.

B. Logistics, Costs, Personnel

The summer schools were funded by grants from the NSF CPATH program. In-kind donations of labs, lecture halls, and technical support were provided by Peking University and University of Oregon, while industry partners Intel, Microsoft, and Google provided travel support for their instructors. Out of town faculty received a full stipend for travel, housing, and meals, and out of town students received a partial stipend for travel, housing, and meals. In 2010 the total cost was close to \$50,000. A major commitment of time and energy was expended by the management group from the University of Oregon and Peking University to prepare and run the event. Our administrative assistant who lived for seven years in Beijing provided invaluable assistance with the local arrangements and clear communication with our colleagues at Peking University. The 2011 the summer school was funded by grants from the NSF CPATH program and from the University of Oregon College of Arts and Sciences. Instructional faculty were compensated through the UO Summer School tuition receipts. The total cost was close to \$60,000.

C. Challenges, Sustainability and the Future

The key challenge in sustaining the Pacific Rim Summer Schools is funding. While hosting universities are often able to provide in-kind support, a revenue source is needed for student financial aid, staff for logistics and publicity, and at a minimum

faculty travel support. We believe that a research theme is essential to the sustainability of the Pacific Rim Summer School. To this end, we are investigating the development of a focus that combines the goals of the i18n project with the research interests of the i18n leadership team. One area under discussion lies in the intersection of distributed data mining and software engineering, while another is computer security. Both areas are accompanied by issues related to cross-cultural and international ethical considerations. The Summer School Advisory Board is looking to return to Asia for Summer 2013. A switch to a research emphasis will involve establishing new ties with Pacific Rim faculty interested in a target research area as well as development of new projects and curricula.

Our activities during 2007-2011 were focused on building a community of computer science educators and industry partners interested in internationalization of computer science education. During this period, we developed cutting-edge curricula, strengthened our Pacific Rim community ties, and held two successful summer schools. What is needed now is a well-designed research study to evaluate the effectiveness of our curricula and of the two-week summer school in preparing students for their future professional endeavors.

VI. IMPACTS ON UNDERGRADUATE CS EDUCATION

Computer science education needs enhancement in several key areas in order to better prepare graduates to work in the de-facto global distributed software team environment.

Global distributed software development: students need to be exposed to the formal methods, logistical, and cultural issues of working in a software team distributed across geographic, cultural, and timezone barriers. Our industry partners especially emphasized the value of student exposure to these topics before entering the job market.

Cross-cultural communication for software teams: productivity, motivation, and overall success are greatly improved when team members are sensitive to communication across cultures.

International computer ethics and societal impacts: students must graduate with a global understanding of these topics rather than the western-centric view of current computer science courses in the U.S.

Cross-cultural HCI: courses need to be enriched with cross-cultural content towards the broader view of universal HCI. The current draft of ACM Curriculum 2013 echoes our belief in the need for i18n in the sections on social/professional responsibility (tier 1) and HCI (tier 2).

Our findings show that international experiences must fit conveniently into the heavy requirements and constraints of a computer science major. Furthermore, majors need to be educated to value international experiences such as study abroad, foreign language and international studies courses. We found it important to offer financial support for students to attend the school.

Faculty and students at Asian computer science departments are very eager for more engagement with their western counterparts at the undergraduate level. While research collaborations and exchange programs for international faculty and

graduate students are fairly common, there are fewer formal opportunities for exchanges among undergraduates.

We plan to continue to develop and disseminate our course modules in DSD, cross-cultural communication, and international computer ethics for the computer science education community to use in required courses for CS majors in software engineering and computer ethics, as well as for topics in introductory courses for majors and non-majors. A by-product of our curriculum innovation in soft skill areas such as cross-cultural communication and international computer ethics has led us to new cross-disciplinary interactions with faculty in several non-science departments. Our CPATHi18n management team worked with faculty in the School of Law (intellectual property law in China); School of Business (cross-cultural communication, team-building and leadership); Asian Languages, The Oregon Confucius Institute, and the Oregon K-20 China Flagship Language Program. We participated in a grant from the Dept. of Education to the Oregon Center for Asian and Pacific Studies and received a small grant from the Oregon International Studies and Global Scholars Program to support curriculum development in the above areas. These new ties enriched all participating disciplines.

VII. ACKNOWLEDGMENTS

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Work in Progress: Preliminary Survey Results on the First Year of the Bologna Process in Engineering Education in Spain

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Abstract— This paper shows the preliminary results of a study carried out by the IEEE-Education Society Spanish Chapter on the state of implementation of the Bologna process in engineering degrees along Spain and the opinion of teachers about the main aspects of this implementation. These include the implementation of new learning methodologies (problem-based learning, collaborative learning, project-based learning, etc.), resources, assessment criteria, workload of students and teachers, the support of each university for the EHEA implementation, and the general satisfaction (or not) about the EHEA. The aim of this paper to contribute to a reflexive debate, not only in Spain but also in the international community, about the advantages and drawbacks of the EHEA implementation in engineering education.

Keywords-component: EEES, Engineering Education, Bologna Process

I. INTRODUCTION

The objectives of the EHEA (European Higher Education Area) or colloquially known as Bologna Process are to provide instruments to understand and compare the different education systems more easily, to facilitate the recognition of professional qualifications for both national and international mobility, and to progressively increase the collaboration across European universities towards the convergence of educational structures. Independently of these objectives, in Spain the Bologna Process or EHEA has been the opportunity to change deeply the university degrees. One of the main ideas of EHEA is to focus on a learner-centred approach as opposed to the traditional teacher-oriented approach. From the year 2010, the EHEA has been implemented in all engineering degrees in Spain. Therefore, there exists at least one year of experience applying the Bologna Process. The IEEE-Education Society Spanish Chapter has carried out a study on the state of implementation of the EHEA in engineering degrees along Spain and the opinion of teachers about the main aspects of this implementation. These include the implementation of new learning methodologies (problem-based learning, collaborative learning, project-based learning, etc.), resources, assessment criteria, workload of students and teachers, the support of each university for the EHEA implementation, and the general satisfaction (or not) about the EHEA. The aim of this paper is to show the main results

of this study, and therefore to contribute to a reflexive debate not only in Spain but also in the international community about the advantages and disadvantages in engineering education that the EHEA implementation may provide.

In Section II the survey method is explained. The preliminary results of the study are given in Section III. The paper ends with some conclusions and implications for the future

II. METHODOLOGY

As long as we know this is one of the first studies about the implementation of the EHEA in Spain. Therefore, we didn't want to produce a very large survey form, but to focus on the more general aspects of the application of the Bologna Process, such as the workload, the learning methodologies, the continuous assessment and the general satisfaction degree. The survey involves questions about these issues, some professional information (e.g., years of experience, academic degree) and the degree of participation in the process.

The dissemination of the survey form was performed with the help of members and supporters of the IEEE Education Society Spanish Chapter through the CESEI network [1]. This network is promoted by the IEEE-ES Spanish Chapter [2] and currently is composed of more than a hundred teachers in 40 universities throughout Spain, all of them strongly related to Engineering Education.

Teachers from engineering degrees have filled in the survey since the last week of March 2012. Around 500 teachers from 45 Spanish universities have already answered it (a previous survey carried out by the CESEI was answered by just 126 teachers [3]). In addition, notice we are currently in the second year of implementation of the EHEA. In this way most teachers in engineering education have not any experience in the adoption of the Bologna system and therefore, they couldn't answer the survey.

III. FIRST RESULTS

A. Participation in EHEA

While practically all ages are represented, the majority of teachers are in the age group of 40-49. Around 75% of the teachers have more than 10 years of teaching experience, and

almost half of the teachers have among 10 and 20 years of teaching experience. Most of the teachers have lectured 1 or 2 subjects.

More than half of the teachers acknowledge that they have changed his teaching style with respect to the former one in a high degree. Nevertheless, they feel their colleagues have not changed their styles in a so high degree. Therefore, we can say that the EHEA has promoted a change in the teaching style in the majority of the teachers.

B. Preliminary results

- **Workload:** A main concern for teachers about the EHEA implementation was that it might require a higher workload. Around half of the teachers estimate that their own workload is much higher than the former one and a large number of the remainder ones consider that the workload is just slightly higher. In any way, almost all the teachers feel their workload has increased. This feeling comes to confirm the lack of practical support from the institutions. As a result, teachers consider that their work has increased considerably. The perception in the academic staff about the students' workload is that it has also been increased. In summary we conclude that EHEA has produced an increase in the teachers and students' workload.
- **Continuous Assessment:** A key aspect in the EHEA is the adoption of a continuous assessment model. Previously, the most popular assessment model was the final exam. From the first results of our study, we can see that a large majority of teachers have in a better consideration the continuous assessment than a final exam. Nevertheless, this option is not unanimous. In other way, despite continuous assessment is the recommended method in EHEA, such an assessment method is not mandatory in all the higher institutions, as teachers' perception reflects.
- **Pedagogical Methodologies:** Another main aspect in EHEA is the adoption of new learning methodologies. Around half of teachers admit the adoption of new learning methodologies, while the other half continues using their former methodologies. It is really exciting to consider that around half of teachers have adopted new learning methodologies with EHEA. In addition, the fact that the other half of the teachers has not changed anything doesn't mean that such methodologies were not appropriate.
- **Resources:** This part of the survey was oriented to capture the use of new learning resources. In this way, the survey included directly as possible answers items such as: video, reusable learning objects, games, remote and virtual laboratories, and simulators. We have not paid attention to other more classical resources such as slides, real laboratories, etc.
- **General Opinion:** Teachers were also surveyed about if they feel that students learn more or less in the EHEA model or in the former one. Related with this, teachers' opinions are also divided: around a third of teachers consider that EHEA is better for students'

learning, a quarter is neutral and the remainder ones consider that EHEA is worse. Around half of the teachers find the number of students who fail is fewer than the former model, but they also associate this result with a higher pressure for teachers to get more succeed students. Directly enquired about which model is better, EHEA or the former one, there is not a clear opinion. These results are complemented with the opinion about their preference for the EHEA or the former model. In a high degree, just a few amount of the teachers prefer EHEA, while some are neutral and more than half of the teachers do not prefer EHEA model.

We think that these results should promote a general reflection about the EHEA implementation in all the stakeholders, mainly in politicians and academic authorities. It seems quite challenging to implement a new system when the people that has to use it don't have any faith.

IV. CONCLUSIONS

The EHEA in Spain was implemented from academic year 2010-11. Some years remain to have a complete implementation of the new model in all the academic years of the engineering degrees. Nevertheless, at the time of this study, the results captured are very worrying. On the one hand, teachers and students' workload has increased, but this has not been followed by an increase in the student success. On the other hand, all the teachers and institutions are not adopting the continuous assessment model, that is a key aspect in the EHEA [4]. In addition, universities are not supporting the EHEA implementation appropriately. Moreover, the general feeling about EHEA implementation in Spain is unsatisfactory. At the present time, it seems that the unique positive result from EHEA implementation is the adoption of new teaching methodologies.

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Bologna vs non-Bologna academic outcome in BEng Mechanical Engineering within EHEA

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Abstract— The arising of European Higher Education Area (EHEA) brought up the implementation of new degrees throughout most of European Universities. In the realm of this upcoming environment, during 2009-2010 the School of Design Engineering (ETSID) at Universitat Politècnica de València in Spain, developed a pioneer experience in the first year of the Bachelor Engineering (BEng) degree in Mechanical Engineering, the guidelines of this innovative experience being defined in accordance with the EHEA approaches. Thus, this pioneer experience co-existed with non-Bologna teaching-learning methodology followed in the rest of groups of this BEng degree.

Positive academic outcomes found in this first pioneer group encouraged to extend this experience to the second year of this degree during 2010-2011, in order to ease the upcoming full Bologna implementation. In this line, classroom activities were established so that collaborative work was promoted, autonomous tasks were developed and an assessment that took into account both classroom and autonomous activities was implemented.

In this paper, we present a statistical analysis of the achieved academic outcomes of the pioneer group in the second year of the BEng degree in Mechanical Engineering, relating them to the rest of non-pioneer groups of the same year and degree.

Keywords: *classroom activities; autonomous activities; formative assessment; EHEA adaptation*

I. INTRODUCTION

Over the last years, European Universities have undertaken several reforms within the framework of the Bologna process with the aim of creating a European Higher Education Area (EHEA) and with degree programs based on profile, learning outcomes, competences and student workload [1,2].

The implementation of a competences approach for the design of educational programs has involved the review of teaching, learning and assessment strategies to be used in order to guarantee the development of the required competences [3].

This shifting has meant a change of paradigm: from teacher-centered to student-centered teaching, learning and assessment, in which teachers act as facilitators and guides whereas students play an active role and take the responsibility for their learning [4,5]. It has subsequently been necessary to adopt teaching and assessment approaches that highlight active and dynamic learning and that allow students to acquire the desired competences.

Along this adaptation process, new EHEA structured Bachelor degrees have been finally implemented in most of European Universities. Before this occurred the School of Design Engineering (ETSID) at Universitat Politècnica de València (Spain), developed a pioneer experience during 2009/2010 in one of the groups of the first year of its Bachelor Engineering (BEng) degree in Mechanical Engineering [6] as prelude towards the establishment of the EHEA adapted degrees. Let us mention that as a further step the EUROpean ACcredited Engineer (EUR-ACE) project (2004/06) formulated a framework for the European Accreditation of Higher Education Programs in Engineering to which some national agencies have already adhered (France, Germany, Ireland, Portugal, Russia, and UK), [7]. This is becoming the European counterpart to the well-known ABET, [8].

Logically this experience was designed according to the EHEA approaches by implementing a new teaching-learning system based on active methodologies and formative assessment [9-11], so that the acquisition of knowledge, abilities and competences of students would be promoted. This innovative experience co-existed with non-Bologna teaching-learning methodology followed in the rest of groups of this BEng degree. Academic performance of the students taking part in this innovative experience was later assessed by means of different rates. This analysis showed that active participation of students in their learning process, along a formative evaluation of their progress, improved their academic success [12]. These positive academic outcomes encouraged the extension of this experience to one group of the second year of the BEng degree in Mechanical Engineering during 2010/2011.

“Vicerrectorado de Estudios y Convergencia Europea” and “Instituto de Ciencias de la Educación” of the Universitat Politècnica de València (Spain)

In addition to the above mentioned guidelines, in this second pioneer experience, interest was focused on the further improvement of student success and learning. Thus, for every subject, collaborative classroom activities [12-14] together with autonomous tasks were designed, so that the acquisition of generic and specific competences associated to this BEng degree might be assured. Furthermore, different formative assessment strategies [11] taking into account both classroom and autonomous activities, were implemented.

This paper provides a detailed analysis of the academic performance of this second-year pioneer group on the basis of various rates that have been defined for every subject, degree and student, and a further comparison with those corresponding to the other groups of students, of the same year and degree, which followed non-Bologna teaching-learning methodology.

II. DESCRIPTION

One of the main objectives of this second-year innovative experience in the BEng degree in Mechanical Engineering at ETSID has been the use of collaborative learning methods for classroom activities. As it has been shown in similar experiences of its implementation in engineering higher education, collaborative learning improves the academic performance, promotes the acquisition of generic competences and enhances life-long learning [9, 10, 15-18]. The main collaborative learning methods introduced in this second-year pioneer group were problem-based, cooperative work and project-based learning. Figure 1 displays the instructional methods that have been applied in this pioneer group compared with those used in the other groups following traditional educational approaches, mainly based on lectures and with a very limited use of collaborative methodologies.

During these collaborative activities, students were divided into small groups (3-4 students) in which they solved cases, problems, projects, etc. in the classroom under their instructors supervision, these activities being collected for their evaluation and subsequent feedback. On the other hand, autonomous activities to be performed after class hours were also designed in every core subject of this pioneer group.

Both classroom and autonomous activities were evaluated by using a formative evaluation approach. The implementation of such evaluation involved the use of a variety of assessment strategies (one minute paper, portfolio, report, data recording...) including written exams, in contrast to the exam-based traditional evaluation used in the other groups, Fig. 2.

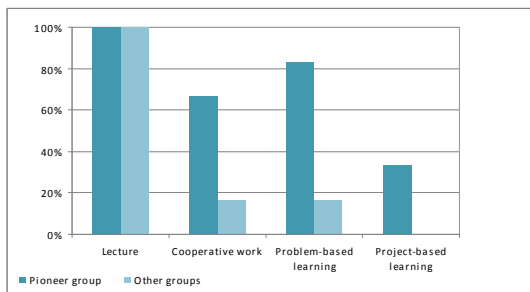


Figure 1. Teaching methodologies in the second year of the BEng degree in Mechanical Engineering during 2010/2011.

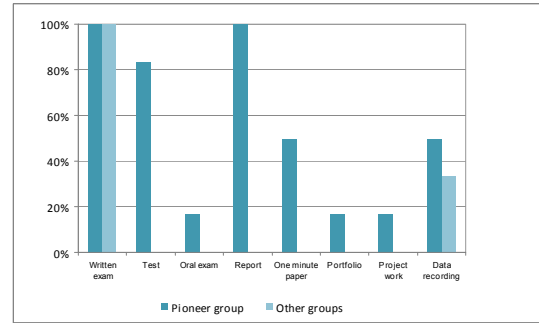


Figure 2. Assessment strategies in the second year of the BEng degree in Mechanical Engineering during 2010/2011.

Assessment of this pioneer experience has been first performed according to the following rates that have been determined for every core subject:

$$\text{Exam attendance rate} = \frac{\text{n}^\circ \text{ students who take an exam}}{\text{n}^\circ \text{ enrolled students}} \times 100 \quad (1)$$

$$\text{Success rate} = \frac{\text{n}^\circ \text{ pass students}}{\text{n}^\circ \text{ students who take the exam}} \times 100 \quad (2)$$

$$\text{Performance rate} = \frac{\text{n}^\circ \text{ pass students}}{\text{n}^\circ \text{ enrolled students}} \times 100 \quad (3)$$

Furthermore, the following overall rates have also been calculated for this degree in terms of both the number of European Credit Transfer System (ECTS) and students:

$$\text{Total success rate} = \frac{\text{n}^\circ \text{ pass ECTS}}{\text{n}^\circ \text{ enrolled ECTS}} \times 100 \quad (4)$$

$$\text{Relative course rate} = \frac{\text{n}^\circ \text{ students who pass all the subjects}}{\text{n}^\circ \text{ students who take all the exams}} \times 100 \quad (5)$$

$$\text{Course rate} = \frac{\text{n}^\circ \text{ students who pass all the subjects}}{\text{n}^\circ \text{ enrolled students}} \times 100 \quad (6)$$

Finally, student success in terms of the number of enrolled ECTS has been determined as well for every student in this BEng degree:

$$\text{Student success rate} = \frac{\text{n}^\circ \text{ pass ECTS}}{\text{n}^\circ \text{ enrolled ECTS}} \times 100 \quad (7)$$

All these rates have been obtained both for the students of the pioneer group and those enrolled in the rest of the groups of the second year of the BEng degree in Mechanical Engineering, in order to perform a further comparative analysis of these results.

In particular, these rates have been determined for 55 students enrolled in the second-year pioneer group of the BEng degree in Mechanical Engineering, and on an average of 315 students enrolled in the other groups of the same year and degree.

III. RESULTS

A. Subject results

First, academic performance of the students taking part in this innovative experience has been analyzed for every subject. Exam attendance rate, success rate and performance rate have been determined for every core subject for the pioneer group and the rest of the groups of the second year of the BEng degree in Mechanical Engineering (Tables I, II and III).

In general, the exam attendance rate has increased for most of the subjects in this pioneer group, when compared to that corresponding to the rest of the groups. However, the success rate is improved for all the subjects in the pioneer group. This group displays an average success rate of 96.6%, whereas in the other groups, success rate is on average 87.1%.

TABLE I. EXAM ATTENDANCE RATES IN THE SECOND YEAR OF THE BENG DEGREE IN MECHANICAL ENGINEERING DURING 2010/2011.

| Subject | Exam attendance rate | |
|--------------------------------------|----------------------|---------------------|
| | <i>Pioneer group</i> | <i>Other groups</i> |
| Mechanics and Theory of Mechanisms | 71.4% | 55.1% |
| Mechanical Technology | 66.7% | 66.9% |
| Fluid Mechanics Engineering | 69.0% | 68.4% |
| Elasticity and Strength of Materials | 71.4% | 71.1% |
| Thermal Engineering | 85.7% | 60.9% |
| Statistical Methods | 88.1% | 75.6% |

TABLE II. SUCCESS RATES IN THE SECOND YEAR OF THE BENG DEGREE IN MECHANICAL ENGINEERING DURING 2010/2011.

| Subject | Success rate | |
|--------------------------------------|----------------------|---------------------|
| | <i>Pioneer group</i> | <i>Other groups</i> |
| Mechanics and Theory of Mechanisms | 93.4% | 93.3% |
| Mechanical Technology | 100.0% | 75.8% |
| Fluid Mechanics Engineering | 100.0% | 83.9% |
| Elasticity and Strength of Materials | 96.9% | 96.7% |
| Thermal Engineering | 94.4% | 82.7% |
| Statistical Methods | 94.6% | 90.2% |
| | | |

TABLE III. PERFORMANCE RATES IN THE SECOND YEAR OF THE BENG DEGREE IN MECHANICAL ENGINEERING DURING 2010/2011.

| Subject | Performance rate | |
|--------------------------------------|----------------------|---------------------|
| | <i>Pioneer group</i> | <i>Other groups</i> |
| Mechanics and Theory of Mechanisms | 66.7% | 51.5% |
| Mechanical Technology | 66.7% | 50.7% |
| Fluid Mechanics Engineering | 69.0% | 57.4% |
| Elasticity and Strength of Materials | 69.0% | 68.9% |
| Thermal Engineering | 81.0% | 50.4% |
| Statistical Methods | 83.3% | 68.1% |

These results confirm a higher performance rate in the pioneer group with regard to the other groups of the same year. On average, this rate is increased in about 15% in the pioneer group. In some subjects (Thermal Engineering), this improvement approaches 30% with regard to the performance rate of the students of the rest of the groups of the same year and degree.

B. Degree results

Academic performance of the students taking part in this pioneer group has later been analyzed for this degree. Total success rate, relative course rate and course rate have been calculated for the second year of the BEng degree in Mechanical Engineering (Table IV).

Active learning and formative assessment implemented in the pioneer group have led to a better total success rate (76%) than traditional teaching and evaluation methods employed in the rest of the groups. This means an increase of this rate of approximately 18%.

On the other hand, in the pioneer group 86% of the students who attempt to pass all the subjects, finally accomplish it, compared with 70% of the students of the rest of the groups.

Results also show a substantial improvement of the course rate in the pioneer group. While approximately 45% of the enrolled students in the pioneer group finally pass all the subjects, only 24% of the enrolled students pass all the subjects in the rest of the groups. Such low values of the course rate imply that next academic year the number of non-continuing students will be significant in these other groups.

TABLE IV. TOTAL SUCCESS RATES, RELATIVE COURSE RATES AND COURSE RATES IN THE SECOND YEAR OF THE BENG DEGREE IN MECHANICAL ENGINEERING DURING 2010/2011.

| Degree rates | Success rate | |
|----------------------|----------------------|---------------------|
| | <i>Pioneer group</i> | <i>Other groups</i> |
| Total success rate | 75.8% | 58.0% |
| Relative course rate | 86.4% | 70.2% |
| Course rate | 45.2% | 24.3% |

These results confirm the better performance of this teaching-learning methodology based on a student-centered model, compared with the traditional one based on a teacher-centered model.

C. Student results

In order to complete the analysis of the academic performance of this innovative experience, the percentage of students as a function of their success in terms of ECTS has been determined as well for the pioneer group, Fig. 3, and the rest of the groups of the second year of the BEng degree in Mechanical Engineering, respectively, Fig. 4.

Results reveal an improvement in the student success of the pioneer group with regard to that of the other groups. In particular, 69% of the students of the pioneer group passed more than 75% of their enrolled ECTS, compared with 43% of the students of the other groups. Furthermore, while 41% of the students of these groups passed less than 50% of their enrolled ECTS, only 26% of the students of the pioneer group failed to pass these ECTS. This significant improvement of the student success in the pioneer group confirms the suitability of the teaching and evaluation approaches that have been implemented in this innovative group.

On the other hand, 0% success corresponds to the dropout percentage. Results reveal that dropout has decreased 5% with regard to that of the other groups. This seems to indicate that collaborative work activities implemented in this group have actually eliminated the dropout rate. Similar results have also been found in other innovative experiences involving group-based methodologies in BEng degrees [19].

With regard to students, these results suggest that this innovative experience has contributed to improve their academic performance.

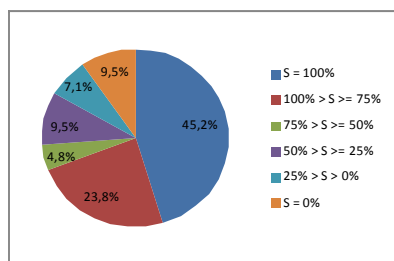


Figure 3. Student success rates (S) in the second-year pioneer group of the BEng degree in Mechanical Engineering during 2010/2011.

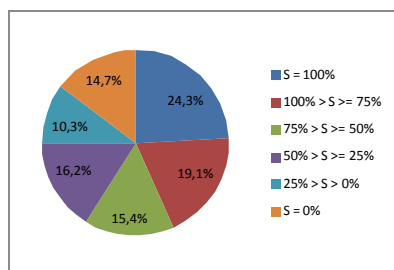


Figure 4. Student success rates (S) of the second year of the BEng degree in Mechanical Engineering at non-Bologna groups of during 2010/2011.

III. CONCLUSION

As a first stage towards the implementation of its new EHEA adapted degrees, during 2009/2010, the School of Design Engineering ETSID of the Universitat Politècnica de València (Spain) developed student-centered teaching and assessment approaches in a pioneer group of the first year of its BEng degree in Mechanical Engineering. Positive academic outcomes of this pioneer group have encouraged the extension of this innovative experience to one group of the second year of the BEng degree in Mechanical Engineering during academic year 2010/2011. For every core subject, collaborative activities have been organised during classroom sessions together with autonomous tasks to be performed after class hours. Both classroom and autonomous activities have been evaluated using a combination of formative assessment strategies.

Academic performance of the students taking part in this innovative experience has been assessed by means of different rates that have been defined for every subject, degree and student. Results have revealed that active participation of the students in their learning process together with a formative evaluation of their progress have led to a considerable improvement of all these rates.

Implementation of teaching methodologies that enhance active and autonomous learning of students together with formative assessment, such as those followed in this pioneer group, promotes their greater engagement. As it has been shown, the performance rate increases as a consequence of the rise of both the exam attendance rate and the success rate in every core subject.

The significant improvement of the overall degree rates under consideration in this study, confirms that the use of a teaching-learning methodology based on a student-centered model, is better than traditional teacher-centered approaches.

Furthermore, the analysis of the student success rate has revealed that personal success has been improved as well in this pioneer group compared with that of the other groups of the same year, following non-Bologna teaching-learning methodologies.

Finally, it has also been found that collaborative work activities together with formative evaluation strategies, such as those implemented in this group, seem to reduce the dropout rate.

ACKNOWLEDGMENT

Authors are grateful to the “Vicerrectorado de Estudios y Convergencia Europea” and the “Instituto de Ciencias de la Educación” from the Universitat Politècnica de València, for financial support through the PIME program during academic year 2010-2011.

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Analizing students performance in an EHEA BEng Industrial Design Engineering degree

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Abstract— European Universities have been exposed to major changes in order to implement the so called Bologna process. Many facets have had to be addressed in the teaching-learning system, moving from a teacher-centered model to a student-centered one, where a competence-based structure had to be facilitated, and so that the basic competences related to the integral formation of engineers should be accomplished along specific competences, making possible a professional profile and enabling the graduates to get integrated into the job market. Hence, this change has provided the opportunity to create a more active and dynamic teaching-learning model, with more personalized methods and the integration of new technologies.

In the midst of this situation, a case study has been undertaken to analyze the consequences of such change in the academic results of the BEng Industrial Design Engineering degree of the School of Design Engineering ETSID (Polytechnic University of Valencia, Spain) along the first course of the European Higher Education Area (EHEA) adapted program and those obtained by the corresponding pre-EHEA course at ETSID.

This paper aims to become an instrument to monitor the development and effectiveness of the teaching-learning policies adopted, thus contributing to the continuous process of educational improvement at ETSID by comparing various performance and success rates.

Keywords: *classroom activities; autonomous activities; formative assessment; EHEA adaptation*

I. INTRODUCTION

Design arises in general as a response to functional and symbolic needs of people in order to get some, social or personal, public or private, well-being goal. Hence Product Design quintessence relies on a crystallizer dimension by means of which some given ideas must become real objects. Industrial Design Engineers must have this in mind since they are involved in the design of products in addition to the resources management and its costs. Most of the standard goods that people buy and use have previously been designed and manufactured., thus it is not strange to find a BEng Engineer in Industrial Design behind the conception or materialization of many of the products that we are continuously using.

From the above it follows that Bachelor Engineering (BEng) in Industrial Design Engineering degree should train professionals with technical and scientific skills to manage the whole production process of products, with a special focus on innovation in a global context. This a consequence of the fact that design brings together technological, economic, functional and stylistic dimensions which enable to carry out the creation and development of a wide variety of products in terms of scale, type and nature. This confluence of different fields in design activities requires a multidisciplinary professional profile coping with humanistic sensitivity as well as scientific and technical knowledge [1].

The need of acquiring these multidisciplinary competences, including a technological and socio-cultural compound, makes that BEng Industrial Design Engineering students must take from the very beginning courses which encourage the development of creativity, pragmatism and drawing skills together with scientific and technical knowledge, as well as the ability of dealing with abstract comprehension which enable them to analyze and synthesize a variety of situations.

The School of Design Engineering (ETSID) of the Universitat Politècnica de València (UPV), Spain, has reviewed its BEng Industrial Design Engineering degree in order to fit the requirements of the European Higher Education Area (EHEA) [2,3]. This adaptation process has given birth to a new study plan based on profile, learning outcomes, competences and student workload, which on the other hand has implied a change of paradigm in the teaching-learning process moving from teacher-centered to student-centered teaching where instructors are viewed as facilitators and guides whereas students play an active role and take the responsibility for their learning [4, 5]. This has brought out the incorporation of teaching [6-9] and assessment [10-12] approaches that highlight active and dynamic learning enabling students to acquire the desired competences.

This paper analyzes some consequences of these changes in BEng Industrial Design Engineering at ETSID. The study aims to compare academic performance between first grade students of the EHEA adapted study plan with the one obtained by the first grade students of the pre-EHEA study plan at ETSID. This study is intended to monitor the effectiveness of different teaching-learning strategies, thus contributing to the continuous educational improvement process at ETSID.

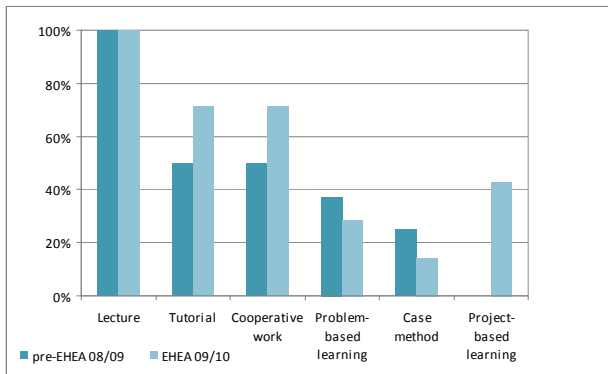


FIGURE 1. Teaching methodologies in Year 1 of the pre-EHEA and EHEA structured BEng Industrial Design Engineering degree at ETSID

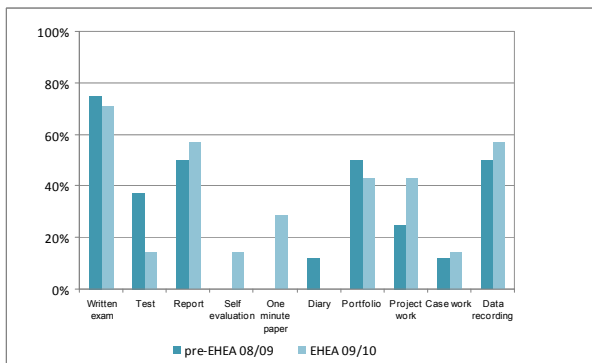


FIGURE 2. Assessment strategies in Year 1 of the pre-EHEA and EHEA structured BEng Industrial Design Engineering degree at ETSID

II. DESCRIPTION

In 2009/2010, the School of Design Engineering (ETSID) of UPV implemented the first year of its EHEA structured BEng Industrial Design Engineering degree.

According to the EHEA requirements, active learning methodologies [6-9] were incorporated and a more significant use of tutorial, cooperative and project-based learning was developed as shown in Fig. 1.

On the other hand, the use of written examinations and tests was reduced and other evaluation strategies [10-12] were applied as shown in Fig. 2 (report, one minute paper, self evaluation, project work, case work and data recording).

The aim of this study is comparing the academic performance of first year students of the EHEA adapted study plan during 2009/2010 with those obtained by pre-EHEA students during the previous academic year 2008/2009. This detailed analysis has been performed on the basis of various rates that have been defined for each core subject:

$$\text{Exam attendance rate} = \frac{n^{\circ} \text{ students who take the exam}}{n^{\circ} \text{ enrolled students}} \times 100 \quad (1)$$

$$\text{Performance rate} = \frac{n^{\circ} \text{ pass students}}{n^{\circ} \text{ enrolled students}} \times 100 \quad (2)$$

$$\text{Success rate} = \frac{n^{\circ} \text{ pass students}}{n^{\circ} \text{ students who take the exam}} \times 100 \quad (3)$$

Furthermore, student success in terms of the number of enrolled credits according to the European Credit Transfer and Accumulation System (ECTS) [13] has been determined as well for every student in both degrees:

$$\text{Student success rate} = \frac{n^{\circ} \text{ pass ECTS}}{n^{\circ} \text{ enrolled ECTS}} \times 100 \quad (4)$$

These rates have been calculated for the students enrolled in Year 1 of the EHEA and the pre-EHEA study plans, 138 and 181 students, respectively.

III. RESULTS

A. Subject results

Initially, the academic performance of all the students of BEng Industrial Design Engineering has been analyzed for every subject.

With the above aim, we have determined for every core subject in the first year of both degrees:

- The exam attendance rate.
- The performance rate.
- The success rate.

Table 1 contains the data of the pre-EHEA case during 2008/2009 while Table 2 contains the data of the EHEA case during 2009/2010.

TABLE 1. Exam attendance rates, performance rates and success rates in Year 1 of the pre-EHEA structured degree during 2008/2009

| Subject | Exam attendance rate | Performance rate | Success rate |
|-----------------------|----------------------|------------------|--------------|
| Physics | 65% | 56% | 86% |
| Mathematics | 74% | 59% | 81% |
| Material Science | 57% | 46% | 81% |
| Engineering Design I | 83% | 69% | 83% |
| Engineering Design II | 85% | 77% | 92% |
| Drawing | 90% | 74% | 82% |
| Fundamental Design | 88% | 88% | 100% |
| Computer Science | 87% | 73% | 84% |

TABLE 2. Exam attendance rates, performance rates and success rates in the first year of the EHEA structured degree during 2009/2010

| Subject | Exam attendance rate | Performance rate | Success rate |
|---------------------------------|----------------------|------------------|--------------|
| Physics | 84% | 69% | 82% |
| Mathematics I | 78% | 71% | 91% |
| Engineering Design I | 77% | 75% | 98% |
| Engineering Design II | 82% | 79% | 97% |
| Drawing | 84% | 73% | 87% |
| Fundamental Design & Creativity | 88% | 88% | 100% |
| Computer Science | 69% | 69% | 100% |

In the EHEA adapted degree, the implementation of a student-centered approach together with compulsory attendance to classroom/laboratories activities has led to an increase of both the exam attendance rate and the performance rate of scientific subjects, i.e. Physics and Mathematics.

However design related subjects display similar rates in both degrees.

These results indicate that changes in the teaching-learning system mainly influence the academic performance of scientific subjects rather than that of humanistic subjects, with traditionally better academic results in this BEng degree.

On the other hand, the success rate of most of Year 1 subjects has improved in the EHEA structured degree with regard to the corresponding pre-EHEA degree.

A closer inspection shows that students who passed the courses got even better grades, as shown by the increasing number of A and B grades in the EHEA degree compared with the corresponding pre-EHEA degree (Figs. 3 and 4).

This result suggests that the combination of a detailed monitoring of students progress by means of formative assessment strategies and their active participation during courses promotes the quality of the teaching-learning process.

B. Student results

In order to complete the analysis of the academic performance of the pre-EHEA and EHEA degrees in Industrial Design Engineering at ETSID, the percentage of students as a function of their success in terms of ECTS has also been determined for both first years.

Fig. 5 displays the pre-EHEA case and Fig. 6 displays the EHEA structured degree.

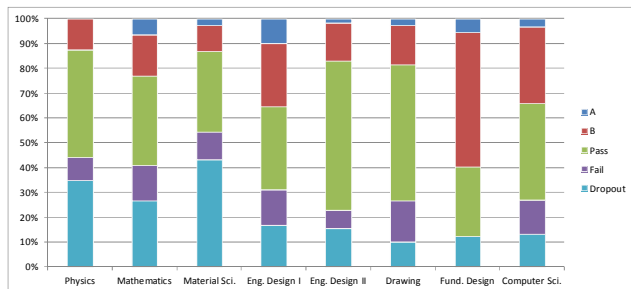


FIGURE 3. Grades in the first year courses of the pre-EHEA structured BEng degree in Industrial Design Engineering at ETSID during 2008/2009

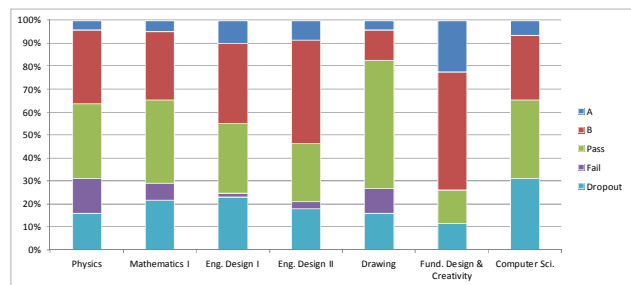


FIGURE 4. Grades in the first year courses of the EHEA structured BEng degree in Industrial Design Engineering at ETSID during 2009/2010

The incorporation of active methodologies together with formative assessment strategies has increased the average success rate from 86% in the pre-EHEA degree to 94% in the EHEA degree. A fast look of the grades obtained by the first year students of both degrees reveals the number of students who failed or dropped out has, in general, diminished.

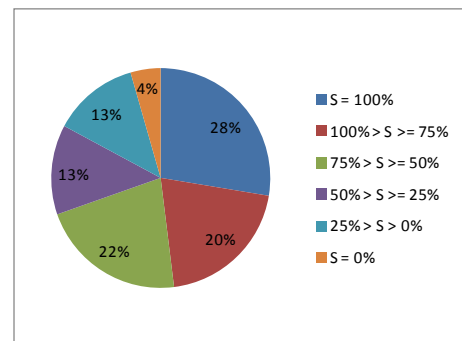


FIGURE 5. Student success (S) in the first year of the pre-EHEA structured BEng degrees in Industrial Design Engineering at ETSID

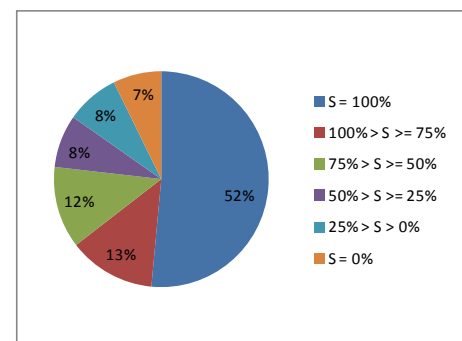


FIGURE 6. Student success (S) in the first year of the EHEA structured BEng degrees in Industrial Design Engineering at ETSID

A 100% success for a given student means that this student has passed all the subjects of which this student has taken the exams.

Results display that while 52% of the first year students of the EHEA structured degree exhibited 100% success, just 28% of the students of the corresponding pre-EHEA degree passed all the subjects they intended to. Furthermore, whereas 30% of the students of the pre-EHEA structured degree passed less than half of their enrolled ECTS, only 23% of the students of the EHEA structured degree failed to pass these ECTS.

This significant improvement of the student success in the first year of the EHEA structured degree confirms the suitability of the teaching and evaluation strategies that have been implemented in this new degree.

On the other hand, 0% success corresponds to the dropout percentage. Results reveal that for both the pre-EHEA and the EHEA structured degrees, the dropout percentage is similar and equal to 4% and 7%, respectively. This indicates that in the first year of the degrees under study, dropout seems to be independent of the teaching-learning methodologies that have been employed.

Similar results have been obtained in previous EHEA adaptation experiences in other BEng degrees at ETSID [14]. It will be therefore convenient to analyze thoroughly these results in order to propose some alternative strategies that might mean a diminishing in this rate in new EHEA structured degrees.

III. CONCLUSION

The keys to the EHEA adaptation lie in the qualitative changes that should be introduced in the teaching-learning process. This has moved from a teacher-centered model to a student-centered model which highlights student participation and commitment. For this reason, it is convenient to assess the impact of these methodological changes in the academic performance in order to identify and promote the best possible educational practices.

This paper has provided a case analysis of the consequences of such changes in the academic results of the first grade students of the EHEA adapted BEng Industrial Design Engineering degree at ETSID and those obtained by the first grade students of the corresponding pre-EHEA degree. This comparative analysis has been performed on the basis of different rates that have been defined for every subject and student.

In general, results have proved that active participation of students in their learning process together with their formative evaluation lead to an improvement of the success rates of most of the subjects. Furthermore, the implementation of teaching methodologies that promote active and dynamic learning of students, such as those followed in the EHEA structured

degree, contributes to their greater engagement. As it has been shown, this has resulted in an increase of the academic performance in scientific subjects rather than in humanistic ones, with traditionally better academic results in this degree.

Moreover, it has also been found that the implementation of a student-centered approach enhances the quality of the teaching-learning process, as proved by the better grades of the first year students of the EHEA adapted degree.

On the other hand, the analysis of the student success rate has revealed that personal success in this new degree has been considerably improved as a consequence of the incorporation of active methodologies and formative assessment strategies. Furthermore, it seems that the dropout percentage is not directly related to the teaching and assessment strategies. In consequence, it has been suggested to further analyze this result, in order to propose some improvement strategies.

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Learning Artificial Intelligence Clip by Clip

Post Class Reflections on the First Online Norvig-Thrun-Stanford-Know Labs Artificial Intelligence Course

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Abstract—The free on-line Artificial Intelligence (AI) course taught by Norvig and Thrun in Fall 2011 is likely to be a game changer in postsecondary education. The huge course enrollment demonstrates that there is a keen interest in this new type of open education, and that no campus-based alternative can be suitable for educating such large numbers of students. The AI course was offered as a sequence of granular, interactive video clips grouped into topics. Homework and exams were video-based as well. This paper provides a critical evaluation of the author's experience as a student enrolled in the advanced track of the AI course. The author is a tenured associate professor at a Canadian medium-sized, research-intensive university. Her expertise lies in Computer Vision, a topic that is closely related to Artificial Intelligence. The paper is based on participatory action research methods.

Keywords: *on-line learning, video-based learning; open education; participatory research methods.*

I. INTRODUCTION

In Fall 2011, Stanford premiered the experimental free online offering of three Computer Science courses: Artificial Intelligence, Databases, and Machine Learning. Our focus is on the Artificial Intelligence course.

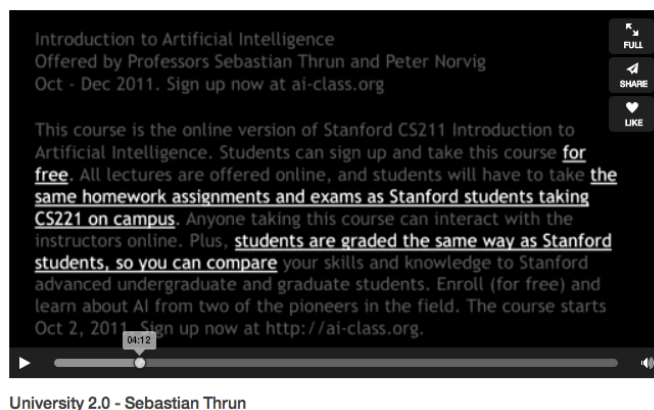
The Artificial Intelligence experiment is likely to be a game-changer in postsecondary education. Three main features differentiate it from previous initiatives in open education:

- The course was free and open to registration for anyone with an Internet connection and an interest in the topic. To account for differences in prerequisite knowledge, the course offered a basic track (no homework, no exams, only completion of quizzes required as a proof of on-line attendance), and an advanced track. Registrants were free to choose any of these tracks.
- For the advanced track, students had to study the same topics, do the same homework assignments and take identical on-line midterm and final exams as the Stanford on-campus equivalent class [1] The grading scheme for Stanford students and on-line student was the same (see Figure 1).

- a statement of accomplishment was emailed to all students passing the AI course. The statement of accomplishment was digitally signed by the course instructors and included a disclaimer that prevents the recipient to claim the course for Stanford credit, or to claim that he/she was registered in a Stanford course.

The Artificial Intelligence (AI) online class [2] was taught during October-December 2011 by two world class AI experts: Sebastian Thrun and Peter Norvig. This experimental offering was made technologically possible by a partnership between KnowLabs and Stanford.

Knowlabs, a start-up company in Silicon Valley, provided new technological solutions for the course delivery. This is how they introduced themselves: *"We're a Silicon Valley-based startup looking to change the future of education by making it more accessible and less expensive. We provide a high-quality online learning experience using interactive videos, intelligent software, mobile apps, and the social web. Our initial launch is online this fall: Introduction to Artificial Intelligence, taught by Sebastian Thrun and Peter Norvig in partnership with the Stanford University School of Engineering. The class is open to everyone at ai-class.com and is run by the technology we are developing for a larger site: **know it**."* (quote retrieved from Schmoller's site [3]. Note: knowlabs.com has now evolved into udacity.com).



University 2.0 - Sebastian Thrun

Figure 1. Snapshot from Thrun's presentation at Digital Life Design (DLD) Conference, Munich 2012 [4]

To summarize, the on-line Artificial Intelligence course offered by Norvig and Thrun in Fall 2011 took on-line education at a new level. This was made possible by new technology for course delivery and grading provided by KnowLabs. The course enrollment was huge: 160,000 students initially enrolled and 23,000 finishing the course on the advanced track according to course announcements [2] and Thrun's DLD presentation [2]). This demonstrates that there is a keen interest in this new type of open education, and that no campus-based education can be suitable for educating such large numbers of students.

This paper provides a critical evaluation of the author's experience as a student enrolled in the advanced track of the AI course. The author is a tenured associate professor at a Canadian medium-sized, research-intensive university. Her expertise lies in Computer Vision, a topic that is closely related to Artificial Intelligence. The paper is therefore based on participatory action research methods. The process of course delivery and the learning experience are analyzed from multiple perspectives (student enrolled in the course, teacher having taught similar courses) with great care for objectivity and non-bias. The main questions guiding this study are as follows:

- What are the pros and cons of video-based on-line learning with respect to traditional in-class learning for computer science courses?
- Can on-line and traditional learning models co-exist?
- Will on-line courses gradually replace traditional courses?

The remainder of the paper is structured as follows. Section II provides an overview of previous initiatives on open education. Section III is dedicated to the analysis of the course content, delivery, and assessment from a teacher's perspective. Section IV provides details about the author's learning experience as a student enrolled in the AI course. The paper ends with a brief overview of recently announced free on-line initiatives and concluding remarks.

II. OPEN EDUCATION

Several major open education initiatives are discussed in this section, namely the MIT OpenCourseWare [5], iTunesU [6], and Khan Academy [10, 11]. The discussion provides some brief historical details for background, then focuses on the distinct educational contributions of each initiative.

A. MIT OpenCourseWare

The MIT OpenCourseware (OCW) project was initiated in 2001, and represented MIT's strategic response to the reverberations of the dot-com phenomenon in higher education [5]. The academic world in the early years of the 21st century was finding itself at crossroads, unable to fully understand the future impact of Internet on the higher education landscape. MIT professor Abelson depicts this state in [5]:

"December 1999 was still full-fledged dot-com euphoria time, and the possibilities for a world-leading university like MIT seemed limitless – and daunting. Three years earlier, the eminent management consultant Peter Drucker had famously

predicted that "thirty years from now the big university campuses will be relics ... The college won't survive as a residential institution,"¹ and murmurs about the displacement of the traditional university rustled throughout the halls of academe."²

The MIT OCW concept was about the free sharing of complete course packages, consisting of lecture materials (slides and sometimes video lectures), assignments, and past exams with their solutions. The OCW framework project was initially established at MIT, but it rapidly grew to include other universities at a global level. According to Carson [5], the OCW consortium was established in 2005 with the mission "to advance education and empower people worldwide through OpenCourseWare". More than 40 Universities worldwide were funding members of the OCW consortium, which estimated to have more than 1700 course packages made available at that time.

The OCW project marked a critical moment in the development of open online education. It defined open education as one of MIT priorities, and in doing so, it steered away from commercial models of on-line education. As Carson states:

"In proposing OCW at a time when the prevailing trends in higher education were toward commercialization and competition, MIT also staked out a new model for the role of universities in the digital environment, one that reflected longstanding commitments in academia to dissemination of knowledge and shared scholarship – a model that would ultimately resonate worldwide."

However, the OCW model does have clear limitations. The shared course materials were developed for traditional class-based courses, therefore their relevance for a global audience was limited. Most of the published course materials had no interactive content. One may argue that the OCW initiative was more relevant for instructors in traditional learning contexts (allowing for the enrichment of their own campus-based courses), rather than for students trying to learn a subject on their own.

B. iTunes University

iTunes University is a free web-based tool provided by Apple [6]. Its latest app-based version, released on January 2012 enables educators to upload audio and video podcasts of their lectures, as well as link these podcasts with other course documents such as handouts, assigned readings, digital textbooks and make their course available worldwide.

iTunes University was first released in 2007, with an initial focus that was similar to OCW. The main effect of iTunesU on higher education was the introduction of podcasting as an educational tool. While audio and video educational materials have existed on the web before iTunesU, podcasting is a distinct phenomenon, characterized by the ease of uploading, downloading, subscription, and sharing of audiovisual content. Most importantly, podcasts are easy-to-consume digital media,

¹ Drucker's quote is from Lenzer and Johnson [7]

² Abelson's quote is also used by Carson [5]

as they can be listened to or watched while commuting, exercising etc.

There are at least two distinct trends in using podcasts in higher education. First, Campbell [7] argues that short podcasts (less than 10 minutes each) can be used in a similar way to movie trailers; they are intended “*not to give away intellectual property but to plant seeds of interest.*” So, podcasts can be used to support and enhance traditional classroom-based education by providing short insights in what the next class will be about, by engaging students in podcasting competitions etc. The podcast is therefore viewed here as an educational pill used for stimulating the student’s interest, motivation, and engagement with traditional classroom-based courses.

Alternatively, a podcast can include the content of an entire class lecture, and therefore it might become a perfect substitute for the lecture. McKinney et al. [8] show via a controlled experiment that using podcasts instead of lectures is a viable alternative. Their study involved undergraduate psychology students who participated either in a podcast condition or in an in-class lecture condition. The lecture condition involved participants listening to a 25 min lecture given by a professor using Powerpoint slides. The podcast condition involved students listening to the exact audio recording of the lecture. Students in both conditions received handouts of powerpoint slides for the purpose of note taking. Their learning was assessed via an exam on the lecture content. McKinney et al [8] found that the students in the podcast condition scored significantly better than their peers in the lecture condition. However, this applied only to students who were taking notes while listening to the podcasts. Their main conclusion is that podcasting is a very viable alternative to class lecture, as long as students maintain the same learning process (note taking while listening). They argue that the main advantage of podcasting over traditional lectures is the ability of students to listen to the podcast on their own time. This argument is also made by Read [9] who points out that podcasts allow for replaying important passages from lectures.

To summarize, the podcasts are still considered most relevant when supporting traditional lecture-based education. It has been shown [8, 9] that when podcasts provide a perfect replica of in-class lectures, the student’s class attendance does not seem to be affected. Podcasting is therefore mostly viewed as an innovative review tool, rather than a replacement for traditional lectures. Moreover, podcasting and open education seem to evolve in parallel tracks. A professor recording her own lectures might or might not post them on an open platform. There is little evidence, as in the case of OCW, of the potential benefits of openly sharing such educational media. Questions have arisen with respect to IP issues on podcast authoring.

However, duplicating lecture content via podcasts or using podcasts as ‘educational pills’ has just scratched the surface of potential educational uses of this new tool. The next section introduces a new way of using audiovisual materials for supporting more active learning strategies in an open education world.

C. Khan Academy

Although Khan Academy [10] is primarily oriented towards K-12 education, we discuss it here because its model is the closest to the AI course. Thrun mentions Khan [4] and its wide-reaching educational videos as an inspiration for changing his own teaching style. Khan Academy offers a free online library of over 3000 short videos covering a diversity of topics (math, physics, chemistry, history, finance etc) as well as over 300 practice exercises.

What is conceptually new about Khan Academy? It does not use videos for motivating students to attend longer lectures; it does not replace traditional lectures with their filmed podcast. Khan Academy rethinks the video podcast as an elemental teaching unit. Each video is about one concept, and it explains it as concisely as possible, so that students can use the new knowledge immediately in practice exercises. The granular videos are organized in a knowledge map, and students get to gradually advance in the map as they master more complicated concepts.

Mastery is key in Khan’s approach to the design of the Academy. He points out that one major flaw in the current educational system is the fact that “*it penalizes you [i.e. the student] for experiment and failure, but it does not expect mastery*”. He further explains this with the analogy of learning how to ride a bicycle:

“I give you a bicycle for two weeks, and a lecture ahead of time. I come back after two weeks. Let’s see, you are having trouble taking turns, you can’t quite stop. You are an 80% bicyclist. And then I say, here is a unicycle...” (transcript from Khan’s TED talk [11], min 8:31 onwards).

In Khan’s view, the traditional K-12 educational system leaves students with many knowledge gaps due to improper teaching and assessment techniques; therefore, it fails to provide students with a solid foundation of basic skills in STEM topics.

With respect to assessment of student’s knowledge and skills, Khan’s academy provides teachers with tools that can very precisely track the student’s progress over time. When students are logged in, the system collects historical data on all exercises that they have attempted, time spent on every exercise, errors made, gradual self-corrections of these errors etc. While this type of data collection is standard practice in financial and marketing fields, it has never been used for educational purposes before. The system can build a very accurate description of the current status of the student’s knowledge without any traditional test being necessary, therefore eliminating the time spent by K-12 teachers on marking.

Perhaps the most significant innovation provided by Khan Academy is related to the new role of video podcasts in the teaching and learning process. Podcasts become the primary source of knowledge rather than a complement to traditional in-class teaching of new concepts. This enables the “class flipping” phenomenon [10], where students are required to watch theoretical videos at home and work on practice problems in class. The teacher becomes a facilitator of the learning process, and steps down from the more central,

traditional role of conveyor of knowledge. The teacher is also aware of all difficulties that students may encounter in their learning (due to the very precise, real-time, on-line ‘portrays’ made available by Khan Academy) and thus can provide highly customized help to every student in need.

To summarize, Khan Academy has elevated podcasts to a new level of educational relevance via three key innovations:

- podcasts are granular and organized in a highly structured manner that enables students achieve mastery; theoretical and practice podcasts are closely interlinked.
- the progress of students engaged in learning with podcasts can be very accurately tracked with monitoring software that is already mainstream in finances and marketing.
- podcasts enable teachers to focus less on delivery of content (lectures) and more on personalized interventions via class flipping.

Are the main principles of Khan Academy applicable or adjustable to higher education? Is it possible or even desirable to foresee a higher education meta-system that functions according to these principles? These are complex questions that might become a hot topic for discussion in the academic world as free online undergraduate courses offered by reputable US Universities multiply.

III. ANALYSIS OF COURSE CONTENT, ASSESSMENT, AND DELIVERY METHODS

The AI course [2] was structured in twenty-two units that closely replicate the typical structure of a traditional lecture-based course. The content of each topic is freely available for viewing by visitors. Homework, exams, and forums are closed for visitors and available only for course registrants; however, homework and exam solutions exist on YouTube, therefore they are in theory accessible to non-registrants as well. Registration to this course was free, however it had to be completed prior to the start of the course (October 2011).

This section provides an analysis of the course content, assessment and delivery methods from an instructor’s point of view. The educational value of the materials and the pedagogical methods are the primary points of discussion. The course content, homework, and exams are discussed in separate subsections.

A. Course content and delivery

Table 1 summarizes data about the topics taught in the AI courses on a weekly basis. Information about who taught each topic, the number of videos that each topic consisted of, and the number of videos ending with a quiz are shown in Table 1.

The videos composing every topic vary in length from 30 seconds to 5 minutes. Short videos typically contain quizzes only. Longer videos introduce usually a new concept. The visual appearance of videos is very informal and lo-tech. According to Thrun [4], all that was needed to record the videos was ‘a camera, a pen, and a napkin’. For answering quizzes/homework/exam questions the student simply has to enter the answer (either a multiple choice or a numerical result)

into a case that is initially specified by the instructor on paper, then activated on screen by software using computer vision technology. An example of student interaction with quizzes is given in Figure 2.

TABLE I. OVERVIEW OF TOPICS TAUGHT IN THE AI COURSE

| Week | Topic | Instructor | Total no. of videos | No. of videos with a quiz |
|------|--------------------------------|------------|---------------------|---------------------------|
| 1 | Welcome to AI | Thrun | 13 | 8 |
| 1 | Problem Solving | Norvig | 38 | 20 |
| 2 | Probability in AI | Thrun | 37 | 29 |
| 2 | Probabilistic Inference | Norvig | 21 | 12 |
| 3 | Machine Learning | Thrun | 37 | 22 |
| 3 | Unsupervised Learning | Thrun | 30 | 16 |
| 4 | Representation with Logic | Norvig | 13 | 6 |
| 4 | Planning | Norvig | 22 | 3 |
| 5 | Planning under uncertainty | Norvig | 27 | 10 |
| 5 | Reinforcement Learning | Norvig | 22 | 3 |
| 6 | HMMs and Filters | Thrun | 22 | 6 |
| 6 | MDP Review | Thrun | 4 | 4 |
| 7 | Midterm | | | |
| 8 | Games | Norvig | 23 | 13 |
| 8 | Game Theory | Norvig | 19 | 10 |
| 8 | Advanced planning | Norvig | 11 | 5 |
| 9 | Computer Vision I | Thrun | 33 | 14 |
| 9 | Computer Vision II | Thrun | 20 | 12 |
| 9 | Computer Vision III | Thrun | 6 | 3 |
| 10 | Robotics I | Thrun | 13 | 8 |
| 10 | Robotics II | Thrun | 11 | 4 |
| 11 | Natural Language Processing I | Norvig | 30 | 10 |
| 11 | Natural Language Processing II | Norvig | 12 | 3 |
| 11 | Optional programming NLP | Norvig | 1 | 1 |
| 12 | Final exam | | | |

From a content-based perspective, the AI course is more broad than deep, as it provides an overview of the many fields related to AI (machine learning, computer vision, games, robotics, natural language processing), as well as a brief introduction to the primary mathematical tools used in AI (theory of probabilities, hidden Markov models, game theory, particle filters etc.). This ratio of breadth over depth is typical for an introductory course. One may wonder though whether linear sequences of granular videos would be effective tools for teaching more specialized, higher-level courses, where interconnections between various topics are more frequent.

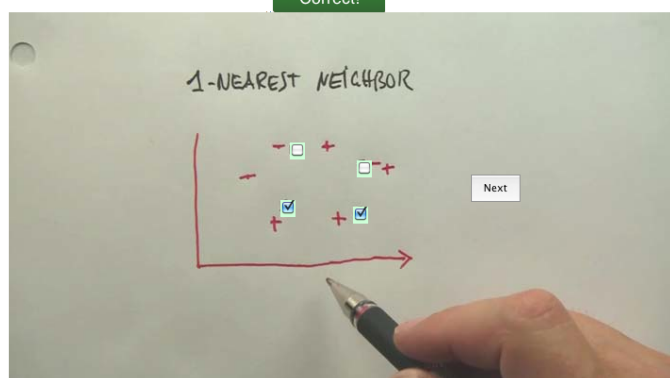
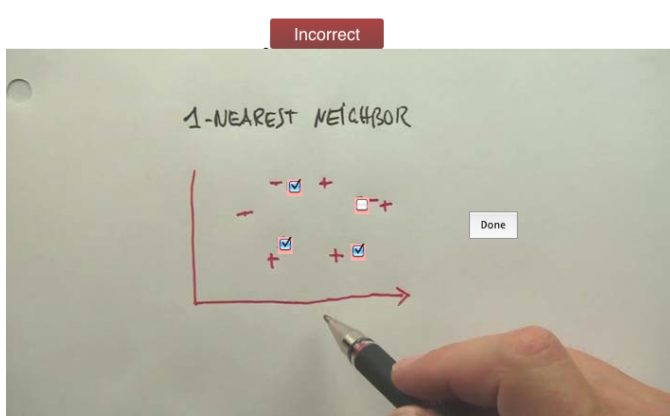
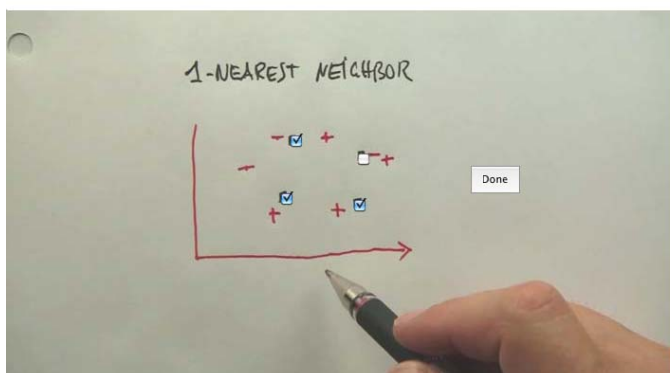
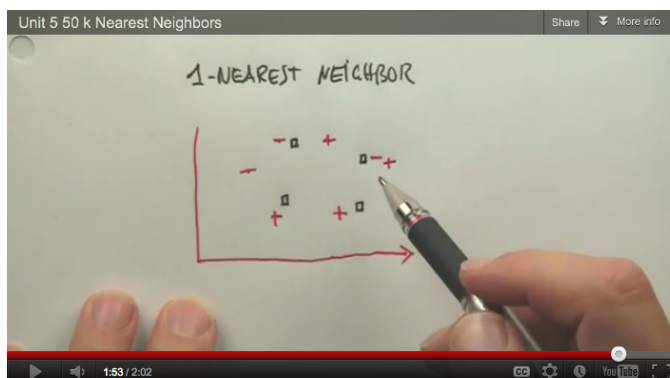


Figure 2. Top to bottom: instructor states the question and draws cases for the student to click on; software creates ‘hotspots’ for each of these cases; student answers by clicking on selected cases; software interprets answer and offers immediate binary feedback. When the answer is correct, the student may proceed to the next video. All snapshots are from [12]

The usage of video clips in the AI course brings elements of novelty with respect to the Khan Academy style. The quizzes are integrated throughout the course (note the large ratio of quiz to non-quiz videos in Table 1). Some quizzes introduce a concept in an intuitive way; an example is the quiz on the nearest neighbor classifier, whose snapshots are shown in Figure 2. Other quizzes are designed as direct applications to concepts already introduced, and they are usually grouped in series with an increasing level of difficulty. Answers to quizzes with explanations are immediately accessible via links provided after the student response has been entered.

The large number of topics covered in the course (see Table 1) reveals that breadth is favored over depth, and this is to be expected in an introductory course. However, there is no clear relation between the topics, no logical ordering. Thrun and Norvig seem to teach on parallel tracks, with virtually no common points. These comments could be of course applicable to traditional in-class courses; however, it is believed that the clip-based nature of the course has a significant impact on the lack of connectivity amongst course topics. The information is encapsulated in video clips in the parallel-serial structure shown in Figure 3, which makes random connections between concepts situated in different topics virtually impossible.

| Topic A | Topic B | Topic C |
|-----------|-----------|-----------|
| Video A.1 | Video B.1 | Video C.1 |
| Video A.2 | Video B.2 | Video C.2 |
| Video A.3 | Video B.3 | Video C.3 |
| Video A.4 | Video B.4 | Video C.4 |
| ... | ... | ... |

Figure 3. Parallel-serial structure of concepts taught in the AI class using video clips.

B. Assessment (homework and exams)

The course was assessed via six homework sets, one midterm, and one final exam. All homework and exams were presented using quiz-like video clips, in a consistent manner to the course delivery.

Homework sets contained questions that were very similar to the quizzes contained in the respective topic. A relatively small number of questions were included in each homework, which provided limited opportunities for practice, as well as a rather incomplete assessment of the student’s knowledge on a particular topic.

The levels of difficulty for midterm and homework were comparable. The final exam contained some non-trivial questions that demanded the ability to generalize concepts learned in class (for instance, counting parameters for a non-binary Bayes network), and to make connections between various concepts (for instance, particle filters and basic probability). This is current practice in the design of final exams; however, the students’ ability to make connections/extensions between/of various parts of the course was not facilitated by the video-based course delivery style.

An interesting collaboration with two German Universities was announced before the midterm. Students enrolled in the on-line AI class were given the opportunity to write the exams in class at either University of Freiburg or Technische Universität München (TUM). For those students passing these exams, certificates of completion of the AI course would serve as certificates of equivalence with the traditional AI class at the University of Freiburg. The announcement can be consulted at <https://www.ai-class.com/home/?page=10>. This type of course equivalence is a “premiere” in the academic world, since it blurs the boundaries between traditional residential education and on-line education.

The overall average student performance in the AI class scored at slightly less than 90%. Compared to traditional class averages, this is extremely high. Thrun talked in [4] about going away from ‘weeder’ course models, which typically fail 20% or more of students initially enrolled. A very high class average is consistent therefore with Thrun’s beliefs. It is difficult to say though whether this high average reflects true mastery of the topics taught. See also next section for some related ideas.

IV. THE AI COURSE FROM A STUDENT’S VIEWPOINT

As a student, the author has definitely appreciated the hands-on teaching approach, and found that immediate experimentation with concepts via quizzes is very engaging, to the point of developing a quasi-addiction to quizzes. The informal, lo-tech aspect of the videos adds an interesting social dimension to the course, which provides the experience of being tutored on an individual basis. This is a very different dynamic from an in-class environment (especially in large classes) where students relate to the teacher as a group. Thrun [4] mentioned the same effect, noting that in-class attendance for the traditional AI course at Stanford had dropped significantly due to the availability of on-line materials.

However, learning on a clip-by-clip basis poses some important challenges with respect to revision of materials. Typical tools that help students engage with teaching materials such as annotating class notes and handouts do not transfer well on video materials. To date, there is no annotating tool for videos. There is no possibility of making explicit interconnections between topics taught in different videos. There is no simple solution for querying the video database with concepts, or for reorganizing it according to new criteria.

The granularity and high consumability of the videos is a mixed blessing. Studying those videos can be squeezed in short spare time periods, which is very convenient for adult learners juggling many responsibilities. However, the author feels that students should not be encouraged towards this type of learning. For a deeper understanding of the course materials, it is preferable to dedicate longer times for study; this might be one of the few arguments in favor of keeping lecture-based teaching (or longer podcasts) alive. The same conclusions apply for exams. While one might be tempted to work on separate small time chunks on a three-hour exam delivered over a three-day period, it is unlikely that the proper level of focus will be reached in this manner. Without proper focus, more difficult questions requiring abstraction and generalization skills will not be handled correctly.

V. LOOKING INTO THE FUTURE

This paper has provided a critical analysis of the first free on-line AI class taught by Norvig and Thrun in Fall 2011. Participatory research methods were used for this study. The paper highlights some strengths and limits of teaching by granular video clips.

The ripple effect of the Stanford experiment in Fall 2011 is currently propagating through elite North-American schools. Thrun has launched his own company www.udacity.com dedicated to free on-line courses in computer science and robotics. A collection of nineteen on-line courses from various universities (Stanford, Berkeley, Michigan) is advertised on www.coursera.com. MIT has launched its own on-line learning initiative MITx (mitx.mit.edu) with one prototype course (Circuits and Electronics) running from March 5 to June 8 2012.

It is difficult to estimate the consequences of this ripple effect on traditional on-campus education. However, it is clear that on-campus education will have to reinvent itself in order to survive in the era of mature on-line teaching technologies and massive on-line learning communities. It is hoped that this paper provides a platform of discussions within the STEM academic community on redefining the roles of on-campus and on-line education, as well as finding their right balance.

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Work in Progress: Redesigned First-Year Seminar Course in Engineering - Delivery, Learning Outcomes Assessment, and Lessons Learned

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Abstract - This paper discusses the delivery of content and rubrics for assessment of learning outcomes in the redesigned version of the critical entry-level course, *First-Year Seminar in Engineering*, for undergraduate engineering students. The *First-Year Seminar in Engineering* at our institution is offered once each year during the fall term. The course comprises 45 to 50 first-year students who will graduate with engineering degrees from four-year programs. The redesign of this course was necessitated by the (1) disparate nature of the content from session to session (2) lack of continuity across sessions, and (3) absence of a common thread to bind the content of the course. For the incoming engineering student to receive both the holistic University experience and develop the ability to learn and retain fundamental engineering principles and practices, the course has been redesigned to incorporate *community-based engineering projects* as the *core theme* of the course. The students formed teams, and maintained *team-based blogs* to document their progress on the engineering project. In addition to the traditional learning outcomes assessment methods (e.g. in-class testing, homework assignments, individual and group reports), rubrics were developed to assess the performance of the students in the engineering projects.

Keywords - Service learning, Course modules, Team blog, Engineering projects

INTRODUCTION

The critical entry-level course at our University, titled *First-Year Seminar in Engineering*, is designed to orient the new student to the University and to introduce engineering as a professional field. In addition, the course seeks to (a) establish the connection with the Liberal Studies Core (b) assist in the transition from high school to university life, and (c) encourage the development of academic, personal, and spiritual aspects of the student's life. The *First-Year Seminar in Engineering* intends to stimulate and enhance the student's interest in and their understanding of engineering.

Unfortunately, the previous offerings of this course failed to deliver the desired learning experiences due to (1) disparate nature of the content and delivery from session to

session (2) lack of continuity across sessions (3) absence of a common thread to bind the content of the course.

The primary aspect of the redesign was to deliver the content in modules which focused on a *central engineering project* comprising *service learning components* and *project-based team-managed blogs*. Service learning is of vital importance in the engineering profession [1], [2] and must be integrated into the engineering curriculum at an early stage of career development. Engineering projects with aspects of service learning are both challenging and motivating to students entering the engineering profession. In addition to teaching the students engineering design and practice in the context of society and values, and instilling the recognition of engineering issues and concerns, engineering project activity with service learning incorporates reflection and collaboration as the critically required facets of engineering education.

In this paper, the approach and implementation of the course redesign based on linking the classroom to the community is discussed and represents the implementation of a work in progress [3] paper presented at the last FIE conference. Section 2 provides details of the approach to course redesign. Section 3 identifies the rubrics adopted for learning outcomes assessment. Section 4 summarizes the delivery of the redesigned course and the process of learning outcomes assessment. The lessons learned are documented in Section 5.

SECTION 2: APPROACH TO COURSE REDESIGN

First, the sessions of the course are reorganized to integrate them around a core theme. The core theme provides the link between the classroom activities in the course and the community through *engineering projects* with clearly identified *service learning components*. Examples of the engineering projects chosen are (a) Solar-panel installation (b) University Community garden fence (c) Roofing materials for energy-efficient buildings, and (d) Vermicomposting bin.

These projects are determined prior to the start of the term in discussions with the Office for Service Learning and the Center for Social Concerns at our University. Funding was provided to each team for their bill of materials. Student

teams were organized and project selections made within the first week (after two sessions) of the term. Figure 1 represents the conceptual bridge between course modules and these projects through *team blogs* for reflection and collaboration.

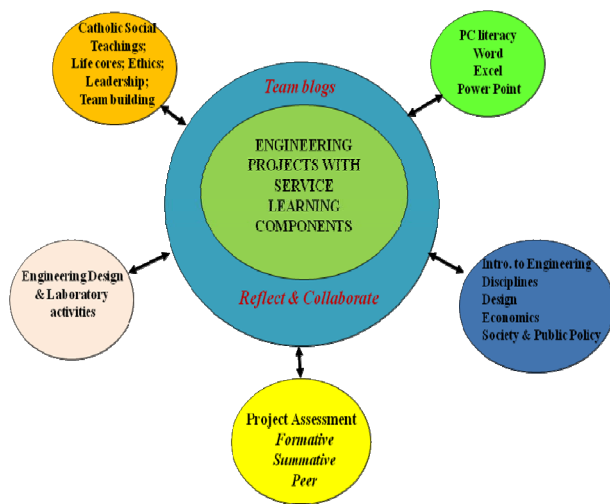


Figure 1. Core theme, course modules, and bridge.

SECTION 3: RUBRICS FOR OUTCOMES ASSESSMENT

The assessment of student performance in the course outcome specific to the service learning experience is based on the following rubrics.

- (a) *Team-based blog*
- (b) *Formative* (in-class presentation – update)
- (c) *Summative* (final report on the core project)
- (d) *Peer or internal* (intra-team performance)

(a) *Team-based blog*

The four categories of assessment of the *team-based blog* are as follows:

1. Overall use of blogs
2. Intellectual engagement with key concepts
3. Personal response to key concepts
4. Engaged writing

(b) *Formative assessment*

The rubric to assess the in-class presentation by each team (progress report) has four categories.

1. Presentation style
2. Team involvement
3. Overall progress
4. Schedule/Timeline provided

(c) *Summative assessment*

The final report submitted by each team at the end of the term is assessed in four categories.

1. Project overview and goals
2. Project description and task plan
3. Discussion of the project tasks completed
4. Conclusions and overall organization of the report

(d) *Peer or internal assessment*

The rubric for each team to assess individual contributions to the team project is based on a scale from 0 (not involved) to 5 (actively involved) for their level of involvement.

SECTION 4: DELIVERY AND RESULTS

The redesigned First-Year Seminar course in Engineering was delivered in the Fall 2011 semester (August 2011 to December 2011) at our University. The following highlights of the delivery are noted.

- Fifty one students were enrolled in the class
- Thirteen teams worked on six service learning projects
- Team leaders received training on the creation and maintenance of team blogs
- Teams completed and submitted *peer assessments* each week
- Teams documented their progress on the project using their team blogs
- Teams provided progress reports as part of the *formative assessment* during the term
- Teams submitted the final report and updated the entries on their team blog page
- *Team blog assessment* and *summative assessment* were completed at the end of the term

SECTION 5: LESSONS LEARNED

The redesigned *First-Year Seminar course in Engineering* successfully met and exceeded the following expectations.

- Relate classroom content to engineering problems in the community
- Understand engineering project constraints and requirements in practice
- Develop leadership and communication skills through team work
- Use the experience to strengthen their preparation for future careers in engineering

The inclusion of innovative instructional and learning tools such as *team blogs* to instill reflection and collaboration has a profound impact on undergraduate engineering education.

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Work in Progress: En route to lifelong learning?

Academic Motivations, Goal Orientations, and Learning Conceptions of Entering First-Year Engineering Students

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Abstract— Although lifelong learning is among the most critical skills required of today's engineering graduates, the complex processes through which individuals develop the attitudes, beliefs, and skills of lifelong learners remains unclear. Instructors have only begun to understand the impacts of academic background, institutional climate, and pedagogy on students' development of the motivations and learning strategies characteristic of lifelong learners. In this ongoing mixed-methods investigation, we draw on existing motivation and self-regulated learning theories to examine how undergraduate students at a small private college and a large public university become more self-directed as they progress through the first two years of their engineering programs. Preliminary findings indicate that first-year students at the two institutions report significant differences in their motivations and goal orientations. Students at the small private college express higher intrinsic motivation and learning orientation, and lower external regulation and grade orientation, compared to students at the large public university. The two groups also show differences in their beliefs about individual versus social learning. We briefly discuss how differences in motivations, goals, and beliefs may impact student responses to early program experiences, and require instructors to tailor their approaches to support the needs of emerging lifelong learners.

Keywords— *motivation, lifelong learning, self-directed learning, self-regulated learning, goal orientation, epistemic beliefs*

I. INTRODUCTION

A capacity for self-directed learning (SDL) and lifelong learning is widely recognized as a critical outcome for today's engineering graduates [1-5], and prior educational research has elucidated what it means for individuals to be self-motivated, self-regulating, and self-determined [e.g., 6,7]. The processes by which teacher-controlled learners *become* self-directed learners, and the roles that pedagogy and learning climate play in these processes, however, remain unclear. Instructors need to gain more insight into the transformation from teacher-controlled to self-directed learners in order to effectively design curricula that support students' emergence as empowered, adaptive learners. To better understand students' growth as self-directed (and eventually lifelong) learners, we initiated a two-year longitudinal study of undergraduate engineering students' development of SDL attributes. We draw upon self-determination and achievement goal theories of motivation [8-15] and social-cognitive frameworks and empirical research in self-regulated learning (SRL) [16-23]. We posit that self-directed learner development is a complex and multifaceted

process shaped by the interaction of specific learning environments with students' learning beliefs, motivations, goal orientations, and metacognitive knowledge and skills. We pose four questions: How are entering students characterized with respect to SDL-relevant attitudes and skills, and how do these attitudes and skills change over a two-year period? What are the gender and institutional differences in entering students' SDL attributes and SDL growth over a two-year period? (4) How do students evaluate learning experiences with respect to their own SDL development?

II. METHODS

The present investigation is a mixed-methods longitudinal study that tracks student SDL development over the first two years of their engineering programs. This paper presents quantitative results from the start of the study, when first-year students were beginning their engineering programs.

A. Participants

Participants in this study are first-year undergraduate students enrolled in engineering programs at two different institutions: a small private college and a large public university. Selection of these schools enables examination of incoming student attributes and SDL development in settings with gender, geographic, learning culture, and academic background diversity. Students in this study experience a variety of pedagogical approaches as they progress through their typical coursework, ranging from open-ended projects to traditional lecture and lecture/lab.

B. Measures and Analyses

This study makes use of several existing instruments to periodically gauge students' SDL-relevant attitudes and skills. **Academic motivations** are measured using the Academic Motivation Scale (AMS) [24]. Based on Deci and Ryan's self-determination continuum [8], the AMS measures *contextual level* motivations, i.e., students' general attitudes toward school and learning, on a 7-point Likert scale (1=corresponds not at all, 7=corresponds exactly) [25-27]. **Goal orientations** are evaluated using the Learning Orientation Grade Orientation (LOGO-II) survey [28-29], which measures college students' predominant attitudes and behaviors with regard to learning, testing, and grading. LOGO-II uses a 5-point Likert scale (1=strongly disagree, 5=strongly agree) and provides learning orientation (LO) and grade orientation (GO) scores

in two parts: (1) academic attitudes and (2) observable behaviors. **Conceptions of learning** are characterized using an adapted version of the Learning Inventory, an instrument that uses a 4-point scale (1=first item agreement, 4=second item agreement) designed to measure conceptions of learning in five areas: (1) external versus internal regulation, (2) reproductive versus constructive knowledge, (3) individual versus social learning, (4) fixed versus dynamic ability, and (5) tolerance of uncertainty [30]. Descriptive statistics were compiled for all survey data, and across-institutional differences were analyzed via independent samples t-tests.

III. PRELIMINARY RESULTS AND DISCUSSION

A. Academic Motivations

As shown in Table I, both of the first-year student groups report generally positive academic motivational orientations, with high intrinsic motivation (IM) and identified regulation (IR) scores, and low amotivation (A) scores. Despite the generally positive AMS findings, the two groups do show statistically significant differences in their motivational orientations. Students at the large public university indicate lower intrinsic motivation and higher external regulation (ER) compared to students at the small private college. Since external regulation is a type of extrinsic motivation associated with attaining rewards or avoiding punishments, the high ER at the large public university suggests that these students could benefit from assistance in transforming extrinsic inputs into personally endorsed, or “internalized,” values and self-regulations [8]. For example, instructors in this setting may help students shift to more autonomous motivations by avoiding excessive external pressures, emphasizing mastery learning, encouraging peer collaboration, and supporting the pursuit of student-endorsed interests or values [31].

TABLE I. ACADEMIC MOTIVATIONS OF ENTERING FIRST-YEAR ENGINEERING STUDENTS.

| AMS Subscale | Small Private College (N=33) | | Large Public University (N=22) | | P-value |
|------------------------|------------------------------|------|--------------------------------|------|-----------------|
| | Mean | SD | Mean | SD | |
| Intrinsic Motivation | 5.95 | 0.83 | 5.38 | 1.31 | .05 |
| Identified Regulation | 5.69 | 0.91 | 5.55 | 0.95 | ns ^a |
| Introjected Regulation | 3.66 | 1.63 | 3.84 | 1.68 | ns |
| External Regulation | 4.25 | 1.56 | 5.34 | 1.10 | .007 |
| Amotivation | 1.24 | 0.54 | 1.48 | 1.20 | ns |

a. ns = not significant

B. Goal Orientations

The LOGO-II results (Table II) indicate that both student groups are more learning oriented than grade oriented, in both their academic attitudes and observable behaviors. The two participant groups do, however, show significant differences in their goal orientations. Students at the small private college report extremely high LO attitudes, and high LO behaviors, indicating that these students generally find learning fun; they have a positive regard for instructors and a negative regard

for easy, but irrelevant, material; and they have positive feelings for formative feedback over evaluative grading. Relative to the small private college group, students at the large public university report lower LO and higher GO attitudes and behaviors, which may indicate that these students have a reduced valuation of ungraded assignments; a stronger tendency to resent material and testing of topics not covered in class; and a stronger tendency to view grades as the basic reason for learning [29].

TABLE II. GOAL ORIENTATIONS OF ENTERING FIRST-YEAR ENGINEERING STUDENTS.

| LOGO-II Subscale | Small Private College (N=33) | | Large Public University (N=22) | | P-value |
|--------------------------|------------------------------|------|--------------------------------|------|---------|
| | Mean | SD | Mean | SD | |
| LO: academic attitudes | 4.00 | 0.58 | 3.60 | 0.51 | .011 |
| GO: academic attitudes | 2.69 | 0.39 | 3.36 | 0.55 | <.001 |
| LO: observable behaviors | 3.17 | 0.57 | 2.34 | 0.47 | <.001 |
| GO: observable behaviors | 1.50 | 0.33 | 1.91 | 0.57 | .001 |

C. Conceptions of Learning

Entering first-year engineering students at the two institutions showed similar beliefs about learning (Table III), with no statistically significant differences in their endorsement of external vs. internal regulation, reproductive vs. constructive knowledge, fixed vs. dynamic learner ability, and certainty vs. uncertainty in learning. The only across-institutional difference was found in the individual vs. social learning subscale, with students at the small private college more strongly endorsing peer learning. This finding may have important implications in the classroom, as first-year students at the large public school may initially show a preference for direct instructor guidance over collaborative exploration of problems with their peers.

TABLE III. LEARNING CONCEPTIONS OF ENTERING FIRST-YEAR ENGINEERING STUDENTS.

| Learning Inventory Subscale | Small Private College (N=33) | | Large Public University (N=19) | | P-value |
|--|------------------------------|------|--------------------------------|------|---------|
| | Mean | SD | Mean | SD | |
| External vs. internal regulation | 2.66 | 0.58 | 2.39 | 0.52 | ns |
| Reproductive vs. constructive knowledge | 3.02 | 0.50 | 2.97 | 0.55 | ns |
| Individual vs. social learning | 3.39 | 0.36 | 3.12 | 0.38 | .014 |
| Fixed vs. dynamic ability | 3.57 | 0.31 | 3.43 | 0.32 | ns |
| Intolerance vs. tolerance of uncertainty | 2.91 | 0.29 | 2.77 | 0.47 | ns |

a. ns = not significant

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Work in Progress: Early Prediction of Students' Academic Performance in an Introductory Engineering Course Through Different Mathematical Modeling Techniques

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Abstract—This paper presents our ongoing efforts in developing mathematical models to make early predictions, even before the semester starts, of what score a student will earn in the final comprehensive exam of the engineering dynamics course. A total of 1,938 data records were collected from 323 undergraduates in four semesters. Employed were four different mathematical modeling techniques: multivariate linear regression, multilayer perceptron neural networks, radial basis function neural networks, and support vector machines. The results show that within the five predictor variables investigated in this study, there is no significant difference in the prediction accuracy of these four mathematical models.

Keywords: *Early prediction; engineering dynamics; students' academic performance; mathematical modeling*

I. INTRODUCTION

Early prediction of how well (or how poorly) students will perform academically in engineering courses helps the instructor design and implement early interventions of appropriate instructional strategies to achieve maximum student learning outcomes [1, 2]. The results of early prediction can also stimulate students, especially those academically-at-risk students, to think about and explore effective ways to improve their learning strategies.

Engineering Dynamics is a high-enrollment, high-impact, introductory engineering course that nearly all students in mechanical, aerospace, and civil engineering majors are required to take. The course covers numerous foundational engineering concepts and principles, and encompasses many fundamental building blocks essential for advanced studies in subsequent engineering courses, such as Machine Design, Advanced Structural Design, and Advanced Dynamics [3].

This work-in-progress paper presents our ongoing efforts in developing a set of mathematical models to predict students' academic performance in an engineering dynamics course. The models can make early predictions, at the beginning of a semester or even before the semester starts, of what score a student will earn in the final comprehensive exam of the engineering dynamics course. The predictive models were

developed by using four different mathematical modeling techniques: multivariate linear regression (MLR), multilayer perceptron (MLP) neural networks, radial basis function (RBF) neural networks, and support vector machines (SVM). The inputs of the mathematical models include five predictor variables: a student's cumulative grade point average (GPA), and grades earned in four closely-related pre-requisite courses, i.e., Engineering Statics, Calculus I, Calculus II, and Physics. GPA is a comprehensive measurement of a student's problem-solving skills. The statics grade was included because numerous concepts of statics (such as free-body diagram, force equilibrium, and moment equilibrium) are employed in dynamics. Calculus I and II grades represent a student's mathematical skills needed to solve calculus-based dynamics problems. The physics grade represents a student's basic understanding of physical concepts and principles behind various dynamics phenomena. The above-described five predictor variables are known before students take the dynamics course. The output of the model is a student's final dynamics exam score.

Extensive literature review showed that no prior literature, except for the authors' own work, exists that compares these four mathematical techniques to model students' academic performance in engineering dynamics. The central *research question* of the present study is: Within the five predictor variables investigated in this study, is there a significant difference in the prediction accuracy of MLR, MLP, RBF, and SVM models? The answer to this research question will help the instructor choose the most appropriate mathematical modeling technique.

II. DATA COLLECTION

A total of 1,938 data records were collected from 323 undergraduates who took dynamics in four semesters: Semesters #1 ($n = 128$), #2 ($n = 58$), #3 ($n = 53$), and #4 ($n = 84$). The majority of the students were either from the mechanical and aerospace engineering major (174 students, or 53.9%) or from the civil and environmental engineering major (93 students, or 28.8%). Each student was associated with six

data: the final dynamics exam score and the scores/grades of the above-stated five predictor variables. For 323 students, there are $6 \times 323 = 1,938$ data records. No significant instructional changes were made across the four semesters that influenced the students' final dynamics exam score.

Before entering into a model, all letter grades were converted into numerical values based on the following scales: A = 4.00; A- = 3.67; B+ = 3.33; B = 3.00; B- = 2.67; C+ = 2.33; C = 2.00; C- = 1.67; D+ = 1.33; D = 1.00; F = 0.00. The numerical values of all data were then normalized through dividing the initial value of the data by its maximum possible value in its same category. The purpose was to avoid the cases in which one variable received a high or low weight due to its initial low or large scale of measurements.

III. MATHEMATICAL MODELS

The full dataset collected in Semester #1 was used to develop mathematical models. Multivariate linear regression (MLR) generated an explicit prediction formula:

$$\text{Final dynamics exam score} = 0.022 + 0.715 \times \text{GPA} + 0.034 \times \text{Statics score} - 0.063 \times \text{Calculus I score} - 0.077 \times \text{Calculus II score} + 0.204 \times \text{Physics score} \quad (1)$$

As seen from Eq. 1, the five predictor variables have different effects on the final dynamics exam score. The commercial software package SPSS and MATLAB codes were employed to develop MLP, RBF, and SVM models. The default value of relevant parameters in SPSS, such as the minimum relative change in training error, the minimum relative change in training error ratio, and the maximum training epochs, were adopted to optimize MLP/RBF models. Because the algorithms were complex [4], no simple mathematical equation can be provided in this paper to show what the MLP, RBF, and SVM models look like.

IV. COMPARISON OF PREDICTION ACCURACY

The models developed based on the dataset collected from Semester #1 were validated using the datasets collected from the other three semesters. Two criteria were used to compare prediction accuracy: (1) The average prediction accuracy (APA): It indicates on average, how well a model predicts final exam scores of all students as a whole in the class. (2) The percentage of accurate predictions (PAP) among all predictions: It is calculated as the number of accurate predictions divided by the total number of predictions. An accurate prediction is defined as the prediction in which the predicted value is within 90~110% of the actual value.

Tables I and II show the comparison of the four mathematical models in terms of APA and PAP, respectively. As seen clearly from Tables I and II, within the five predictor variables investigated in this study, there is no significant difference in the prediction accuracy of the four mathematical models. The four-semester average of APA varies slightly within 2.1% (between 86.6% and 88.7%). The four-semester average of PAP also varies slightly within 2.0% (between 52.9% and 54.9%).

TABLE I. COMPARISON OF THE AVERAGE PREDICTION ACCURACY

| Model type | Sem. #1 | Sem. #2 | Sem. #3 | Sem. #4 | Four-sem. average |
|------------|---------|---------|---------|---------|-------------------|
| MLR | 88.6 | 90.1 | 87.8 | 88.1 | 88.7 |
| MLP | 88.6 | 90.1 | 87.6 | 88.0 | 88.6 |
| RBF | 88.1 | 90.0 | 87.4 | 86.7 | 88.1 |
| SVM | 80.4 | 90.6 | 87.3 | 87.9 | 86.6 |

TABLE II. COMPARISON OF THE PERCENTAGE OF ACCURATE PREDICTIONS

| Model type | Sem. #1 | Sem. #2 | Sem. #3 | Sem. #4 | Four-sem. average |
|------------|---------|---------|---------|---------|-------------------|
| MLR | 54.7 | 62.1 | 49.1 | 53.6 | 54.9 |
| MLP | 54.7 | 60.3 | 45.3 | 51.2 | 52.9 |
| RBF | 50.8 | 62.1 | 49.1 | 51.2 | 53.3 |
| SVM | 56.3 | 65.5 | 47.2 | 47.6 | 54.2 |

V. IMPLICATIONS AND DISCUSSIONS

The above results imply that if one intends to make early prediction of students' final dynamics exam scores, s/he can use any mathematical model, e.g. the simplest model (i.e., the MLR model shown as Eq. 1). That model has a good average prediction accuracy of more than 80%. However, the percentage of accurate predictions is still low (around 50%). This means that other important factors must also be considered in the model to increase the PAP. The other important factors would include 1) students' non-cognitive factors (such as learning style, motivation and interest, time devoted to learning, and family background), 2) the instructor's teaching effectiveness (such as teaching style, course management, and preparation for courses), and 3) learning progression in dynamics [1].

VI. CONCLUSIONS

Four mathematical models were developed based on 1,938 data records collected from 323 students in four semesters. The results show that within the five predictor variables investigated in this study, there is no significant difference in the prediction accuracy of the four mathematical models. The results imply that it is possible to predict, with accuracy of more than 80%, the *average* performance of all students based on rather simple models and using easily available data.

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Work in Progress: How do first-year engineering students develop as self-directed learners?

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Abstract— Although self-direction is among the most critical skills required of today's engineering graduates, the complex processes through which individuals develop the attitudes, beliefs, and skills of lifelong, self-directed learners remains unclear. In this ongoing mixed-methods investigation, we draw on existing motivation and self-regulated learning theories to examine how undergraduate students at two institutions develop as self-directed learners during their first two years of their engineering programs. Preliminary findings indicate that both groups of first-year students make progress as self-directed learners, even after their first semester of college. However, the data indicate marked differences in specific areas of self-directed learner growth at the two institutions. Compared to those at the large public university, students at the small private college report stronger learning goal orientations, help-seeking behaviors, and metacognitive strategy use. We discuss how the learning opportunities and environments may contribute to these differences in learner development.

Keywords: *lifelong learning, self-directed learning, self-regulated learning, goal-orientation, help-seeking, metacognition*

I. INTRODUCTION

A capacity for self-directed learning (SDL) and lifelong learning is widely recognized as a critical outcome for today's engineering graduates [1-5]. Prior research characterizes self-directed learners as those who possess the motivation, or *will*, to engage in learning, as well as an array of behavioral, cognitive, and contextual *skills* that they may readily deploy in the learning environment [6-12]. The processes by which students *become* self-directed learners, and the roles that pedagogy, learning climate, and classroom environment play in these processes, however, remain unclear. This study poses several questions related to SDL development: How do the SDL skills and attitudes of engineering students change during their first two years at college? What causes these changes to occur? What experiences and classroom conditions best promote self-directed learner development? By examining *how* and *why* students progress from teacher-controlled learners to autonomous learners, we hope to inform the design of curricula that better facilitate SDL growth.

II. METHODS

As part of a larger mixed-methods longitudinal investigation that tracks students' SDL development over two years, this study uses qualitative methods to explore shifts in

SDL attitudes and skills in the first year of engineering programs, and to gain insight into *why* the shifts occur.

A. Participants and Environments

Participants in this study are first-year undergraduate students enrolled in engineering programs at two institutions: a small private college and a large public university. The *small private college* emphasizes project-based learning and peer collaboration. In their first term, students at the small private college complete a common set of technical courses and one humanities course, all of which are graded as "pass-no credit." First-year students at the large public university complete a one-credit hands-on engineering project along with a range of more traditional introductory courses offered outside of the engineering school. Students at the large public university receive letter grades in all courses.

B. Data Collection and Analysis

At the start and end of their first term of college, participants in this study responded to open-ended survey questions related to their SDL experiences in high school and college, learning goals, and development as learners. An open-coding method was used to select emergent themes and a framework was created to evaluate individuals' developmental level for SDL-relevant behaviors (effort regulation, time management, help-seeking), cognitions (metacognitive skills and awareness), motivations (extrinsic to intrinsic), and goal orientations. The emergent themes and SDL evaluation framework draw heavily on self-determination, achievement goal, and self-regulated learning theories [8-25].

III. PRELIMINARY RESULTS & DISCUSSION

After only one academic term, engineering undergraduates at both institutions showed signs of SDL skill and attitude development. The qualitative data indicates shifts in students' behavioral self-regulatory strategies at both schools, as well as increased learning goal orientation, metacognitive strategy use, and help-seeking strategy use at the small private school.

A. Similarities Across Institutions

The start of college prompted significant behavioral strategy development at both schools. As one male student from the small private college describes, "*With so much on my plate being on three extra-curricular teams and taking a full course load, I have so little time that I have gotten much better*

at time management... The primary driving force behind this change has been the sheer decrease in the amount of free time I have during the semester. With so much going on all the time and fun activities always going on that I could participate in, I need to really manage my time in order to learn through all of my classes and teams." Similarly, many students from the large public university spoke about improving their time management skills, and they contrasted the college environment with that of high school. As a male student comments, "I have learned that procrastination is the enemy. In high school it's docile and easy to flirt with, without any repercussions. With the speed of the quarter system, it is a luxury that we can no longer afford. This has taught me to, in general, manage my time in a more sane fashion and procrastinate less." Students attribute their behavioral shifts to the increased challenge of the schoolwork and the availability of interesting new opportunities. Time and effort management, two important behavioral self-regulatory strategies [26-29], emerge at both schools and appear to be prompted by an increase in learning activities and workload, combined with feelings of being overwhelmed.

B. Differences Between Institutions

Student responses reflected an emergence of different goal orientations, help-seeking skills, and metacognitive awareness at the two schools.

1) Goal Orientation

Prior education research shows that goal orientations can have a significant impact on self-regulated learning outcomes [e.g.,13,20,30,31]. Students at the large public university reported primarily performance-oriented goals. For example, one male student from the large public university expressed a goal of "getting an A" in his math class. Another male student reported, "The main goal that I set for myself last quarter in calc 4 was to complete all the homework." In contrast, students at the small private college tended to report learning-oriented goals that ranged from course-specific learning to broader, long-term competency development. One female student set a course-level learning goal as follows: "For a particular project in a design class, I set goals to get better at coding and to have a better understanding of motors." Another female student focused on larger competency goals to develop design and creativity skills, and to explore unfamiliar topics: "In [design class], my learning goals were primarily design based. I wanted to improve my ability to solve design issues creatively, effectively, and practically." The more learning-oriented goals set by the small private college students appear to be linked to the classroom environments at that institution. Non-graded, heavily project-based first-semester experiences at the small private college encourage (and sometimes require) students to set their own goals, pursue their own interests, and focus on learning, collaboration, and exploration of personal interests over performance, competition, and instructor constraints.

2) Help Seeking

Help-seeking is a resource management strategy that is important to self-direction [12,23,28,32]. At the large public university, students rarely mention going to others for help; while at the small private college, help seeking seems to be a regular practice. One female student describes the situation in

this manner, "Prior to that semester, I was pretty confident that I could learn a lot by studying by myself. However, through this semester, I learned that I will have to find as much help as I can, rather than struggle and waste time while trying to figure something out. I learned to rely on others more to learn better." Students at the small private college seem to have internalized the importance of help seeking and collaboration as useful strategies that can enhance their learning. They report that both in-class environments (e.g., project-based courses) and out-of-class academic culture influence the development of their help-seeking behaviors. Although the impetus to seek help is typically a desire to reduce stresses on their time, the learning-oriented environment at the college may help students gain comfort in engaging others in finding solutions to problems.

3) Metacognition

Metacognition, a key component of SDL that interacts with motivations and behaviors [26,28,33], appears to develop differently at the two schools. Students at the small private college show a marked improvement in their metacognitive skills after the first semester. One male student described discovering new insights about his own learning process in his first semester, "I've discovered that I am certainly not an auditory learner, preferring instead to learn by doing or experiencing. I would much rather carry out an experiment or simulation than listen to lectures or write out problems." In contrast, students at the large public university engaged in less reflection overall - and those who did, focused their reflection more on their behaviors than their learning. A male student's response illustrates this: "A moment of self-realization really was a large turning point in my outlook towards each class. I thought of myself in the future, and didn't want to look back and regret any decisions I had made regarding my education. Also, my GPA the first quarter was not something to brag about, and that really made me change the way I was approaching my college curriculum." Although this student is taking responsibility for his learning and linking actions to outcomes - signs of SDL development - he remains focused on extrinsic goals such as achieving good grades and avoiding feelings of guilt.

IV. CONCLUDING REMARKS

As early as the first academic term, engineering students at the two institutions appear to develop a range of SDL-relevant goals, behaviors, and cognitive strategies. Students link their SDL attitudes and skills directly to their *learning experiences* and *learning environments* - a promising finding for instructors who seek to design SDL-supportive courses and programs. In the words of students, key factors include the level of *exposure* to self-directed activities (e.g., open-ended projects), the amount of *choice* to set one's own goals and pursue one's interests, the available *resources* and *support* (professors, peer mentors, course assistants, course scaffolding), and the *academic culture* of the school.

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First-Year Engineering Students' Peer Feedback on Open-Ended Mathematical Modeling Problems

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Abstract—Peer feedback is a key component of STEM education, but there is not an accepted pedagogy for teaching students effective critical feedback skills. The quality and nature of current peer reviews must be understood to establish what students need to learn to give effective feedback. This research begins to identify the nature and quality of peer feedback on mathematical models through a mixed-methods approach. The quantitative analysis shows that students typically score models higher than an expert, and the qualitative analysis shows that most students do not address the mathematics used in solutions but rather focus on the presentation of solutions. This research indicates that students need better guidance on how to engage in a more critical feedback process on solutions to open-ended problems. This research also raises some new research questions.

Keywords – *peer feedback; mathematical modeling; first-year engineering; model-eliciting activities*

I. INTRODUCTION

Giving feedback is a process of identifying a gap between current and optimal solutions; then determining methods to advance the current work [1]. Feedback involves analyzing solutions, critiquing current shortcoming, and brainstorming potential improvements. Feedback is necessary to improve the quality of solutions to complex problems and professionals' work. Feedback can be a formal or informal process of critically evaluating one's work by peers or superiors. Formal feedback is a deadline-driven, often criteria-driven, review of a work in progress. This may more commonly be feedback from a supervisor or instructor, but is not limited to feedback from an authoritative figure. Informal feedback is any other feedback that occurs throughout the progression of work, such as team discussions.

The ability to provide formal and informal feedback is an especially crucial skill for science, technology, engineering, and mathematics (STEM) professionals because participation in feedback is so embedded in practice. Giving ethical and professional peer feedback on technical work, acknowledging criticism, utilizing peers' feedback to advance one's work, and helping colleagues professionally advance are recognized by the Institute of Electrical and Electronics Engineering (IEEE) to be important components of professional engineering practice in industry that require effective peer feedback skills [2]. Peer review is a vital step in the dissemination of rigorous research within the STEM research communities through journals and conferences [3]. Without this sharing of research, the STEM communities could not advance. Due to the need for informal and formal feedback in STEM careers, it is vital to

teach future STEM professionals how to give and utilize effective feedback during their undergraduate education. Teaching peer feedback to students not only enables them to give effective feedback, but it also enhances their communication, teaming, and critical thinking skills. All of these skills are nationally and globally recognized to be key for engineering students to develop [4,5] and are important for all STEM students.

Although an ability to provide peer feedback is a vital skill for STEM students to develop, there is a lack of research on how to foster effective learning of this skill. Nelson and Schunn recognize the lack of direction on how to facilitate students' learning of peer feedback skills and state this need cannot be addressed without understanding student performance [6]. They state it is important to research and understand the quality, nature, and impact of current peer feedback. Through an understanding of the gap between current and ideal peer feedback performance, further research can be conducted to determine effective teaching methods to close the established gap. The goal of this paper is to begin to characterize this gap, specifically in the context of mathematical model development.

Much research has already been conducted on the implementation of Model-Eliciting Activities (MEAs) [7]. MEAs are open-ended, authentic, mathematical modeling problems used in the First-Year Engineering (FYE) program at Purdue University [8]. MEAs are utilized in other undergraduate engineering courses at several other universities, including California Polytechnic State University and the University of Pittsburgh [9,10]. Successful MEA implementation requires steps that prompt students to iteratively and critically evaluate their own team's solution (informal feedback) and assess another team's solution (formal feedback). Through previous quantitative research on students' perceptions of their ability to give formal peer feedback on solutions to MEAs, students thought they gave good critiques of peers' work and gave the best advice on the Mathematical Model (MM) component of feedback on the *Just-In-Time Manufacturing (JITM)* MEA [11]. However, analysis of student work on the *JITM* MEA revealed that there were major changes in the mathematical models of only 11 out of 50 teams' solutions (22%) after formal peer feedback [12]. Since students think they are capable of giving good feedback on others' models, but there is a lack of impact on the quality of the solutions following peer feedback, the research team will specifically focus here on peers' ability to give feedback on the MM component of the *JITM* MEA.

The research questions are: (1) What is the accuracy of peer versus expert scoring of the Mathematical Model dimension?, (2) What is the nature of peer feedback on the mathematical aspects of solutions?, and (3) What are the students' perceptions of the quality and nature of the peer feedback received as it pertains to the mathematical aspects of solutions?

II. SIGNIFICANCE OF WORK

Students' learning of how to give effective peer feedback is a key component of their education [1,4,5,6]. Since it is the responsibility of educators to ensure this learning, it is important to begin to determine peer feedback pedagogies to facilitate this education. Once the current quality and nature of peer feedback and students' perceptions of their work is better understood, an effective pedagogy for enhancing students' feedback skills can be determined [6]. Peer feedback pedagogies are becoming even more crucial for STEM learning, not only for teaching students how to develop this vital skill, but also for ensuring an effective learning environment. Today's STEM courses are transitioning from traditional lectures to collaborative and team-based pedagogies, which increases the amount of unmonitored peer interaction. To encourage the most positive team interactions in emerging STEM pedagogies, there needs to be strategies for teaching how to give constructive feedback to mitigate neutral and negative effects that can occur with ineffective feedback [6].

III. THEORETICAL FRAMEWORK

Lesh and his mathematics education colleagues spearheaded the development of the Models and Modeling Perspective (M&MP) [13] and the six design principles that guide the development and implementation of MEAs [14,15]. These principles ensure problems are set in realistic contexts that elicit mathematical model development and require a natural documentation trail. These activities expose students' internal thought processes and conceptual understandings via their approach to solving a given problem [13]. These principles, when paired with engineering practices, are the foundation for the design, implementation, and assessment of MEAs in the FYE program [16]. This work is also informed by the theory of conceptual change [17], which expresses the importance of characterizing students' initial/current behavior in contrast to behaviors we would like them to eventually display.

To understand the complexity of the MEA learning experience, as well as to continue to improve teaching practices, a design research approach is adopted [18,19]. This approach allows researchers to "trace the evolution of learning in complex, messy classrooms and schools, test and build theories of teaching and learning, and produce instructional tools that survive the challenges of everyday practice" [20].

IV. METHODS

A. Settings and Participants

All FYE engineering students (1200-1700 per year) solve authentic engineering problems in teams of 3 to 4 students through MEAs. In Fall 2008, approximately 1200 students completed three MEAs. This study is concerned with the second of these: the *JITM* MEA. For this MEA, teams develop

a mathematical model to rank prospective shipping companies in order of most to least able to meet the client's timing needs based on historical late delivery time data for each shipping company (this MEA is described in greater detail in [21]). All MEAs are solved using the same implementation sequence and assessed using the same *MEA Feedback and Assessment Rubric (MEA Rubric)*. The implementation sequence in this particular semester was: 1) individual problem formulation to understand the problem context, 2) team generation of Draft 1 of their MEA solution, 3) feedback from Graduate Teaching Assistants (GTAs), 4) team revision of Draft 1 to create Draft 2, 5) individual peer calibration, 6) individual double-blind peer review of teams' Draft 2 solutions, 7) team revision of Draft 2 to produce a Final Response, and 8) final grading by GTAs. Peer calibration is training for peer review. Each student individually critiques one prototypical student solution. Then, each student is shown an expert's review of the same solution and is prompted to compare their feedback to that of an expert with the intent to improve their feedback abilities [11].

All of the GTA and peer feedback of team solutions are completed using the *MEA Rubric* which focuses on three dimensions: Mathematical Model (MM), Re-Usability & Modifiability (R&M), and Share-Ability (Audience) [22]. The MM dimension ensures the mathematics utilized address the complexity of the problem. The R&M dimension evaluates a solution's ability to be used by the client for new but similar situations and modified easily by the client for slightly different situations. The Share-Ability dimension considers how easy it is for the client to apply the solution.

B. Data Collection

The implementation of the MEA was supported by a web-based interface connected to a database system. This system was utilized to collect student and GTA work throughout the MEA sequence. To address the research questions, the focus here is on the student peer feedback for the *JITM* MEA. Peer feedback consisted of numeric scores and written feedback for each of the three *MEA Rubric* dimensions. Peer feedback associated with only the MM dimension was analyzed for this study. Within the MM dimension of the *MEA Rubric*, there are three scored items. One item addresses MM Complexity - the evaluation of the utilized mathematics to address the complexities embedded in the problem. To clarify, the evaluator is not looking for a complex solution but rather a simple and elegant solution that addresses what makes the problem difficult to solve. This study focuses on students' ability to apply this one item. The item requires peers to select a level to which the solution addresses the complexity in the problem (Table I) and respond in writing to three prompts. The three prompts ask peers to 1) "summarize in your own words the mathematics used in the procedure", 2) "state the results found by applying the procedure as written to the historical data for the *eight* shipping companies, providing some quantitative results", and 3) "provide constructive recommendations on how to better address the complexity of the problem or eliminate errors".

The peers' scores and responses to the three prompts are the primary source of data analyzed in this paper, and will be

supported by the students' perspectives on the overall peer review process. These perspectives emerged from semi-structured interviews with 24 student participants who shared their experiences with the *JITM* MEA sequence after completing the MEA.

TABLE I. *MEA RUBRIC* MM COMPLEXITY PEER SCORING RUBRIC

| Score | Score Description |
|-------|---|
| 4 | The procedure fully addresses the complexity of the problem. |
| 3 | A procedure moderately addresses the complexity of the problem or contains embedded errors. |
| 2 | A procedure somewhat addresses the complexity of the problem or contains embedded errors. |
| 1 | Does not achieve the above level. |

C. Data Analysis

The peer feedback data collected were analyzed using a mixed-methods approach. The evaluation includes a quantitative assessment of the peer application of the scoring rubric (Table I) and a qualitative assessment of the written peer feedback. The student interviews were qualitatively analyzed. Out of ~1200 students enrolled in the course (~350 teams), students from 11 teams (42 students) participated in the individual student interviews. These 11 teams' Draft 2 solutions were analyzed and scored by an expert grader, who has a high level of understanding of MEA solution assessment and scoring. The expert scored the *JITM* MEA using the MM Complexity criteria as shown in Table II (information only seen by GTAs and professors). These scores were then quantitatively compared to the peers' (28 student reviewers) scores to understand the accuracy of peer scoring using the MM Complexity item of the *MEA Rubric*.

TABLE II. EXPLANATION OF MEA SCORING FOR MM COMPLEXITY

| Score | Description of MM | Mathematics Used in MM |
|-------|-----------------------------------|--|
| 1 | no variability or distribution | central tendency (mean or median) |
| 2 | variability without distribution | variability (e.g. standard deviation) |
| 3 | distribution without a tiebreaker | distribution (e.g. histogram or frequency of one or more values) |
| 4 | distribution with a tiebreaker | same math as score 3 with tiebreaker |

The 11 teams received feedback from 28 students (ranging from 1 to 4 peer review/s per team). The 28 student reviews on the MM Complexity item were qualitatively analyzed to understand the nature of the peer feedback. Coding of the feedback was done to determine which of the three *MEA Rubric* dimensions the students' actually provided feedback on when assessing the MM dimension.

The 24 students' interviews were qualitatively analyzed using an emergent coding scheme [23] to determine the students' perceptions of the peer feedback received and process in general, as well as their perspective of the quality and nature of the feedback that they gave to other teams. When relevant, some of the teams' *JITM* MEA solutions were also analyzed for change to understand the interview responses. It is assumed that this sample group of students interviewed is representative of the population of their fellow classmates.

V. FINDINGS

The quantitative comparison of the peers' and expert's MM scores on the 11 teams' Draft 2 solutions is shown broken down by team in Fig. 1. It shows a range of scores amongst the peers and an overall differing average peer score compared to the expert (Fig. 1). Only 3 out of the 11 teams (Teams 7, 8, & 11) received the same score from each of their two peer reviewers. Out of the 11 teams, no team received the same average peer score and expert score.

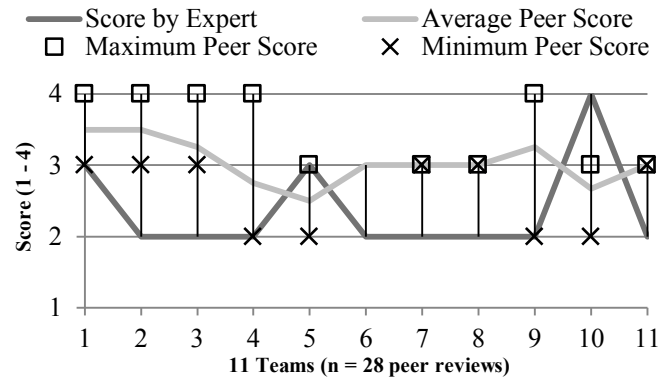


Figure 1. PEER VS. EXPERT SCORES ON MM COMPLEXITY

Table III is a tabular comparison of peer scores to expert scores that shows the distribution of each set and break down of each peer score. The expert scores consist of lower scores (mode = 2; $\mu = 2.4$) and the peer scores consist of higher scores (mode = 3; $\mu = 3.0$). It was found that 19 out of 28 peers rated the MM Complexity of the teams' solutions higher than the expert (Table III). The majority of the peers (82%) scored the teams' solutions a 3 or higher, when the majority of expert scores (8 of 11 teams) were a 2. Also it can be seen in Table III that only 5 out of the 28 peers (18%) scored the MMC the same as the expert.

TABLE III. PEER VS. EXPERT SCORES ON MM COMPLEXITY

| Peer → | | Scores (1 - 4) | | | | # of Teams Expert Scored |
|----------------------------|----------|----------------|---|----|---|--------------------------|
| Scores (1 - 4) | Expert ↓ | 1 | 2 | 3 | 4 | |
| | 1 | | | | | 0 |
| | 2 | | 3 | 13 | 5 | 8 |
| | 3 | | 1 | 2 | 1 | 2 |
| # of Peers that Gave Score | 4 | | 1 | 2 | | 1 |
| | | 0 | 5 | 17 | 6 | |

Results of the qualitative analysis of the peer feedback on the MM parallel the quantitative findings; students struggle to make mathematical model recommendations (Table IV). Even though the math model is the component of the MEA solutions that needs the greatest work (average expert scoring—all on a scale of 1-4—for the 11 teams on Mathematical Model: 2.4, Re-Usability & Modifiability: 3.1, and Share-Ability: 3.3), the students commonly gave praise or commented on the Share-Ability aspect within the MM dimension. In fact, 18 out of 28 peers gave recommendations that related to the Share-Ability

dimension and only 4 out of 28 peers (Peers: 6, 7, 23, & 25) gave a recommendation that related to the MM dimension (Table IV). Only 2 peers gave R&M recommendations related to irrelevant scenarios, so it will not be discussed further.

TABLE IV. PEERS' WRITTEN FEEDBACK AND SCORES ON THE MM

| Team# | Peer# | Peer Review on the MM | | | | Scores | |
|--------------------------------------|-------|-----------------------|-----|---------------|--------|----------|-----------|
| | | MM | R&M | Share-Ability | Praise | by Peers | by Expert |
| 1 | 1 | | | x | x | 4 | 3 |
| | 2 | | x | | | 3 | |
| 2 | 3 | | | x | x | 4 | 2 |
| | 4 | | | x | | 3 | |
| 3 | 5 | | | x | x | 3 | 2 |
| | 6 | x | | | x | 3 | |
| | 7 | x | | | x | 3 | |
| | 8 | | | | x | 4 | |
| 4 | 9 | | | | x | 3 | 2 |
| | 10 | | | x | | 2 | |
| | 11 | | | x | | 4 | |
| | 12 | | | x | | 2 | |
| 5 | 13 | | | | x | 3 | 3 |
| | 14 | | | x | x | 2 | |
| 6 | 15 | | | x | | 3 | 2 |
| 7 | 16 | | | | x | 3 | 2 |
| | 17 | | | x | | 3 | |
| 8 | 18 | | | x | | 3 | 2 |
| | 19 | | | x | | 3 | |
| 9 | 20 | | | x | x | 2 | 2 |
| | 21 | | | | x | 4 | |
| | 22 | | | x | | 3 | |
| | 23 | x | | x | | 4 | |
| 10 | 24 | | x | | | 3 | 4 |
| | 25 | x | | | | 3 | |
| | 26 | | | x | x | 2 | |
| 11 | 27 | | | x | | 3 | 2 |
| | 28 | | | x | | 3 | |
| # of coded written feedback segments | | 4 | 2 | 18 | 13 | | |

Out of 28 peers, 13 gave positive feedback that consisted of direct statements that confirmed the team had addressed the problem complexity, praised the team for a really good model, and/or indicated that the peer was not capable of critiquing the work because the mathematical model was so well developed (Table IV). One example of peer feedback that consisted of only praise is the review from Peer 8: *"I currently have no recommendations because your team seemed to address all aspects of the problem. You explained your mathematical reasoning also."* This review was given to Team 3, who received a 2 on their MM Complexity from the expert.

The peers' MM recommendations that related to the Share-Ability dimension consisted of requests for grammatical fixes, explanations of how to use the mathematics or computer tool, and/or sample calculations. For example, Peer 3 gave Team 2 the following advice related to verbal communication: *"... The information is a little hard to decipher, and I had to read it a couple of times before understanding the process. Perhaps rewrite it to be a little more easily understood. Otherwise it's a good procedure and can be followed."* Although not related to the mathematics used, suggestions similar to these were seen to

be helpful by teams during solution revision. One student interviewee from Team 2 stated: *"I think a lot of what we responded to was the share-ability and how adaptable it was to other people that didn't really know exactly what we were trying to say."* During revision, Team 2 responded to their peers' reviews and focused on Share-Ability, even though they scored a 2 on the MM. Team 2 was not the only team that was given advice to improve their share-ability, while the expert scored the MM at a level 2. Out of the 8 teams that the expert scored at a level 2, only 2 teams (25%) received MM feedback.

Advice on MM Complexity was given by only four peers. These peers took different approaches: Peer 6 identified errors through the use of a specific example, Peer 7 addressed a specific portion of data (outliers), Peer 23 specifically pointed out a missing step (tiebreaker missing), and Peer 25 questioned the current math used in Team 10's solution. Peer 6 wrote to Team 3, *"I think they have taken into account most of the complexities. They're mathematical model is good. I just want to recommend to them that if the standard deviation for a team is 0 and their average time is 300. This means that this team is the winner according to your procedure. But the team mentioned above is consistently late. So do think over it."* Peer 7 wrote to Team 3, *"...However, your model doesn't talk about outliers or what to do with them..."* Peer 23 wrote to Team 9, *"...Also include what to do in the case of a tie breaker..."* Peer 25 wrote to Team 10, *"Does the average really provide a good estimate? What if the range was very big? Is there a way of combining both? Why is percentage on time the deciding factor for ties? Why not the other calculations like standard deviation?"* These are examples of MM recommendations that should encourage teams to re-evaluate their current models. However, Team 10 already had an expert score of 4, so they could not receive a higher score on their MM Complexity. Team 3 and Team 9 still had a lot of room for improvement due to an expert score of 2 on their MM Complexity. It is important to note that the students did not see these expert scores since this analysis was completed later for research purposes only, so this is just an indication of each team's standing at the time they received the feedback.

Even though Team 3 had 2 peer reviews (Peer 6 & 7) that addressed the MM Complexity, their final MM still only consisted of mean and standard deviation, and thus a final score of 2 (Table II). A member of Team 3 reported making significant changes after peer feedback. When asked how Team 3 handled their peer feedback, he reported using two peers' reviews, *"...But the two that were good offered pretty excellent suggestions for our mathematical model and we -- can't remember what this one guy said, but he was a huge part in picking what we wrote."* A review of Team 3's Draft 2 and Final Response revealed that the only change made was the addition of this sentence, *"This allows for the standard deviation to never become zero."* The only change in their model addressed why they did not need to consider the scenario given in feedback from Peer 6.

Team 9, who was given specific advice to add a tiebreaker from Peer 23, did not make any changes to their model and remained at an expert score of 2 on their Final Response. In their solution, the team did address the peer's advice by writing, *"In all calculations in this procedure, carry out all numerical*

answers and calculated data to three decimal places. This is to decrease the chances of having to use a tie-breaker procedure.”

While there was opportunity for both Team 3 and 9 to make significant MM changes, they did not. As a reminder, Team 3 and 9 did receive an average peer score of 3.25, Team 3 received praise in all 4 peer reviews, and Team 9 received praise in half of their peer reviews.

Although there was minimal MM constructive feedback in the reviews, the peers’ summary and results from applying the teams’ mathematical models show adequate effort on the part of the reviewers. The majority of the peers (79%) were successful in accurately summarizing the mathematics found in the models. Also, the majority of the peers (75%) were able to apply the mathematical models and generate the same or similar results as the teams. The interviews confirm this finding - students widely reported generating results using the teams’ mathematical models. Out of the 24 interviewed students (from the 11 teams), 10 students said they focused on the MM dimension in their peer feedback.

Of the 10 students who said they focused on the MM, one student (Peer 21) stated, *“A lot of mathematical stuff was mostly what I liked to focus on, because I’m not too good with the Share-Ability or the Re-Usability stuff. I like math, so I think the majority of my feedback consisted of how they could change around their mathematical model.”* Peer 21 gave Team 9 a score of 4 and the following feedback for the MM Complexity dimension: *“You guys pretty much nailed it on the head as it was very detailed math”*. Team 9 only received a score of 2 from the expert. Peer 21 was one of three peers who was able to generate results, but gave a high score to the team and praised them on their ability to address the complexity of the problem without giving any recommendations. This is one particular peer that stated their feedback focused on the mathematics, but showed an inability to give critical or constructive feedback on that MM dimension.

VI. CONCLUSIONS AND IMPLICATIONS

This mixed-methods analysis provides evidence that students need more guidance on how to give and receive critical feedback on the mathematics used in models. This was thought to be an issue by Carnes, Cardella, and Diefes-Dux (2010) when it was found that students’ solutions do not improve significantly following peer review [12]. The qualitative analysis shows that the students typically understand how to summarize and apply the models, but they lack the ability to give constructive feedback. Even though 42% of interviewed peers explicitly said they focused on the MM, only 14% of peers gave MM recommendations within their feedback. The students may spend the majority of their time summarizing and generating results, but this is not sufficient to prompt change in students’ models. The element of feedback that could lead to improvement is missing from the peer feedback.

There are three potential reasons for the lack of constructive feedback regarding MM Complexity that have been identified. The students may not be able to critique other teams’ models because (1) they do not understand the foundational mathematics of the problem, (2) they do not understand the

concept of constructive feedback, and/or (3) they have a lack of understanding of the established dimensions of the rubric.

Although the students are capable of summarizing and applying the mathematical models, they still may not have a strong enough understanding of descriptive statistics to critique other teams’ models. If the students do not have the appropriate understanding of the domain knowledge, or have not thought through the full complexity of the problem, they could perceive the other teams’ models as having a sufficient process for addressing the complexities inherent to the problem. In this case, the students may have not understood the statistics well enough to advise their peers to progress from looking at the central tendency to the distribution of the data. To address this potential problem, there should be instruction in the classroom on the relevant domain knowledge prior to students participating in the peer feedback process.

One way to determine if students’ lack of statistical understanding is a factor in the effectiveness of students’ reviews is to investigate whether the students’ quality of their own models is related to the quality of their feedback. A study could analyze whether peers who come from teams with high quality mathematical models are better able to give constructive feedback than peers who come from teams with poor quality solutions. For example, a comparison could be made between the mathematical model solutions of Peers 6, 7, 23, & 25, since they were the only peers to give constructive feedback along the MM dimension, and Peers 8, 9, & 21, since they only praised teams on their current models, even though the expert gave the teams a score of 2. This could reveal whether or not having a high quality solution, in terms of math, gives a student a better ability to critically evaluate a solution and give constructive feedback along the MM dimension.

It is also important to understand what peers view as constructive feedback. For example, 10 out of 24 interviewed students specifically stated they focused on giving feedback on the mathematics in the models, but only 4 out of 28 students that gave feedback gave recommendations along the MM dimension. One specific example of this confusion was shown with Peer 21, who discussed a concentration on the mathematics of the solution, but did not give any recommendations to improve the team’s model in the feedback. Clarification in class on the difference between various types of feedback, including summarizing current work, applying mathematics, and constructive feedback to improve work may be needed. Constructive feedback can consist of comments identifying errors or shortcomings and advice on how to improve the current solution. Helping students understand the different levels of feedback may enable them to give more constructive feedback.

A second issue was that peers did not address the appropriate dimension, MM Complexity, within their feedback. To ensure students address all relevant issues within the feedback, there should be clarification in the classroom regarding rubric dimensions prior to the peer feedback process. This could be completed by supplying the class with examples of feedback for the various dimensions and then challenging the students to identify the dimensions that various feedback examples are related to.

It is also important to recognize that effective peer feedback requires two parties: 1) someone to give constructive feedback and 2) someone to utilize the received feedback. It appeared that teams not only had difficulty giving feedback, but also receiving feedback. For example, Team 3 received two peer reviews and Team 9 received one peer review that addressed shortcomings in their model, but both teams only made very minor changes. This could have been caused by the high peer feedback scores (Fig. 1 and Table III) which may have left the teams satisfied with their current solutions. This lack of response could have also been caused by the mismatch between the feedback peers wrote and the scores they gave. For instance, Peers 6, 7, 23, and 25 all gave constructive feedback on the MM Complexity dimension but also gave the respective teams scores of 3 or higher. In contrast, all five peers that gave teams a score of 2 on the MM dimension only gave constructive feedback on the Share-Ability dimension and over half of them included some praise within that portion of their feedback.

Both the highly positive peer scores and mismatch to written feedback could have caused the lack of response to peer reviews. To mitigate this potential problem, peer scoring as part of the feedback process could be removed. If peer scores are a part of the peer feedback process, they should at least be removed from the feedback that the students receive. After the removal of peer scores, analysis of written feedback should be completed to determine the change in peer solutions to determine any positive or negative effects. Furthermore, research will be needed on the interaction between peer reviews and team revisions to understand the lack of change in solutions even when constructive reviews are given.

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Special Session: An Interactive Exploration of Gender and Engineering: Unpacking the Experience

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Abstract—The engineering student experience is understood to differ for male and female students; gendered interactions affect the development of academic and professional role confidence, as well as engineering identity. The purpose of this session is twofold. First, we aim to introduce participants to concepts of gender schemas, privilege, and identity using a range of interactive activities, including brainstorming and structured discussion. Second, we intend to share information about and obtain feedback on a Gender Discussion Exploration Kit, which the participants will be encouraged to review, use, and share at their home institutions.

Keywords- gender; engineering; technology; STEM

I. CONTEXT

The engineering student experience is understood to be different for male and female students, in many ways. For example, fewer women than men are enrolled in engineering programs. Female engineering students who successfully complete their programs have lower self-confidence in their engineering skills than their male counterparts [1]. Women also have lower retention rates in both engineering programs [2] and in professional practice [3]. This lower retention rate is linked to both the lower self-confidence and also to a pervasive sense of not belonging [4]. This is not an exhaustive list; it merely serves to illustrate some of the ways in which gender affects the experience of being in an engineering program and in the profession at large.

While considerable effort has been centered on studying the student experience, the focus of this special session is to provide faculty and other members of the educational community with a model for understanding gendered interactions in academic environments. The session will further attempt to support participants in building an understanding of how these interactions affect the student experience.

This special session has several goals. The first is to engage participants in a discussion-centered learning experience about gendered experiences in engineering education. The second is to provide participants with the tools and confidence to lead such a discussion at their home institutions. To this end, we are developing a Gender Discussion Exploration Kit, which provides the materials and information necessary to facilitate this conversation. The third goal of the session is to introduce

participants to the kit, and to solicit their feedback on its design and content.

II. AN INTERACTIVE DISCUSSION

To facilitate small-group discussion, the participants in this special session will be divided into groups of 4-6. The session will focus on self-reflection, discussion, and sharing among the participants. The content and format of the discussion will be guided by the Gender Experience Discussion Kit, discussed in the next section.

During the session, participants will be asked to explore their own understandings of and relationship to gender by engaging in a range of activities, including the following:

Implicit Awareness Test: A series of images will be shown, and participants will be asked to immediately respond by noting and recording images they associate with women and men. As the goal of implicit awareness tests is to reveal unconscious biases, this part of the session will aim to allow participants to reflect on their own implicit biases [5].

“Unpacking the Invisible Knapsack”: Participants will be introduced to the concept of ‘privilege,’ based on the essay by Peggy McIntosh [6]. They will be asked to “experience privilege” through a set of exercises, to write a list of examples of privilege based on their gender and other dimensions of identity, and to share and discuss these lists.

Gender Schemas: The workshop facilitators will discuss gender schemas, our mental models of the behavior of others, and how these schemas affect social and other interactions [7]. Participants will be asked to provide examples of gender schemas in action and to discuss them in their group.

Identity Threat: The concept of identity threat will be discussed, and participants will be asked to provide examples of identity threat and to discuss them with their group.

After the interactive activities above, participants will be provided with copies of the draft Gender Discussion Exploration Kit materials (which will have been used to structure the session). They will be asked to review the materials and provide feedback on design and content. More details on the Kit follow.

III. THE GENDER DISCUSSION EXPLORATION KIT

For a number of years, we (the facilitators of this special session) have been leading a co-curricular discussion group on gender and engineering education at Olin College, an undergraduate engineering school that is unusual in that it has an institutional commitment to gender parity. (Approximately equal numbers of male and female students are admitted each year.) Several of us have research programs that focus on the engineering student experience at the intersection with the issues of gender, and one of us (DC) regularly speaks to student and industry groups about gender and science/technology. Our dissemination efforts frequently result in participants and audience members reporting that exposure to these ideas—gender schemas, privilege, identity and self-confidence—is transformative: that it changes the way they view interactions they have had within the context of their own educational or professional experience.

We are in the process of distilling our experiences and insights into a downloadable Gender Discussion Exploration Kit that students, faculty, and other community members in education can use to facilitate discussions around gender and technology, as described in the previous section. The fundamental premise behind this Kit is to provide a scaffold that anyone with an interest in the area can use to facilitate these valuable discussions. A goal of this session is to bring our working version of the Kit to participants from a range of institutions, in order to test it and gather feedback.

The downloadable Kit is still in the prototyping stage, but we anticipate that it will consist of a number of components:

- a slide deck that the lead facilitator can use to walk participants through the material;
- printable discussion and activity prompts;
- additional notes and background material;
- handouts for participants;
- feedback forms.

The Kit utilizes structured discussions as a medium to convey and assimilate these ideas (rather than, for example, readings) for two primary reasons. The first is that a discussion format leverages the participants' own experiences; a discussion allows participants to reflect on their interactions in the context of schemas and privilege, thereby reinterpreting their own discourse and that of others. By sharing these interactions, facilitators and participants demonstrate that a) there are a wide range of gendered interactions, b) these interactions are a part of our daily communications, and c) these types of interactions have affected all of us. The second reason is that sharing their experiences in an interactive session allows participants to begin developing a common understanding and awareness of these issues within their community.

The Kit itself will be available online (the proposed URL is <http://gender.olin.edu>) in a range of appropriate formats (e.g., PDF, Keynote, PowerPoint; both US and international paper sizes). We intend to release it under a Creative Commons Attribution-NonCommercial-ShareAlike (CC BY-NC-SA) [8]

license. This would allow users to freely share the materials (with attribution), to use it for non-commercial purposes, and to edit the material as desired, with the caveat that any modified form of the Kit must be made available under the same license. We will encourage people who modify the Kit to share their changes with us; the intent is that the Kit will continue to evolve to meet the needs of its users.

In order to evaluate the impact of the Kit, we will track downloads and encourage users to provide feedback on their experiences. We will also create an online survey in order to gather more detailed information from facilitators. Finally, we will provide a link to an online survey as well as a printable feedback form for participants, so that feedback can be provided to both the facilitator and to us as the Kit creators. Two kinds of feedback will be sought: usability feedback (was everything comprehensible? was it easy to use? did you feel confident using it?) and feedback on the participants' experiences (did the session change your understanding of your experiences in engineering school? if so, how? how do you think this session will affect you in the future?).

IV. CONCLUDING REMARKS

In addition to a demonstrated need for research on gender and the student experience within engineering education environment, there is a great need for providing students, faculty, and other educational and professional community members with the tools to understand how this experience is affected by gender. From research on students, we know that interactions are colored by gender schemas and privilege, which affects the development of academic and professional role confidence, as well as engineering identity and belonging. We hypothesize that providing students (and faculty) with the tools to develop and explore this area will have a positive impact on their persistence and happiness within the engineering environment, both in the university setting and the post-graduate engineering practice.

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Special Session: Raising P-20 Engineers – Nurturing Creativity and Curiosity by Getting STEAMd

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Abstract – The primary goal of this special session is to engage participants in a dialogue regarding two skills critical to the personal and professional development of engineers, creativity and curiosity, and discuss and practice pedagogies for nurturing them in students through STEAM (STEM + art) activities. The emerging STEAM approach emphasizes a hands-on, project-based, interdisciplinary approach to the study of science, technology, engineering, and math (STEM). To emphasize the importance of using engineering design principles to integrate learning in science and math and gain technological literacy, we also refer to this approach as STEAMd. By the end of the workshop, participants will be introduced to key concepts in the engineering design process, the STEAMd initiative, and Dweck's groundbreaking work on "mindsets"; be able to identify methods for integrating engineering design and art activities into STEM studies; and gain experience in using STEAMd activities to promote the development of creativity and curiosity while strengthening critical thinking and problem-solving skills. This special session will be of interest to those involved in P-20 engineering education and in developing a philosophy of engineering education that stresses the development and maintenance of non-traditional skills that are nonetheless critical to the processes of innovation and invention.

Index Terms – Creativity, curiosity, Engineering Teaching Kits, mindset, P-20 engineering education, STEAMd.

INTRODUCTION

Creativity and curiosity are vital to the processes of innovation and invention, and innovation and invention are vital to meaningful and significant outcomes in science, technology, engineering, and mathematics (STEM) and, eventually, to the ability of a society to be competitive locally, nationally, and globally. However, the way in which people perceive "creativity" and "curiosity" – as either innate talents or skills that can be learned – may affect the degree to which they develop and implement truly effective solutions. The implications of these "mindsets," to use Carol Dweck's terminology, are very important not just for the nurturing and support of creativity and curiosity, but to all knowledge, skills, and abilities important to success in engineering.

The primary goal of this special session is to engage participants in a dialogue regarding two skills critical to the personal and professional development of engineers, creativity and curiosity, and discuss and practice pedagogies for nurturing them in students through STEAM (STEM + art) activities. The emerging STEAM approach emphasizes a hands-on, project-based, interdisciplinary approach to STEM studies. To emphasize the importance of using engineering design principles to integrate learning in science and math and gain technological literacy, we also refer to this approach as STEAMd. Engineering design activities will be supported by Engineering Teaching Kits (ETKs). ETKs are self-contained STEM education standards-based units grounded in the constructivist philosophy of education [1], [2] and the principles of guided inquiry and active learning [3] which engage students in a series of age-appropriate engineering design challenges to reinforce selected concepts in math, science, and technological literacy. They were initially developed in conjunction with the Virginia Middle School Engineering Education Initiative (VMSEEI) for students in grades 6 – 8 [e.g., 4 and 5], but have been proven scalable for use by students throughout P – 12.

By the end of the workshop, participants will be introduced to key concepts in the engineering design process, the STEAMd initiative, and Dweck's groundbreaking work on how perceptions of the malleability of intelligence and talent affect achievement; be able to identify methods for integrating engineering design and art activities into STEM studies; and gain experience in using STEAMd activities to promote the development of creativity, curiosity, and a growth mindset while strengthening critical thinking and problem-solving skills.

CONCEPT OVERVIEW

Dweck proposes a social-cognitive approach to the analysis of motivation, (Achievement) Goal Orientation Theory in [6]. According to this theory, a person's motivation to achieve is driven initially by his/her perception of intelligence as either fixed or malleable; this perception in turn affects goal orientation, which is either learning/mastery (goal is to increase competence) or performance (goal is to gain/avoid judgment of competence) in earlier models; and expanded to learning, performance, work-avoidance (goal is to minimize effort), or a combination thereof in later ones. The combined effects of goal orientation and level of

confidence in present abilities affect one's ability to achieve goals. [7] Following research and the maturation and generalization of these findings has culminated in the concept of "mindsets." A mindset is a belief about your skills and abilities. If you believe that a certain skill or ability is an innate talent and no amount of work will alter what you've been given, then you have a "fixed" mindset. If you believe that you can develop a skill or ability through practice and dedication, then you have a "growth" mindset. A growth mindset supports resilience and perseverance, qualities necessary for long-term success. [8]

The following definitions will be used: creativity – the primary components of scientific creativity are convergent, divergent, and logical thinking [9]; curiosity – "an appetitive state involving the recognition, pursuit, and intense desire to investigate novel information and experiences that demand one's attention" [10, p. 159]; innovation – the adaptation or modification of an existing principle, product, or process; and invention – the development of a heretofore unrealized principle, product, and/or process.

ETK BACKGROUND

Since 2002, teams of students and faculty at the University of Virginia (UVA) have developed, tested, and distributed ETKs for use in middle school science and math classes. [4], [5] An ETK is a set of five 50 minute lesson plans designed to teach math and science concepts within the context of engineering design. Lessons are structured to develop understanding of key concepts at both abstract and concrete levels. ETKs promote awareness of and excitement about the nature of engineering. Students develop an appreciation for the tradeoffs involved in the practice of engineering, and how engineering decisions have an impact on society and the environment. Each ETK emphasizes the engineering design approach to problem solving through a series of design challenges, and includes real-world constraints such as budget, cost, time, risk, reliability, safety, and customer needs and demands. ETKs are also designed to integrate other subjects in the curriculum with the exploration of math, science, and engineering concepts.

WORKSHOP AGENDA

The workshop is structured as follows:

- **Welcome, Introductions, and Agenda Review** (10 minutes)
- **Initial Exercises** (20 minutes)
Participants will work through a set of multimedia STEAMd activities designed to pique interest in exercising one's curiosity and creativity through the practice of the engineering design process. ETKs used include *Catapults in Action* (energy and simple machines), *HoverHoos* (hovercrafts: flight, propulsion, and Newton's Laws), *Save the Penguins* (heat transfer and shelter design and construction), and *Under Pressure* (submersibles: buoyancy, drag, and propulsion).

- **Overview of Important Concepts** (15 minutes)
We will review research on creativity and curiosity from the psychology and education literature, and on the STEAMd movement and its demonstrated abilities to encourage the development of creativity and curiosity. Additionally, Carol Dweck's Achievement Goal Orientation Theory, which has matured into the concept of "mindsets," will be reviewed. [2] – [4] A group discussion of experiences and concerns will follow.
- **Follow-on Activities** (40 minutes)
Participants will work in groups with the facilitators to work through additional design activities. We will also discuss scaling the activities to various grade levels. This discussion will include a review of expectations as to cognitive development and skill levels for students in those grades.
- **Concluding Activities and Discussions** (5 minutes)

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Improving Students Understanding of Engineering Concepts Through Project Based Learning

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Abstract—Traditional methods of teaching are falling short in engaging students at higher levels of learning. To adequately prepare students for engineering practice, innovative methods of teaching, learning and assessment are required. Particular emphasis should be placed on enabling students to make the connection between theory and practice. The authors discuss how the approach of “theory to practice” was implemented using project based learning and case studies in two courses at the United States Coast Guard Academy. Students’ feedback and other assessment tools indicated that students were engaged in a higher level of learning and understanding of engineering principles.

Keywords—case study; design, geotechnical engineering; project based learning; reinforced concrete

I. INTRODUCTION

With the current trend in globalization, engineering educators continue to be challenged in preparing graduates who understand global and societal issues, have the ability to solve complex problems and adapt to technological changes, and meet the needs of the engineering profession. To address this challenge, innovative methods of teaching and learning are required with particular emphasis on making the connection between theory and practical application. The traditional teaching method used at most engineering institutions has been lecturing or “teaching by telling” where students are passive spectators. The traditional teaching approach is based on precise, well defined problems and formal definitions presented to students in a one-way, lecture format. Concepts are presented as well-structured subtopics with the connections between them and real world applications left for the professor to develop. In general, the traditional teaching approach is a three-step system of lecturing, assigning of reading and homework, and testing. This teaching approach has been demonstrated to engage a low level of learning as students gather information from lectures and memorize facts and procedures in order to pass exams. Students complete the courses with only a limited understanding of concepts and have limited opportunities to integrate concepts. There is a growing need to modify the traditional style of lecturing and transition to a more balanced format of teaching that involves using practical projects in the classroom.

A vast amount of published literature emphasizes that learning and retention are enhanced by performing real project activities which simulate the actual work environment. This

reinforces the ancient Chinese philosopher Confucius who said: “I see and I forget, I hear and I remember, I do and I understand” [1]. Various learning paradigms have emerged in the past few decades to enhance student engagement and improve learning. Common terms used to describe these paradigms are: *case studies, project-based learning, interactive learning, active learning, role playing, and computer simulations*. These learning paradigms are used by engineering educators to achieve a higher level of learning based on the six levels of cognitive domain in Bloom’s Taxonomy [2]. These levels (lowest to highest) include: (1) the fact-based knowledge, (2) comprehension, (3) application, (4) analysis, (5) synthesis, and (6) evaluation. Educators have considered Bloom’s Taxonomy of learning to be a valid benchmark that measures a student’s level of understanding in the learning process.

In order to enhance student learning at the higher levels of Bloom’s Taxonomy, engineering faculty throughout the nation are engaged in innovative methods of teaching. Dewoolkar reported hands-on inquiry educational modules used in two undergraduate geotechnical engineering courses at the University of Vermont [3]. The four modules initiated in two courses were designed to achieve three objectives: (1) meet the goals of the civil engineering curricular reform (e.g. inquiry-based experiential learning and civic engagement through service learning); (2) reach higher levels of Bloom’s Taxonomy in specific topical areas addressed by the modules; and (3) help meet ABET student outcomes and civil engineering program specific criteria. The modules were conducted within team settings and required students to write formal technical papers and reports followed by presentations. The student self-assessment results and direct assessments of student work indicated that many curricular reform objectives, ABET student outcomes were achieved, and higher levels of Bloom’s Taxonomy were reached through those modules. Chinowsky introduced an alternative approach to construction and management education at the University of Colorado by changing from lecture to project-based format [4]. In project-based learning (PBL), students are challenged with open-ended problems requiring greater application of multiple engineering concepts as well as requiring interaction with outside experts from the construction industry and related professions. PBL teaches concepts through real life problems, creating an association between theory and practice. This association enables students to better retrieve the pertinent theoretical

knowledge when faced with real world engineering problems. Chinowsky proposed a cognitive concept model called the “Knowledge Landscape Approach” that construction engineering educators are encouraged to adopt. In this approach, students are required to evaluate project scenarios with a diverse range of external and internal project variables that require both technical and non-technical skills to be applied during the solution process. This concept supports the PBL perspective that engineering is a knowledge transformation process where solutions are generated by transforming and integrating existing and context-dependent knowledge. Powers and Dewaters reported that the development of project-based units as outreach activities for middle school students in science and technology classes increase student’s awareness and aptitude for math, science, and engineering [5]. These project-based units replicated Clarkson University’s successful efforts in utilizing PBL in educating multidisciplinary undergraduate teams. This approach has been shown to improve the understanding of basic concepts, to encourage deep and creative learning, and to develop teamwork and communication skills.

Akili presented the process of developing a case study and case history course in geotechnical engineering at Iowa State University [6]. The case studies were designed to engage students in a learning process through analysis, open discussion, and ending with evaluations and recommendations. The course focused on engineering design and practice, teamwork and leadership development, organizational management, and communication skills. Case studies were used to extend the learning experience beyond the traditional classroom activities and expose students to the analysis and decisions encountered by practicing engineers. Delatte reported on the integration of failure case studies in the undergraduate civil engineering and engineering mechanics curricula [7]. Delatte compiled details of failure cases and related them to the principles and concepts in various undergraduate engineering courses. He developed resources for faculty that include a book, several publications, and a companion website. It was demonstrated that the study of failure cases enhanced student learning of basic concepts and enabled them to understand the role prevention of failure plays in engineering design. Case studies can tie together technical aspects, ethical issues, procedural issues, and help students engage in a higher level of thinking to synthesize and evaluate the relevant concepts.

Project-based learning and case studies were implemented in two courses (*Geotechnical Engineering Design* and *Reinforced Concrete Design*) at the United States Coast Guard Academy (USCGA) to encourage a high level of intellectual stimulation by challenging students to become effective learners thus improving their competency to solve real world engineering problems. The authors discuss the development and delivery of the projects used in the two courses as well as assessment results of both students’ performance and course evaluations. The integration of case histories and field trips to enhance student learning are also presented.

II. DESIGN PROJECTS AND CASE STUDIES

In the *Geotechnical Engineering Design* course at USCGA, students are required to complete a series of open-ended design projects that are structured to balance the need for fundamental engineering instruction with an infusion of skills required for engineering practice. The course is purely project-based and the projects are intentionally open-ended, requiring students to make decisions and develop alternatives, similar to what is expected in actual engineering practice. Case studies and case histories involving design, construction and legislative disputes were also used to simulate real life engineering practice. This course plays a vital role in the assessment of ABET student outcomes within the Civil Engineering curriculum and is used as a source of assessment data on performance indicators (PI) listed in Table I. The PIs represent the skills, knowledge and competencies students should develop in meeting the corresponding student outcomes. The student outcomes listed in Table I have multiple performance indicators; only the PI assessed in the Geotechnical Engineering course are listed.

TABLE I. PERFORMANCE INDICATOR ASSESSED IN GEOTECHNICAL ENGINEERING DESIGN

| Student Outcome | Performance Indicator (PI) |
|--|--|
| CE01 – Can apply knowledge in the areas of structural, construction, environmental, and geotechnical engineering. | Apply fundamental principles needed to solve a civil engineering problem in the geotechnical engineering subfield. |
| CE03 - Can design a system, component in the context of structural, environmental and geotechnical engineering. | Apply engineering principles and design concepts (including design codes and specifications) to solve a civil engineering problem. |
| ED03 - An ability to design a system component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. | Apply engineering principles and design concepts (including design codes and specifications) to solve a civil engineering problem. |
| ED05 - An ability to identify, formulate and solve engineering problems. | Apply theories, assumptions and principles to the problem by demonstrating the use of relevant formulae and relationships, verify results. |
| ED08 - Understand the impact of engineering solutions in a global, economic, environmental, and societal context. | Clearly articulate and defend choice of an engineering solution. |
| ED11 -An ability to use techniques, skills, and modern engineering tools necessary for engineering practice. | Use computer programs in analysis and design. |

A. Design Projects

The main focus of the *Geotechnical Engineering Design* course is to provide students with a well-rounded exposure to the geotechnical engineering design process. Students are required to complete six projects that build on each other in several modules. The course is structured such that part of the lessons are used to cover basic concepts and design principles, but most of the time is spent discussing and working on the projects either individually or in small groups. Details of the projects and the learning outcomes are presented in Table II.

The projects are designed to lead students through several levels of Bloom's Taxonomy within the cognitive domain. In project 1, students are required to remember previous material learned in the prerequisite course and make the connection with the design process--this is mostly related to the knowledge level of Bloom's Taxonomy. By the completion of project six, students' cognitive learning is expected to have occurred at all six (knowledge, comprehension, application, analysis, synthesis and evaluation) levels of Bloom's Taxonomy. The transition is also summarized in Table II.

TABLE II. PROJECT DESCRIPTION AND LEARNING OUTCOMES

| Project Title | Description | Learning Outcomes |
|--|--|--|
| Project 1: Subsurface Investigation | Students are provided data from a geotechnical investigation including laboratory and in-situ tests results. They were required to prepare a geotechnical report and recommend suitable soil parameters for the design of a foundation system as well as evaluate the adequacy or completeness of the investigation program. If found inadequate, they are to propose a new investigation program to collect the additional data required. Must justify proposal of new investigation including economic implications. Prepare detailed report in acceptable engineering format. | <ul style="list-style-type: none"> • Critique on the quality and completeness of a geotechnical investigation. • Identify and/or determine suitable soil parameters required for design. • Familiarization with minimum standards for tests and boring (amount & depth requirements) • Recommend possible foundation options based on soil properties (no foundation design required at this stage). <p><i>Remembering previously learned materials in Soil Mechanics and making the connection to their relevance in the design process. Low level of critical thinking in evaluating adequacy and suitability of the geotechnical investigation for the proposed construction.</i></p> |
| Project 2: Construction Dewatering | For a proposed construction site, ground water was encountered at shallow depths and a dewatering program recommended lowering the water table in order to construct the foundation. Students are required to design the dewatering system using well-points to ensure the foundation is constructed above the water table. Students are required to select the relevant size of the pipes, soil parameter and determine the capacity of the required pump. They are also required to sketch a layout showing the location of the well-points. | <ul style="list-style-type: none"> • Identify purpose of dewatering • Familiarization with construction dewatering methods. • Exposure to hydrogeology and ground water engineering. • Design of a dewatering system. <p><i>Grasping the importance of dewatering and its role in construction safety. Apply knowledge to complete design process.</i></p> |
| Project 3: Bulkhead Design | Students are required to apply the theory of lateral pressures to design a retaining bulkhead structure for a water front facility for mooring Coast Guard cutters and small boats. Due to tidal fluctuations, reasonable assumptions must be made on the height of the water level to be used in the design. Furthermore, the navigational draft of the largest cutter to be moored must be considered and a dredging depth recommended if required. Some constraints are placed on the soil and environmental conditions. Design must meet stability and other requirements. | <ul style="list-style-type: none"> • Apply the theory of lateral stresses • Identify effect of soil profile and surface on lateral stresses. • Determine net loading on bulkhead due to active and passive lateral forces. • Design a steel sheet-pile bulk head including selection of suitable sheet-pile section to meet allowable stress requirements. • Design an anchor or tie back to meet stability requirements. • Familiarization with design codes. <p><i>Higher level of critical thinking and application of knowledge to complete design process. Evaluation through making judgment based on constraints.</i></p> |
| Project 4: Retaining wall Design | A retaining wall at a Coast Guard facility needs to be rehabilitated or replaced. Students are required to design a new retaining wall and are required to determine suitable dimensions for the wall, evaluate stability of wall by checking factors of safety against overturning, sliding, and bearing capacity failure. Determine the ultimate bearing capacity. Determine the amount of reinforcement for the stem, | <ul style="list-style-type: none"> • Apply the theory of lateral stresses • Identify effect of soil profile and surface on lateral stresses. • Determine loading on wall due to active and passive lateral forces. • Design a reinforced concrete retaining wall to all stability requirements. • Determine the amount and size of reinforcement required. • Determine construction cost. |

| | | |
|---|---|--|
| | heel and toe (as per ACI 318), prepare detailed drawing showing reinforcement. They must also make recommendation to ensure that the problems of the existing wall are avoided as well as recommendation to minimize impact on mission readiness of the station during construction. | <ul style="list-style-type: none"> • Apply ACI 318 reinforced concrete design code. <p><i>Application, analysis and evaluation through making judgment on cause deterioration, choosing correct parameters to complete design, breaking down design problem into components.</i></p> |
| Project 5: Pile Foundation Design/Drilled Shaft Design | Information of the structural load and soil profile is provided and students are required to design a pile foundation system. Design must include the determination of the bearing capacity of pile group system, settlement calculations and a comparison between piles and drilled shafts. Students are also required to evaluate and select the "best" option based on several constraints. Students must compare the results from their hand calculations with those from a pile design software. | <ul style="list-style-type: none"> • Identify soil design parameters. • Apply different static formulas to determine pile capacity. • Identify effect of soil profile & properties on capacity. • Understand the importance of load tests. • Design single pile & pile groups to meet vertical loading requirements. • Determine settlement of single pile & pile group. • Familiarization with methods of constructing drilled shafts. • Design a drilled shaft. <p><i>Application, analysis and evaluation through choosing correct parameters to complete design, breaking down design problem into components. Synthesis by comparing design options and writing a comprehensive report.</i></p> |
| Project 6: Design of Shallow Foundations | The foundation for a new facility requires the use of a mat foundation system for the main building, and isolated footing for a walkway. Students must design the mat foundation for the structural loading using the rigid closed form solutions and one isolated footing ensuring that ACI standards are met. Information on the soil properties are provided; student are also required to determine whether settlement is within acceptable limits as well as check other relevant factors of safety. | <ul style="list-style-type: none"> • Select design parameter based on soil properties • Understand the practical importance of flexural principles and apply them. • Understand the interaction between soil and foundation. • Design a mat foundation. • Design an isolated footing. • Use design codes. <p><i>All six levels of Bloom's Taxonomy in cognitive domain. High level of critical thinking, making the connection with practical applications of knowledge gained in other civil engineering courses. Development of some professional judgment.</i></p> |

In the *Reinforced Concrete Design* course, a multistory building design project was recently created and various teams (3-4 students per team) were assigned the task of designing one of the floor systems. Design components for this project include a one-way slab, various beams and girders, interior and exterior columns along with foundation elements. This project lends itself well to continued development and integration with other courses where students can draw upon their knowledge of foundation design (through the *Geotechnical Engineering Design* course), as well as their knowledge of constructability issues, construction cost estimating, and life-cycle cost analysis (through the *Construction Project Management* course). Detailed assessment of this design project is ongoing, but early indications show that it is providing students with the opportunity to reach the higher levels of the cognitive domain.

B. Case Studies and Oral Presentation

Within geotechnical engineering, understanding the interaction between the soil and the constructed structure is very important. Given the fact that it is difficult to accurately predict the soil behavior and that the soil profile of a proposed construction site is determined by nature, there are usually high risks involved in geotechnical engineering design. Advancement in technology and observation of soil behavior through instrumentation and research has helped geotechnical engineers better understand the interaction between soil and

structure to reduce the associated risks. Some of this knowledge was acquired through the study of situations where something went wrong in the design or construction leading to a failure or safety concerns. In order to engage students in this process of forensic investigation and evaluation, case studies were used. Suitable case studies were extracted from the archives of the *Association of Engineering Firms Practicing in the Geosciences* (ASFE) [8] and from Delatte's book "*Beyond Failure*" [9]. ASFE has an extensive archive of practical case histories, several of which were used to engage students in open discussions on the lessons that can be learned from unsuccessful projects. The cases are not limited to design, but include project and construction management, as well as consultant-client relation issues. "*Beyond Failure*" is an excellent resource in which the case studies are grouped by courses and subfields. Detailed background information and analysis of the failure cases are provided and supplementary material is also available on a companion website.

In addition, there is a field trip component to the *Geotechnical Engineering Design* course to provide an opportunity for students to visit a construction site and witness firsthand construction and constructability issues of a design. The objective of these trips is to reinforce concepts and principles discussed in class through exposure to practical applications. Field trips provide familiarization with equipment, operation, production management and problem solving in real life conditions. Instructors also use the opportunity to emphasize important concepts and applications during the visits.

III. INFORMATION LITERACY

In engineering practice, there are occasions in which the engineer must seek out information in order to successfully complete a project or in some cases to be awarded one. To simulate this and encourage some aspect of information literacy, students in the *Geotechnical Engineering Design* course are required to research a geotechnical topic (new to students) and give a 10 minute presentation to the class. The main objective of this component was to encourage students to research a project involving a soil improvement or ground modification technique and present it as part of the case study discussions. A list of topics was generated by the instructor, but students had the option of presenting on their proposed topic with prior approval from the instructor. The topics must be from a geotechnical journal or magazine article involving a case study and/or practical application of any ground improvement technique. During the presentation, students were expected to address: the site description, problem statement (why was ground improvement used), type of technique, problems encountered, cost (if available), and other design alternatives considered. In the *Reinforced Concrete Design* course, students make presentations early in the course, with the goal of increasing awareness of industry issues and strengthening the tie of theoretical concepts and principles to engineering practice. Each student is assigned a section or a topic covered in the American Concrete Institute (ACI) Building Code to present to the class. Sample topics considered for presentations are: loading, design strength, spacing limits of reinforcement, max/min reinforcement, bearing strength, shear strength, flexural reinforcement,

development length, slenderness effects on compression members, and shear in footings. Students are expected to investigate the underlying purpose of the topic, not just summarize or paraphrase the code, explain the meaning of the topic, its importance to the course objectives, and how it relates to the design process. In addition to the presentation, students are required to provide a handout to supplement their explanations. Through this assignment, students are exposed to the ACI Building Code and topics to be presented in the course.

IV. DESIGN-BUILD-TEST PROJECT

Typical undergraduate civil engineering programs require students to take a course in reinforced concrete design with no laboratory component. Such a course may incorporate the analysis and design of a multistory building or investigate case studies when new topics are introduced. The *Reinforced Concrete Design* course at USCGA incorporated a course requirement that have students design, construct, and test full-scale, reinforced concrete beams with five unique failure modes. This component of the course is performed by teams of students throughout the semester as a term project. Teams of four to five students select one mode to predict the typical failure mechanisms: shear, compression (brittle), transition between compression and tension (brittle and ductile), and one of two modes of ductile failure related to the magnitude of the tensile strain in the reinforcing steel.

Each reinforced concrete beam is assumed to have constant material properties, constant span length of 16 ft, cross-sectional area of 160 in², similar loading conditions, and an overall weight of approximately 2700 lb. Each team designs the reinforcement necessary to demonstrate the assigned failure mode and submit design calculations in a technical report. The design process is iterative with continuous faculty feedback provided after each submittal. Design submittals are required after coverage of singly reinforced beam design, shear design, and doubly reinforced beam design. Three weeks before actual construction of the beams, teams submit material requests to the faculty for the construction of the beams. To ensure adequate lead times for the purchase of reinforcing steel and to provide students with the greatest exposure to different sizes of rebar, a list of preselected reinforcing steel rebar is provided to assist the students in selecting the bar sizes for their selected failure mode. Once reinforcing steel bars become available, the four or five student teams meet to build the reinforcement cages. In the meantime, formwork is built by laboratory technicians for all the beams. On the day of placing the concrete, all the teams come together to place the reinforcement cages in the proper formwork location and help construct all of the beams at the same time. Ready-mixed concrete of a specified strength is delivered by truck and students work together to properly place the concrete in the formwork, finish the surface, prepare standard concrete cylinders for compression testing as well as perform the slump test. Teams take turns to maintain the proper curing schedule of the reinforced concrete beams until testing. Students enjoy working together and seeing their designs come to life.

Throughout the curing process, each team is assigned additional responsibilities to conduct compression tests on three concrete cylinders on the specified date to determine the concrete strength at 1, 2, 4, 7, 14, and 28 days. Prior to beam-testing day (28 days after casting), teams are asked to analyze their constructed beams and calculate the expected failure load. As part of the final technical report, teams are expected to help each other when loading each beam to failure using the full-scale testing apparatus. The testing apparatus is used to apply concentrated point loads at the 1/3 points along its length. Typical failure loads range between 50,000 and 120,000 pounds per beam. During testing, students are able to see first-hand how constructability issues can impact the performance and failure modes of the beams. They also gain a better understanding of the various failure modes for reinforced concrete beams and appreciate the factors of safety built into the ACI concrete building code. Each team submits a final technical report that includes iterations of flexural and shear design, analysis of the constructed beam with expected failure load, test results, conclusions, and recommendations.

In designing the beams each team was required to develop several Microsoft Excel spreadsheets to analyze basic reinforced concrete beams for flexure (singly or doubly reinforced), shear design, and the analysis of a typical reinforced concrete beam-column. Developing these spreadsheets requires a good understanding of reinforced concrete design principles and concepts, ACI code requirements and other factors that influence the design of reinforced concrete members. The spreadsheet allows students to focus on the fundamental logic necessary to complete the assignment.

V. ASSESSMENT AND STUDENT FEEDBACK

In addition to the graded assignments, student feedback was collected using in-class surveys. The focus of the survey was to have students self-assess their understanding of the principles and provide feedback on the effectiveness of the instructional method in meeting the course objectives. Data from the in-class end of semester survey for both courses indicated that approximately 90% of the students felt that they acquired a good to excellent understanding of the concepts and principles. Students felt the project design format enhanced their learning in both courses. Results indicating the level of understanding of the concepts and perception of the classroom instruction are presented in Figures 1 and 2. Additional details of the student feedback and self-assessment are summarized in Tables III and IV. Most of the results from the in-class survey are in agreement with students' performance on the direct measure assessment tools (graded projects and other assignments). The *Geotechnical Engineering* course is fairly new; it was first offered as an elective in 2008 and became a required course in 2009. Since then, other instructors have observed that students performed better on their senior capstone design projects. The PBL components of the *Reinforced Concrete Design* and *Geotechnical Engineering Design* courses have helped students understand the overall design process, improve their comprehension of basic design principles—knowledge and experience required for successful completion of capstone projects.

The structure of the Civil Engineering Program and class sizes at USCGA make it challenging to concurrently use different types of instructional methods (traditional and PBL) in courses offered. Therefore, it has not been possible to use control groups to fully quantify the impact of PBL on intellectual development. However, future plans include developing assessment tools that will be used concurrently in both courses to track the level of students' improvement and understanding of engineering principles and design concepts throughout the semester. One of the common assessment tools will be a grading rubric that will be used to evaluate students' ability to perform the following:

- Define the problem statement, identify constraint and scope of the project.
- Identify objectives and gather information from relevant sources such as codes and specifications.
- Identify and select appropriate analysis, design method(s) and design parameters.
- Consider practical constraints and constructability issues.
- Apply analyze and design methods.
- Prepare professional design drawings and sketches.
- Present details of analysis and design in a professional engineering report.

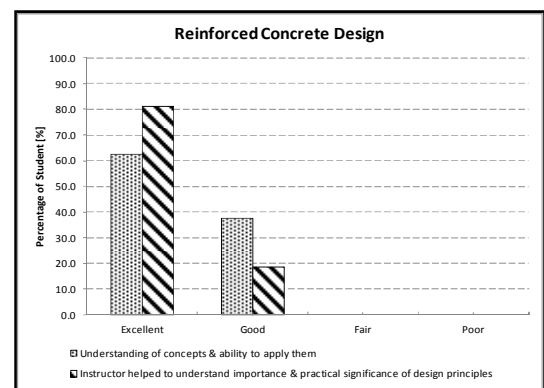


Figure 1. Students' Self Assessment in Reinforced Concrete Design

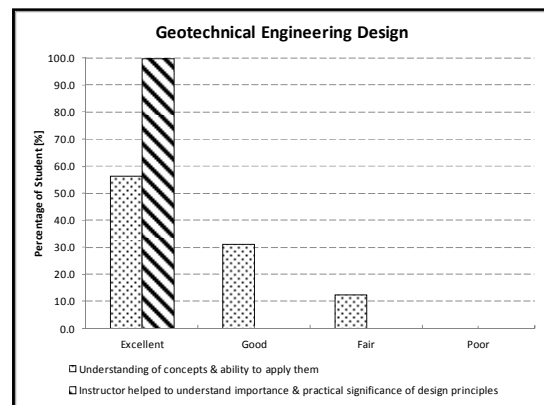


Figure 2. Students' Self Assessment in Geotechnical Engineering

TABLE III. SUMMARY OF STUDENT FEEDBACK IN REINFORCED CONCRETE DESIGN

| Survey Question | Excellent [%] | Good [%] | Fair [%] | Poor [%] |
|--|---------------|----------|----------|----------|
| Understanding & ability to apply concepts and design principles. | 62.5 | 37.5 | 0.0 | 0.0 |
| Instructor helped you understand importance & practical significance of concepts & design principles. | 81.2 | 18.8 | 0.0 | 0.0 |
| Ability to analyze & design reinforced concrete beams. | 56.2 | 37.5 | 6.2 | 0.0 |
| Ability to analyze & design columns. | 62.5 | 37.5 | 0.0 | 0.0 |
| Ability to analyze & design footings. | 18.8 | 56.2 | 18.8 | 6.2 |
| Ability to develop a spreadsheet application to analyze & design reinforced concrete structural members. | 25 | 12.5 | 31.3 | 31.3 |
| Use of engineering codes and design charts. | 47.8 | 37.5 | 12.5 | 6.2 |

TABLE IV. SUMMARY OF STUDENT FEEDBACK IN GEOTECHNICAL ENGINEERING

| Survey Question | Excellent [%] | Good [%] | Fair [%] | Poor [%] |
|---|---------------|----------|----------|----------|
| Understanding & ability to apply concepts and design principles. | 56.3 | 31.3 | 12.5 | 0.0 |
| Instructor helped you understand importance & practical significance of concepts & design principles. | 100.0 | 0.0 | 0.0 | 0.0 |
| Ability to describe relevance of site investigation & determine geotechnical parameters from tests. | 43.8 | 37.5 | 18.8 | 0.0 |
| Ability to select suitable design parameters based on soil profile, construction & other constraints. | 56.3 | 31.3 | 12.5 | 0.0 |
| Ability to analyze interaction between soil & geotechnical structure in a design problem. | 25.0 | 56.3 | 18.8 | 0.0 |
| Ability to apply soil-structure interaction to design. | 25.0 | 56.3 | 12.5 | 6.3 |
| Use of engineering codes & design charts. | 50.0 | 37.5 | 6.3 | 6.3 |

Students were also asked in the end of semester survey to provide additional information on how they felt about the format of the two courses affected their learning. Typical comments for both courses are summarized as follows:

- The projects helped reinforce the concepts presented in class.
- Enjoyed building and testing reinforced concrete beams to failure.
- It helped make the course easier to understand.
- Worked hard and learned a lot of new material.
- I understand more of the concepts when we had example projects.
- The flexible format enhanced the learning experience; using class time on projects helped a lot.
- I enjoyed the projects and the design aspects of this class.
- I thought the open-ended projects were extremely valuable in learning, thinking and applying the concepts.
- The projects were helpful and hands on.

In addition to course feedback, students were asked to complete a survey subsequent to the field trip. This provided students with an opportunity to comment on the effectiveness

of the trip in making the connection between the principles and concepts presented in class and the real world applications. The students' feedback on the field trip survey has been overwhelmingly positive.

VI. CONCLUSIONS

The students' feedback and in-class performance affirmed the effectiveness of the project-based learning and case study review implemented in the *Geotechnical Engineering Design* and *Reinforced Concrete Design* courses at the United States Coast Guard Academy. Through multiple iterations of these courses, students demonstrated a high level of understanding of the engineering principles and design concepts addressed in both courses. The two courses will continue to focus on improving students' abilities to think critically and apply their knowledge of fundamental engineering principles to solve real-world problems. It continues to be a challenge to consistently maintain very high levels of learning due to the diversity and varied educational backgrounds of the student population. Nonetheless, project-based learning and case studies can be adapted to address these generational challenges in students' learning abilities, personality types, and educational experience. This flexibility helps to ensure a larger percentage of the students are actively engaged in their intellectual development and gain practical design experience to better meet the needs of the engineering profession.

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Constructive scaffolding for accessible PBL

Situated meta-critique in the classroom

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Abstract—We reflect on the success of embedding legal, social, ethical and professional issues (LSEPI) into computing courses while at the same time encouraging a "growth mindset" in our students. We review the only compulsory course for our first year computing undergraduates, with a broad range of technical ability, impairment and educational background. We chose problem-based learning (PBL) as a natural fit with contextual demands but also paid special attention to the scaffolding required to make PBL effective with novice learners. Our main PBL element is a final "capstone" activity, in which small multidisciplinary teams of students who have not worked together before, design and deliver a Web-based game inside a week, using techniques and technologies seen during the preceding 12 weeks. This paper describes the approaches taken to practical and tutorial learning events and evaluates the results of the PBL phase. The main contributions of this paper are a) the identification of PBL as a vehicle for delivering generic graduate attributes (GGA), b) the use of PBL with novice learners, and c) the use of situated meta-critique as a constructivist trigger for developing self-reflection.

Keywords Problem-based learning, HCI, growth mindset, first year computing undergraduates, situated meta-critique

I. INTRODUCTION

Building on previous work [1] we reflect on the success of embedding legal, social, ethical and professional issues (LSEPI) into technical courses within our School of Computing, while at the same time encouraging a "growth mindset" [2] in our students. In the UK, state funding of universities is contingent on meeting such needs and this is currently referred to as the "Graduate Attributes" agenda [3] and is one of a number of external drivers for curriculum design. Some of these are **mandated** by the UK government through its Quality Assurance Agency and described as Enhancement Themes¹. These are essentially what a university must conform to. Others are **promoted** by professional bodies such as BCS, The Chartered Institute for IT, who accredit degrees towards achieved Chartered Professional status, or trade bodies such as ScotlandIS, IntellectUK or TIGA, who represent the views of employers, and to whom we must react effectively. Lastly there are areas where individual academics, based on their reflective practice and pedagogical research

interests, can operate ahead of the previous two sets of stakeholders, and the encouragement of a "growth mindset" among students is an example of this proactive approach.

We reflect here on the first three deliveries of a first semester, first year undergraduate course (one sixth of a full year's academic credits). We argue in favor of using PBL to deliver on contextual and discipline-specific demands. We then explore our success in achieving the desired growth mindset, and the extent to which this learning is achieved and retained, reflecting on the notion of "deep learning". First, however, we present some contextual information about the students and the course, before reviewing the literature on problem-based learning, scaffolding to support PBL, and the notion of mindset. We follow this with a description of how we ran the module before reviewing the outcomes and identifying priorities for further development.

II. CONTEXT

A. Learners

"Introduction to Human Computer Interaction", is the only compulsory course for all (typically 200) first year students in the school. These students are diverse - a broad age-range, multiple first languages and nationalities, 10-15% with impairments such as dyslexia or Asperger's syndrome. While most students in a School of Computing anticipate and desire to learn technical subjects, far fewer approach the human aspects of technology with as much enthusiasm. In this module, however, we lay the basis for later work in effective requirements gathering, design, and legal, social, ethical and professional issues (LSEPI). Three years ago, in designing this course, our challenges were to encourage a stronger sense of self-efficacy, to embed basic understanding of LSEPI and to lay the groundwork for achieving the required graduate attributes. At the same time we had to ensure the achievement of the required subject matter learning outcomes. Additionally we had to reverse what was then an unacceptable failure and drop-out rate amongst first year students which stemmed at least partially from a predictable drift in attendance starting around mid-trimester. Our institutional policy of avoiding end-of-trimester examinations for first year undergraduates presented an opportunity to engage in some innovative activities in the final two weeks of the trimester. At that time, the students would be free of any other academic obligations,

¹ www.enhancementthemes.ac.uk contains many publications on this topic

and access to dedicated resources would be much easier with all formal classes having come to an end.

III. LITERATURE REVIEW

A. Delivering “graduateness”

In 1964, Justice Potter Stewart ruling in a pornography case in the United States Supreme Court concluded that “I know it when I see it, and the motion picture involved in this case is not [pornography]” ([12]). Since then the phrase has been debated in legal circles and appropriated in many other contexts. It could equally well be applied to the problem of defining what it means to be a university graduate, a debate that has grown increasing more intense over the last few decades.

Australian academics, in particular, have been influential, and Simon Barrie’s considered approach [13] provides an excellent snapshot of academic opinion at the time. Barrie demonstrated a diversity of opinion among Higher Education (HE) teachers as to what constituted generic graduate attributes (GGA). His framework, summarized in Table 1, divided that opinion into four categories, two of which were further labeled “additive” and the other two “transformative”. The additive view of GGA is that they are transferable soft skills which are essentially distinct from any discipline-specific skills that the student might learn during a course of study at university. The transformative view, in contrast, holds that GGA are integrally connected to discipline-specific skills and allow the student to apply those skills more effectively in context.

Table 1: Generic Graduate Attributes [4]

| Group | Category | Conception of GGA |
|-----------------------|------------|--|
| Additive | Precursor | Generic skills acquired prior to university entry and therefore in advance of discipline-related skills |
| | Complement | Distinct and can be acquired independently of discipline-related skills |
| Transformative | Translate | Facilitate the application of discipline-related skills in the world and acquired in parallel with discipline-related skills |
| | Enable | Are inextricably linked with discipline-related skills and are acquired at the same time |

The diversity of opinion exposed by Barrie, and the challenge in reconciling discipline-specific needs, puts into stark relief the difficulties of attempting to pin down a single list of GGA that all academics would be willing to endorse. Indeed, since the articulation of a classification of perspectives, opinion appears to have diverged rather than converged [14]. Building a consensus around the definition of candidate skills, such as “critical thinking” throws up challenges when cross-disciplinary requirements come into play. Nevertheless, Green et al. [14] provide a strong argument for preferring the transformative view of GGA, which they develop as **specifist** (integrally related to discipline-specific knowledge and skills) and **relativist** (necessarily different from one discipline to another).

Despite the seemingly intractable problem of achieving academic consensus over the definition of GGA, universities are nevertheless under pressure to articulate their approach to

delivering employable graduates. Nowhere is this more clearly exemplified than in Scotland where the Quality Assurance Agency for Higher Education, Scotland (QAAS) maintains a rolling program of work whose aim is the enhancement of the student learning experience in Scotland. Through a series of “enhancement themes” Scottish universities contribute to reflective and developmental projects, the most recent of which, entitled “Graduates for the 21st Century” (G21C) ran between 2008 and 2011. A concluding summary of the G21C theme makes specific reference to need to allow HE institutions and subject disciplines to fine-tune the outputs and approaches [3], and the set of GGA identified during the theme – shown in Figure 1 – is therefore necessarily couched in general terms. The final framework based as it is on current existing practice demonstrates a balance between the managerial need for articulation of goals and the complex nature of the area.



Figure 1: Scottish GGAs [3]

B. Psychological mobility

Several of the attributes identified in [3] are concerned with the graduate’s responsibility for on-going personal development, typified by “lifelong learning”. This growth-oriented perspective, however, is not one that can be assumed to exist in all students and often needs to be actively cultivated during a higher education program.

Indeed, encouraging students to take a “deep” approach to learning rather than a “surface” approach has been a recognized problem for higher education for around 30 years [15]. According to a study at an Australian university [16] school leavers demonstrated a tendency towards a surface approach compared to mature students, and the authors suggest that school leavers may be more syllabus-bound and rely more on rote learning because of their recent secondary school experience. This observation accords well with Perry’s (1970, cited by [17]) finding regarding the development of a student’s conception of knowledge over time. According to Perry, the conception of knowledge shifts through a series of recognizable stages from the dualistic right-or-wrong perspective at one extreme to a commitment within relativism at the other.

In this context, the role of the tutor is to manage the student's transition from a simplistic understanding of the subject through to the more sophisticated understanding expected of the university graduate. However, attempts to modify the learning environment to promote the deep approach have met with mixed results [18]. One explanation for this may lie in the development of the deep/surface distinction articulated by Dweck [19]- that a psychological disposition towards an entity or incremental self-theory can be identified in children as young as 10, and this disposition can be reinforced according to the learning goals they are set during their school years, and the feedback they receive. Those with an entity self-theory, or "fixed mindset", hold the belief that intelligence is fixed, and that learning consists of the accumulation of essentially independent facts, while those espousing the incremental self-theory, or "growth mindset", believe that intelligence is malleable and that learning consists of mastering the subject. Mindset can thus be interpreted as a precursor to a particular approach to learning, and the university tutor may have considerable work to do to instill a growth mindset before a deep approach can be expected to emerge.

Dweck's view is that learners' beliefs about learning, knowledge and their own abilities directly impact their selection of approach to learning, and by extension on the quality of that learning. A similar relationship between beliefs and behavior was articulated by Bandura, in his work on self-efficacy [20]. He hypothesized that a strong sense of self-efficacy – a belief in one's own capabilities to carry out the behavior required to deliver a particular outcome – predicts a greater expenditure of effort to achieve an outcome and the sustaining of that effort over a longer period. Both of these behaviors could be used to characterize a deep approach to learning in a student making sense of subject material. A low sense of self-efficacy in contrast would predict a greater tendency to give up on a difficult task. Dweck [19] calls this the "helpless response" exhibited by students with a fixed mindset compared to the perseverance or "mastery-oriented response" of those with a growth mindset. In his original work, Bandura suggested that self-efficacy could be enhanced by persisting in activities which appeared initially threatening, but which eventually proved to be safe. Studies of self-efficacy among university students have borne out this prediction, indicating that it is not only possible to influence self-efficacy through intervention, but also that the most effective way to do so was through "enactive mastery experiences" [21]. These are experiences in which the student is exposed to apparently difficult tasks in which they can test their own capabilities and experience authentic success.

C. Solution opportunities

Originally pioneered with highly motivated medical students in the 1960s [4], PBL has been adopted more recently by teachers in a range of university-level courses [5] as well as in some high school settings (eg. [6]). As an inherently constructivist approach it promises to encourage high levels of self-efficacy among learners [7]. Although proponents (eg. [8]) claim PBL provides a more engaging alternative to traditional university instruction, the poorly-structured nature of realistic problems leads some (eg. [9] [10]) to suggest that PBL may be less appropriate for learners who have not yet developed a high

degree of self-direction. On the other hand, various forms of scaffolding have been suggested to compensate for the lack of structure (eg. [11]; [6]), and adequate attention to appropriate scaffolding was clearly essential in our application of PBL to novice learners. We saw PBL as a natural fit with disciplinary demands on the one hand and contextual demands on the other. Computing professionals are continually presented with novel, poorly-structured problems in a constantly changing technical environment while externally the generic graduate attributes agenda requires students to develop a reflective, self-directed approach to their own skills development. Other authors have drawn similar conclusions in other disciplines such as engineering for example [22].

The constructivist position casts the tutor's role as that of facilitator while the learner constructs personal knowledge of a subject through experience [22]. Despite debates about the nature of constructivism (e.g. [23]) and a persistent mismatch between teachers' beliefs about constructivism and their actions in the classroom (e.g. [24]), it remains a leading model of academic learning. Much of the debate surrounding constructivism arises from the fact that a theory of learning is not the same thing as a theory of instruction [25]. Unguided discovery learning in which the learner sets the learning goals, pace, process, etc. might be considered the most extreme form of constructivist learning. In this model, a learner typically selects a problem on which to work which then subsequently determines the content of the learning programme. However, this form of problem based learning (PBL) has been shown to be less effective than those which are structured by a tutor (See [25] for references). Proponents of PBL on the other hand argue that scaffolding provided by a tutor is required for successful PBL [26] and that effective pedagogical design centers on the choice and application of appropriate scaffolding for the subject domain. This disagreement suggests the need for a more nuanced approach to PBL such as that offered by Barrows (1986 cited by [27]) which is shown in Fig. 2. For models other than "Pure PBL" which corresponds to Kirschner's undirected learning, scaffolding is provided by the tutor. It should be pointed out that the model in Fig. 2 in which PBL is the broad category which is then subdivided is not the only way of conceptualizing the field. Prince and Felder [28] for example prefer the term *inductive teaching and learning*, in which PBL, as a technique, is contrasted with project-based learning and a number of other approaches. Their arguments correspond closely with those presented here, and in addition they review a number of empirical studies which demonstrate the medium- to long-term benefits of problem- and project-based learning, compared to more traditional ones in the field of engineering.

The term "scaffolding" was originally introduced [28] to describe support activities for children between 3 and 5 trying to solve a puzzle with wooden blocks. The concept is equally applicable to older students working in the zone of proximal development [22] to describe the support provided to enable them to perform tasks they would be unable to do independently. The term is specifically chosen to emphasize the temporary nature of such support so that when the learner has achieved competence, the scaffolding can be removed. Hmelo-Silver et al. [26] discuss a wide range of support that

could be considered scaffolding for PBL which includes traditional lectures as well as other more subjective interactions between learner and tutor.

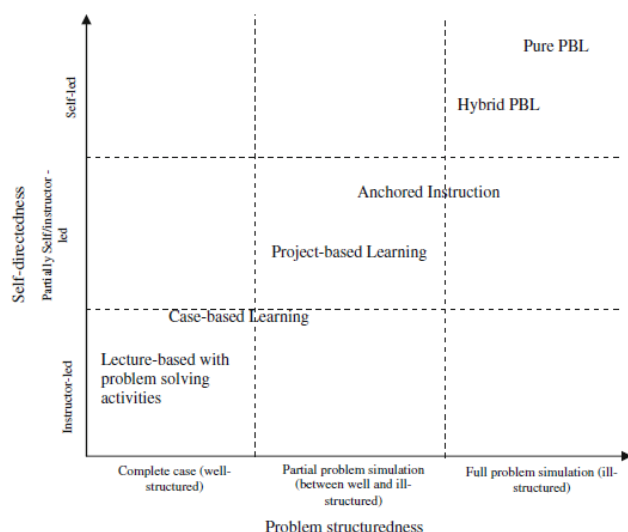


Figure 2. Six representative PBL models in Barrows' PBL taxonomy [27].

In seeking to make sense of the array of scaffolding available, others [29] distinguish between hard scaffolds which are prepared in advance, and soft scaffolds which are situational and ad-hoc. In this classification, lectures are clearly hard scaffolds, and question-and-answer techniques to guide the learner's thinking are soft. However, the distinction does not capture the possibility that some scaffolds may be both planned and situational, such as a problem-specific critique session. A further useful distinction not found in the literature therefore is between preparatory scaffolds and others which are concurrent with the problem-based activity. This leads to a 2x2 matrix shown in Table 2.

Table 2: Scaffolding approaches

| | Hard | Soft |
|--------------------|--|--|
| Preparatory | Traditional lectures, tutorials, etc | Feedback during tutorials, modelling during practical exercise, etc. |
| Concurrent | Scheduled group events during the PBL exercise | General ad-hoc support |

It should be noted that a particular scaffolding activity (eg. expert modeling of a technical strategy) may feature in more than one quadrant. Thus the model represents a tool for planning PBL activity rather than a static taxonomy of activities.

IV. IMPLEMENTATION

A. Module Design

The approach we took best corresponds to Barrows' *Project Based Learning* in that the main problem-based element was an independent group project which followed a relatively traditional series of learning events. The final project requires

that students work in small multidisciplinary teams of to design and deliver a Web-based game using techniques and technologies seen during the preceding 12 weeks. The problem is of realistic complexity and only loosely structured, thus fulfilling the requirements for a PBL subject. To further add to the realism it is time-limited, and concurrent scaffolding measures are provided as the work progresses.

The first four weeks involve the students learning and applying Benyon's [30] PACT techniques (People carry out Activities in a Context, using Technology), gradually learning about the people-technology system. The middle four weeks involve learning how to give and take criticism of requirements and designs, and to formulate and apply criteria for evaluation. The last four weeks combine learning the formalities of group-work, with some case studies and research technology designed to develop imagination. In parallel students' technical skills are leveled up.

B. Preparatory elements

Of the three main components of the module, only lectures were delivered in an entirely traditional way while a more inductive approach was used in practical sessions and tutorials. The practicals were focused on establishing a minimum skill level with basic Web technologies which could then be relied upon during the project itself. Self-study materials were provided at the beginning of the module, and later a series of staged practical problems and reference material was introduced. Students were instructed to make use of the scheduled practical session to consult with the module tutor, but also to continue working on the practical tasks during private study time. The intention was to instill in students a sense of responsibility for their own skill development, and to encourage the development of personal strategies for information discovery when faced with a novel problem. As expected, some students took this in their stride, while others expressed their frustration in the final module evaluation at the lack of direct step-by-step instruction in the practical stream. This divergence can easily be interpreted as a difference in mindset and self-efficacy.

A hands-on workshop approach was adopted for the tutorials associated with the module. The tutorial classes were large - typically 40-50 - split up into tables of 5-7. Each table tended to have the same groups as the students were in for weekly meetings with their Personal Development Tutor (PDT), and thus were usually all classmates from the same degree course, and with identical timetables. These students tended to know each other well after the first few weeks – a specific goal of our PDT system. In the tutorials, students were asked to put techniques into practice, such as storyboarding, design critique and system specification. The usual format was an introductory stage, which included expert modeling of the technique in question, followed by a staged exercise in which students worked in groups to apply the technique. Each tutorial concluded with a sharing of final results in which each group could see the work of others and could raise issues. Stationery items such as flip chart pads, marker pens and post-it notes were provided to encourage active participation, discussion and the development of final artefacts.

An underlying theme from lectures was the need to be conscious about ways in which documentation communicates ideas and choices to other stakeholders. This is exemplified by a particular tutorial exercise in which groups created and reviewed a system specification. To demonstrate the importance of accuracy and attention to detail, one group prepared the specification for a simple computer-based game using a simple template and a second group provided feedback on the content from the perspective of a development team who would have to implement the application. Finally, the first group had the opportunity to correct and complete their initial specification by responding to the feedback from the second group, before presenting their specification to the rest of the class. In other classes we used a third group to critique both quality of the second group's critique, and the adequacy of the first group's response. Because the exercise allows for several layers of evaluation of one group's input by another in the context of a goal-oriented activity, we refer to this process as "situated meta-critique". As preparation for the final project, the purpose of this type of activity was to emphasize the need for accurate and complete communications when working in a team. The group presentations at the end of the module demonstrated that the majority of project teams had taken this on board and had put considerable effort into their design documentation.

For the final project, teams of five students were constructed according to their specialist subject areas. A typical team would therefore include at least one software engineer, digital media designer and business computing specialist, and some also had computer networking students. Coming from different courses, team members were unlikely to know each other well, and therefore have only the common experience of the HCI module on which to build their working relationship. The approach to team construction actively encourages students to adopt roles within their teams that are appropriate to their own specialisms and therefore imposes a certain degree of reflection on the type of skills that they are supposed to be developing. The project task is to design and implement one of four simple Web-based games for one of four specific target audiences with rich contextual issues to consider (such as off duty soldiers in a war zone, rally car drivers between races, people with limited memory capacity, children in a kindergarten), and is designed to occupy the students on a full-time basis for an entire week (35 hours) in a week when the students have no other classes or assessments due.

The week begins with a workshop session on teamwork during which the students discover with whom they will have to work. The kick-off session and the final presentation of results, at the beginning of the following week, are the only compulsory events related to the project. However, several opt-in sessions are offered to the teams to guide their work. At the start of the project week, a software design workshop specific to each of the games is held during which the software developers from different teams can contribute to the development of a viable application design. These are lively affairs in which there is a good level of active participation from the students. Often though, the first workshop takes the students by surprise and has to be repeated. However, this helps to underline the need to be aware of what is going on.

In the middle of the project week, a series of design critique sessions are run, this time organized around the intended target audience rather than the game itself. This allows the team designers to discuss different ways in which the interface can be adapted to suit a particular group of users. As with the code design sessions, participation is lively.

In addition to these hard concurrent activities, soft concurrent scaffolding is provided in the form of student demonstrators and ad-hoc access to tutors. Teams draw on these resources heavily during the week, and there are always interesting problems to deal with. The ratio of students to tutors during the project is very high (approximately 100:1), and the effect is that teams are forced to focus their questions very specifically. This leads to a demand-led model of support in which students are obliged to take responsibility for identifying, describing and resolving problems.

V. RESULTS

The student attendance stayed reasonably strong throughout the term with at least 75% attending at least one class each week, an improvement on previous years. The pass rates were comparable with other modules as can be seen in Table 3, demonstrating that the PBL approach had no adverse effect on student attainment despite the inexperience of the cohort.

Table 3: Module pass rates

| Module | Numbers and pass rate | | | |
|--|-----------------------|------|------|-----------|
| | all | pass | fail | pass rate |
| Introduction to Human Computer Interaction | 197 | 174 | 21 | 88% |
| Being Digital | 47 | 40 | 7 | 85% |
| Digital Imaging | 70 | 59 | 11 | 84% |
| Information Systems in Organisations | 150 | 143 | 7 | 95% |
| Software Development I | 142 | 133 | 7 | 94% |

Given the aim of improving student engagement with the material, and the development of self-directed learning skills, comments provided by the students themselves in the end-of-module questionnaire gives a better measure of the success of the module as a whole. Feedback was collected using a standard pro-forma which asks students to rate the module on a five point scale from very poor to very good. In addition, free text comments are invited on the least and most rewarding aspects of the module. Out of a total of 102 questionnaires received, 34 chose to mention the final project in their comments, and of those 29 were positive and only 5 were negative. These results, shown in Table 4, indicate that the approach taken was successful in providing an engaging experience for the majority of students. The following exemplify positive comments about the project:

"Having a physical item (...) to show at the end of the course. It felt like I had something to show for my effort."
"The intensity of the [project] process felt meaningful and productive. Good professional atmosphere during this time. Not taken on a task like that before."

The negative comments tended to be less detailed, but two of the more informative focused on the fact that the students already had experience of group work, and therefore learned

nothing new during the project. This perspective could be interpreted as indicating a fixed mindset showing that some work still needs to be done on communicating the rationale to the students. We also plan further support in web-authoring for the practical classes.

Table 4: Student ratings and feedback

| | Very good | Good | Neutral | Poor | Very poor |
|------------|-----------|------|---------|------|-----------|
| Rating | 22 | 56 | 22 | 2 | 0 |
| Project | | 29 | | 5 | |
| Practicals | | 13 | | 26 | |

VI. CONCLUSION

The available evidence suggests that the course design is generally successful; however, there are specific issues that remain to be dealt with, the students who did not understand the purpose of the final project being one example. Another is the dissatisfaction with the practical element of the module as shown in Table 4. Informed by reflection on the experience so far, the priorities for further development are:

- More scaffolding for practical skill development
- Preparation for tutorial session in the form of expert modeling during lectures
- Further refinement of the general format for tutorial sessions including wider use of situated meta-critique

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Work in Progress: A Quantitative Study of Effectiveness in Group Learning

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Abstract—It is generally assumed that group studies are more effective for students than individual studies. The objective of this work in progress is to quantitatively evaluate and analyze the effect of collaborative studies on individual students performance. This effort would help the student stimulate interest in group learning and collaboration along with exposing them towards multiple problem solving approaches while working individually or in groups. This way the students are challenged to use their existing knowledge and approach, and augment it further with the knowledge and approach provided by group partners. While there are several efforts that focus on developing new group learning techniques, we intend to study the efficacy of previously proposed techniques under various test settings for EE and CS courses without significantly diverting from the course framework.

I. INTRODUCTION

Group learning in students has always been advocated as the best form of knowledge dissemination [1], [2]. The idea seems logical and intuitive as it paves way for collaborative learning environment in which multiple users with different skills and intellect assist each other in learning and understanding a topic. There have been studies in the past that have shown the effectiveness of group learning in certain topics [3], [4]. However, the biggest challenge in evaluating the efficiency of this approach is to establish a testing mechanism that is neither biased nor flawed. It is difficult to quantify the learning progress made by an individual student unless there is an exam that can test a student's ability on a given topic while working individually or in a group. The biggest problem in this evaluation is that you give the same set of questions twice, there is a high probability that the second exam using same questions was already compromised since students discussed the answers. At the same time, if they are not tested on the same set of questions, there is always a chance that the students may have known one set of questions better than the other. Moreover, if the students already know that they will be evaluated in groups, it may affect their performance as is a possibility that not everyone may contribute to the best of their ability in the group assignment.

Hence, the first task towards quantitative evaluation of group learning outcome is to design a testing mechanism that has the least bias and is still technically equivalent in all test cases. Further, the test should also ascertain the effect of student performance under various marking schemes, multiple choice or single answers with and without negative marking. The

rationale behind this approach is that students tend to be more conservative in answering questions when there is a scope of negative marking as compared to no negative marking. So the testing mechanism we have proposed also takes into account the effect of group learning under such a scheme. We can state that group based performance is better than individual performance only if it holds true under all different types of marking schemes.

In the next section, we discuss the testing methods employed and some background on the students as well as the subject. Further sections discuss the results and analysis of these testing methods to achieve a quantitative assessment of effectiveness in group learning over individual learning.

II. BACKGROUND OF TESTING TECHNIQUES

We conducted this study in March 2011 and March 2012 with the students of Digital Communication course. This course is offered to second year (fourth semester) students of IIIT Delhi. The students were oblivious to the fact that there will be a surprise quiz as the instructor had only given announced quizzes in the entire semester. Further, the second quiz in the very next class was also unannounced to minimize the effect of other factors such as the level of preparation. The students were given a surprise quiz based on the topics already covered in previous classes of the course. The topics covered in this quiz dealt with modulation techniques and bandpass communication techniques.

In the 2011 batch, there were 42 students (out of a class size of 57) who took all the quizzes individually and in groups while in the 2012 batch, there were 19 such students (out of a class size of 36) who took all the tests individually as well as in groups. In the first part of this study, we intentionally kept the group size limited to two students. All other students for whom the data was incomplete, were not included in the analysis. No special effort was made to increase class participation in order to maintain the surprise factor.

The first quiz was a mix of 15 multiple choice and fill in the blank type questions and there was no negative marking (+1 for correct and 0 for incorrect). There were multiple sets of question papers all having the same questions but different ordering of questions. Once the students completed this quiz, they were asked to repeat the quiz and this time they worked in a group of two students. In the next class, students were given another surprise quiz containing a different set of 20

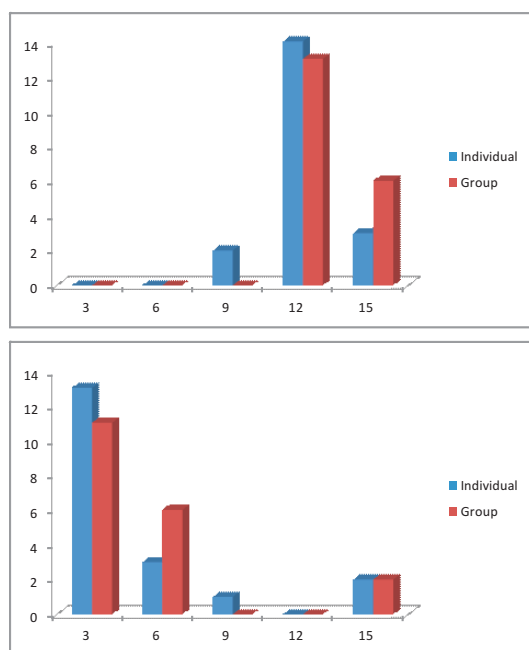


Fig. 1. Histogram demonstrating the performance of 2009 batch students in quiz 1 (top) and quiz 2 (bottom). X-axis represents the marks obtained and Y-axis represents the number of students.

questions on the same topics covered in quiz 1. However, this time the quiz had negative marking (+1 for correct and -1 for incorrect). Once they finished this quiz, they were again asked to repeat the quiz while working in a group of two students.

III. ANALYSIS AND RESULTS

Since the questions were from similar topics and almost similar in complexity for both quizzes, it was expected that the performance of students, both individually as well as in a group, will be better even if the quiz was negatively marked. The mean and variance for the first quiz, while working alone, was 10.36 and 5.08 respectively and while working in group it was 12.68 and 5.82 respectively. For the second quiz (with negative marking), the mean and variance while working alone was 2.55 and 10.07 respectively and while working in group it was 4.57 and 10.92 respectively.

The histograms in Figures 1 and 2 show that in group quiz, there are more students in the higher bins thus indicating better performance of the students in group quiz than individual quizzes. Analyzing the marks obtained and correlation between group and individual observations shows interesting results. The correlation between the first group and individual study was 0.27 whereas the correlation in the second group and individual quizzes increased to 0.53. Our results based on the rank order test [5] shows that group performance is statistically different and better than individual performance in both the cases.

IV. CONCLUSION AND FUTURE WORK

We believe that this work will serve as a good resource for faculties to benchmark the performance of students working

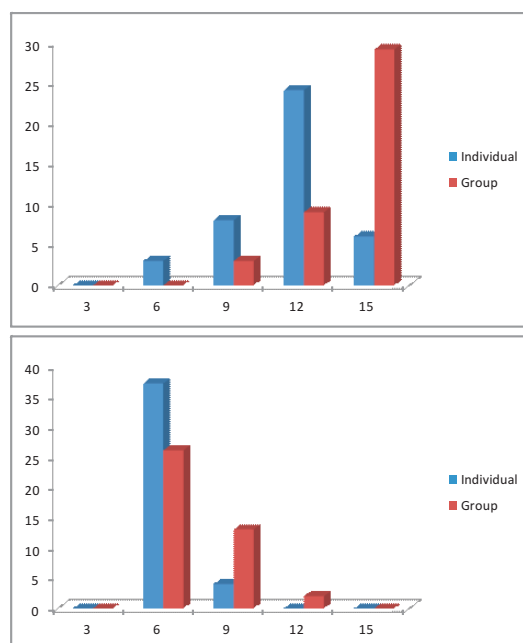


Fig. 2. Histogram demonstrating the performance of 2010 batch students in both quiz 1 (top) and quiz 2 (bottom). X-axis represents the marks obtained and Y-axis represents the number of students.

TABLE I
PEARSON CORRELATION BETWEEN INDIVIDUAL AND GROUP QUIZZES.

| | 2009 | 2010 |
|---------------------------------------|------|------|
| Quiz 1 Individual - Quiz 1 Group | 0.27 | 0.56 |
| Quiz 2 Individual - Quiz 2 Group | 0.54 | 0.88 |
| Quiz 1 Individual - Quiz 2 Individual | 0.51 | 0.50 |
| Quiz 1 Group - Quiz 2 Group | 0.46 | 0.54 |

in groups. The deliverables of this work simple quantitative methods that can be used under various grading schemes. In future semesters we also intend to incorporate other kinds of testing schemes and also study the effect of surprise factor on group performance. Another interesting study could be to identify the optimal group size that facilitates maximum learning.

ACKNOWLEDGMENT

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Results From an Action Research Approach for Designing CS1 Learning Environments in Tanzania

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Abstract—One of the most debated areas of computer science education is how to arrange programming courses. One of the debates is concerned with the amount of guidance a learning environment should grant to the learner. This research study reports on development and testing of a model where students work on their homework under guidance, facilitated by active student-teacher collaboration, continuous feedback, and student support. While qualitative results, observations, and student feedback about the intervention were exclusively positive, controlled experiment showed no significant advantage over the control group. This paper reports the results of the experiment described above, and suggests ten hypotheses for further research.

I. INTRODUCTION

Over the course of development of programming education at Tumaini University in Tanzania, several visiting professionals from developed and developing countries have attempted their own approaches to teaching programming. In general, the learning outcomes have remained unsatisfactory. In order to explore the reasons behind the challenges of programming education, in 2009 we started to systematically collect and combine the teachers' experiences, ideas, and best practices together.

In the course of curriculum development at Tumaini University, it has become clear that curricula and pedagogy can not be imported from western institutions, but must be based on contextual understanding [1]. Standard curricula, such as the ACM/IEEE Computing Curriculum [2], does not fit a Tanzanian institution as-is. The pattern of factors which affect learning in different contexts, countries, cultures, and continents, vary a lot. In our case, many of the contextual factors that affect learning are still unknown. In order to better understand the contextualizable elements of education, we decided to include action-research based development and research activities as a part of teaching.

By utilizing the action research approach, this research study extended our previous research by focusing on students' problem solving processes during homework practice and exercise work. Hands-on practice is essential for acquiring programming skills. Most of that practice is typically conducted on students' own time, in an environment that educational psychologists consider to be "minimally guided", and hence not suitable for novice learners [3]. By utilizing ideas from successful pedagogical approaches, such as the eXtreme Apprenticeship (XA)-method [4], we developed and

tested a model where students work on their homework under guidance with active student-teacher collaboration, continuous feedback, and student support constantly available.

The aim of this study was twofold: Firstly, to test the impact of this pedagogical vehicle on learning outcomes, and secondly, to gain a better understanding of the students' problem solving processes during hands-on practice. This study used a randomized controlled research setup, triangulated by a survey study and by qualitative data collection through participant observation.

II. BACKGROUND STUDIES

Since 2007, Tumaini University's IT program has seen several attempts to teach programming, by teachers from Spain, Uganda, USA, and Finland (e.g., [5]). These approaches have mostly utilized a traditional lectures-exercises-homework-pattern, with several pedagogical extensions. The extensions include the use of a program visualization tool Jeliot [6], the *coding-while-lecturing*-technique [7], and various approaches for generating contextual learning materials, course content, and e-learning support tools.

In 2009 we started to collect and combine teachers' views of factors that affect the learning environment and their ideas for improving the learning environment [5]. The teachers' views revealed challenges related to students' educational background, lack of equipment (hardware and software), lack of study materials, lack of efficient learning strategies, great variation in students previous skills within a class, erroneous assumptions about and feelings of insecurity towards programming, time management issues, counterproductive group work dynamics, and language problems. Concerning what worked well, the teachers named easy interaction in classroom and positive experiences with e-learning materials. The teachers suggested several improvements, such as increasing individualized and of open-ended exercises and need for affective support.

As a starting point, we came up with a five-factor model of challenges in learning programming (Table I), and proposed several practical ideas on how to address them [5].

For addressing the factors identified in Table I, we designed a contextual set of pedagogical practices based on educational theory: this included further utilization of the *coding-while-lecturing* technique, using contextualized affective support

TABLE I
FIVE-FACTOR MODEL OF CHALLENGES IN PROGRAMMING COURSES [5]

| Component | Explanation |
|---|--|
| Educational Background | Due to the multidimensional nature of the Tanzanian education system, the background skills in science topics, language, and problem solving vary a lot. |
| Learning Strategies (Deep/Surface Learning) | The mainstream learning strategy is rote memorizing and surface learning, aimed at solving well-defined, closed problems. |
| Motivational Orientations | Students risk generating extrinsic motivations when their learning strategies fail. |
| Groupwork Tendencies | Communal groupwork tradition, inherent in many African cultures, has both positive and negative effects for learning. |
| Study Environment and Habits | Language problems, copying, and plagiarizing of coursework is a common challenge. Internet, availability of computers for training, and other teaching facilities are often lacking. |

based on the self-determination theory (SDT) [8], introducing an adaptive set of multi-level exercises, and switching to constructivist student-centered classroom interaction. While the introduction of these approaches provided some promising results [7], [5], the performance results still remained too low.

In order to investigate the students' viewpoints to learning programming, we conducted a mixed-method study on the new pedagogical arrangements [5]. Through action-research based teaching, we formed a set of hypotheses and open questions regarding, for instance, programming language choice, affective support, students' backgrounds, academic performance, and learning outcomes. As the lack of deep-level learning skills and suitable problem-solving skills was confirmed to be one major challenge [5], it was selected as a priority for further research.

Those students, who lack the deep-level learning and problem solving skills that are essential for understanding computer programming, will easily resort to unproductive learning strategies, such as rote memorizing. When that method inevitably fails in programming classes, extrinsic motivation grows, which, in turn, results in attempts to pass the course through whatever means available.

If one looks at time usage by learners in programming courses, a major part of that time is spent on homework and other tasks that students are required to perform outside the instructed learning sessions. In our earlier experiences, even though we had put great effort into designing the classroom learning environment and exercises, something was still missing. We did not know how learning happened outside the school walls, and we had no means of changing any habits that students might have had.

A. Investigative Learning Environment Design

In this research study we utilized an *investigative learning environment* design, which extends traditional teaching environment by adding several research-oriented activities to the teaching. Our approach includes, in a cyclical process, a background study; a literature study; a detailed plan for teaching, designing, and conducting research; teaching and

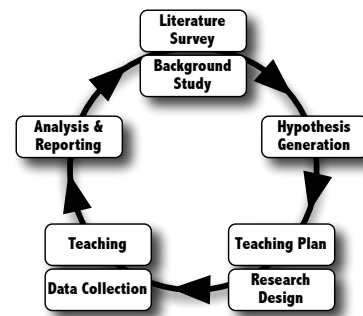


Fig. 1. Cycle of Activities in Investigative Learning Environment Design [9]

researching in collaboration with students and other staff (by observing, interviewing, and surveying); combining the results systematically; and iterating the cycle [9].

We taught the class and conducted the research in a small collaborative team of three teachers-researchers. Each of us worked in different roles—as teachers, researchers, observers, and interviewers—discussing the learning environment, combining our viewpoints, and making further plans. In this context, our research-oriented approach was superior compared to the traditional modes of teaching and researching, because it allowed us to make well-informed, flexible choices over the learning environment. The cycle of work is described in the figure below.

III. THEORETICAL FRAMEWORK

A. Programming Pedagogy: XA–Method

A strong movement in the pedagogy of programming describes programming as an application of problem solving, while another movement considers the learning of syntax and structure to be the most important issue [10]. According to the problem-solving approach [11], the ideal chain for cognitive accomplishment in programming instruction starts with novices learning language constructs, progresses to novices being able to combine programming structures together, and finally progresses to novices acquiring the generic problem-solving principles behind the processes. The student at the highest level will learn to transfer the learned skill to other programming problems, and to other problem-solving domains also, even if they are not related to programming [11]. It has been argued that in a typical programming course too little time is spent on practice in order to support the necessary cognitive chain for learning [11]. Additionally, little is known about the factors that affect the learning process in different cultures.

A promising modern approach to instruction is the XA–(eXtreme Apprenticeship) *method* [4]. The XA–method emphasizes practical work, questions the utility of instructivist lectures, and advocates strong teacher-student collaboration through one-on-one advising with continuous feedback. The core ideas of the XA–method are, firstly, that the craft of programming can only be mastered through practice, which must be done as long as necessary, and, secondly, that the

problem solving process must be promoted with continuous feedback, which in XA is seen as a necessity to make the learning process meaningful and effective [4]. One study showed that introduction of the XA-method resulted in significant decrease in dropout rates and in significant increase in pass rates and grade distributions in CS1 courses [4]. The main requirements for the XA-method are substantial increase in lab hours, considerable increase in the number of teachers or teaching assistants, and extended exercise sets for practice.

B. Minimally Guided Environments

The environment where students work with their homework in computer programming courses, outside the instructed learning sessions, is a prime example of a minimally guided environment (MGE) [3]. Educational psychologists argue that a minimally guided environment offers weak prospects for novice learners, who require direct instructions and guidance on procedures and concepts related to the topic [3]. Minimally guided environments interfere with the natural processes of human cognitive architecture, and unguided learning may have many negative results such as acquisition of misconceptions and disorganized knowledge, which may need to be later unlearned. For novice learners who are learning a cognitively challenging task, guided learning practices provide greater potential for efficient learning [3].

IV. RESEARCH QUESTIONS AND DATA ANALYSIS

There were two main objectives for this research: firstly, to test how a guided learning environment in exercise work affects the learning outcomes, and, secondly, to gain deeper understanding of the students' problem solving processes when they work on their homework. Main research questions of this study were:

- *RQ1*: What are the main factors that influence a student's problem-solving process when working with practical exercises?
- *RQ2*: What is the impact of guided exercise sessions to the learning outcomes?

The first research question (*RQ1*) was approached from two directions. Firstly, researchers observed and wrote detailed observation notes during the guided practice sessions. Secondly, a survey study was conducted among the learners.

The second research question (*RQ2*), was answered by using a controlled pretest-posttest research setting. A class of students was randomly split to half. The first group conducted their homework exercises under guidance, while the second group worked on their own. The experimental and control groups were switched half-way the study, so that everyone received equal amount of guidance during the course. The learning outcomes were frequently measured by giving both groups quizzes after the completion of each set of exercises. The grading of the exercises was conducted by, and co-validated between two teacher-researchers.

V. RESULTS: A GUIDED ENVIRONMENT

This research was conducted in the course *Programming II – Introduction to Object Oriented Programming*, which is a second year course in Tumaini University's IT program. We decided to continue with the previously developed pedagogical approaches (see Section II), and in addition extract ideas from the XA-method [4] to add into the learning environment guided practice sessions with continuous, collaborative student-teacher feedback loop. The first exercise set of the course, which was primarily for rehearsing content from *Programming I*, was used as the pretest condition for the research. For the second and third exercise sets we arranged two full day (from 9am to 5pm) *code-camp practice sessions* at a computer hall on the main campus. In these code-camp sessions, students were provided with a set of exercise tasks, a computer, guidance, and a peaceful and less formal (as compared to the lectures) environment for working.

We had three teacher-researchers working in different roles during the course, as instructors, observers, researchers, interviewers. We also had one additional teacher who joined in to instruct at the code camp sessions. For those of us working in the role of instructors, we designed several guidelines.

- 1) Only individual work is allowed. Thus, students are not allowed to discuss with each other during practice.
- 2) Exercises are continued as long as necessary to gain the required skills—no exceptions.
- 3) The learner should not be left without help at any time, but the learner should continuously receive small signals to tell if he or she is progressing in the right direction. The instructor must constantly be aware of the activities of each student.
- 4) The instructor must never give correct solutions, but must direct each student's thinking to the direction of the solution.
- 5) Syntax mistakes are corrected and explained by the instructors whenever those mistakes keep the student from focusing on the high-level problem solving.

In the sessions each student picked up an exercise task from the instructors, and then individually started to work on that. When facing any trouble, the student was able to call an instructor for help. Instructors also went around the class to observe the progress of students and to give guidance when necessary (even if not asked for). When the student completed the task, he or she presented it to the instructors and if the student's solution was correct, he or she was allowed to proceed to the next task.

The instructor-researchers continuously asked students questions, trying to get a clear picture of the students' thinking and problem-solving process. Students were encouraged to draw or verbalize what they would need in order to build the required program in full. The researchers wrote down extensive field-notes of their observations. We aimed to provide a continuous feedback loop and to recognize the stages of problem solving with each student as they appeared during the visualizations and verbalizations of building the program.

A. Observation Notes and Survey Study (RQ1)

The first broad theme that arose from the observation notes was concerned with the multiple problem types that students faced during their work on the exercises. Examples of common problems that students brought up were difficulties with understanding the task description, challenges in formulating a plan for solving the problem, and syntax problems, such as missing commas. The continuous feedback loop was effective and necessary for all the above-mentioned problems that the students faced.

The second theme that was brought up was concerned with the enthusiasm, interest, motivation, and determination of the students to work and to complete the exercises. The code-camp sessions were designed to be relaxed with a sense of freedom from restrictions. The students could go outside to enjoy soda and snacks anytime they wanted to, and they were also free to leave should they wish to do so. Still, most of the students worked intensively with only very short breaks, for almost the full time of the sessions. The students seemed to appreciate and enjoy the personal contact and the continuous feedback loop, and all students seemed to be well concentrated.

The students' comments during the guided learning sessions were typically very positive. One student mentioned it to be "*the first time I started to understand programming.*" Several students who reported struggling with their home exercises gave similar feedback. Students showed remarkable motivation and effort throughout these long sessions: For example, in all sessions most students continued to work although they were asked to have a break outside. Another comment from a group of students revealed that they had "*never programmed so much before*"—this may refer to the challenges that occur with group work methods in programming courses.

1) *Student Viewpoint*: To gain deeper insights to the students' views of the course activities, we conducted a survey study. That survey asked 12 questions measuring the perceived utility of the different parts of the learning environment (course materials, classroom interaction, unguided practice, guided practice). The survey also collected some demographic data.

For the survey, we got a response rate of 25 ($n = 25$). The survey results revealed that the students considered programming to be a moderately difficult topic: the question *Programming is a very difficult topic* resulted in a mean of 4.3 on a scale from 1 (not at all true) to 7 (completely true). Programming was also considered to be an interesting topic (*Compared to other topics, I find programming to be a highly interesting topic* resulted in mean 5.16). In an earlier study students ranked programming to be by far the most difficult topic in the IT program [12].

Overall, students considered that all the course activities support learning quite well. The question *In general, the course activities supported my learning* resulted in a mean of 5.64. Also the means for the questions which measured the opinion on learning materials (mean 6.08), classroom interaction (mean 4.92), unguided homework exercises (6.12) and guided learning sessions (5.96) were all high. It is interesting that while the observers as well as students considered the

guided learning sessions to be very valuable, in the survey students perceived unguided exercises to be slightly more useful for learning than guided exercises were. There clearly is a role for both activities.

The positive role of guided learning came also clear in the free comment section of the survey study. A representative example of a typical student's comment towards guided learning was: "*The guided exercise lesson was very interesting and helpfull [...] it provide a direct support to individual students when he/she faces challenge on entire exercise. Due to this model being helpfull, I suggest to be used not all programing class but also with other topics, because it increases understanding and concept acquisition.*" (Student, IT 2). The exact roles of guided and unguided environments call for further research.

Another constantly recurring theme in the free comments section was time management issues. Many students reported that they have too many concurrent courses, all with high workload. Without careful time management and prioritizing, there is not enough time for deep-level learning in every study topic.

The *code-camp* sessions were an eye-opening experience to observe the issues that affect students' learning when they are working on their exercises. This study revealed many obstacles and barriers that restrict the learning of programming. Time management, group work dynamics, and language problems exist worldwide, but their extent may vary a lot between different institutions.

According to our observations, the guided environment directly addresses some of the learning barriers related to time management issues, group work dynamics, and language problems by restricting the environment to promote only individual work, and by directing the study activities towards programming tasks only. The environment also provides necessary affective support which gives the ever needed motivation for students. By guiding the environment, we were able to gain understanding on the actual problem solving process in a situation where learning is not restricted by external barriers.

In the guided environment we found out that the students' learning processes were very sensitive to many kinds of errors or interruptions. Often, when a student was stuck with problem formulation or syntactical error for too long a time, that student easily lost motivation. The guided learning environment with continuous feedback helped to address also these issues.

The *code-camp* sessions provided students an environment that eased each student's workload on organizing his or her study work. When students work simultaneously with multiple courses, they have to actively prioritize and make choices on which homework they will work at each moment. In a situation where a student is frustrated with a missing comma for 30 minutes, that student might easily choose to switch to study another topic. According to several studies the self contains limited resources related to self-control, which is depleted by every act of volition [13], [14]. Thus, it is more exhausting to be responsible for one's own active choices than to be in a situation where someone else is responsible for making

the choices [13]. Sensitivity of the learning process to minor yet frustrating problems also suggests that the simpler the programming language syntax, the better.

In our guided environment students were freed from the psychological burden of making active choices, but they were able to better concentrate on deep-level learning than they can in the work that they conduct on their own time. The guided environment also partly solved the earlier issues with group work. When the environment set the rules for group dynamics, it inhibited some aspects of groupwork that previously hindered learning, such as unbalanced workload and weaker group members not getting enough practice. However, externally given rules also inhibited the positive aspects of students' freely formed group and work dynamics, so the outcomes might not be solely positive.

From the teacher's side, organizing the guided learning practices consumed a lot of resources. In the future, we will recommend the invitation or hiring of older students from each class to work as course assistants. As we got promising results both from student feedback as well as the observed results in development of programming skills during the sessions, in the future we propose the preparation of the student assistants to follow the principles described earlier in this paper. We will also recommend the changing of the regular course structure of two lectures per week into one full guided day of programming per week for the whole semester.

B. Controlled Research Setup (RQ2)

To our surprise, the results of the controlled research setup contradicted our positive observations during the code camp sessions. In the pretest condition, a one-way ANOVA was conducted to make sure there is no difference between the performance of the randomly assigned groups. The guided (G_G) and unguided (G_{UG}) groups performed equally well, with almost equal mean performance ($G_G = 2.23$, $G_{UG} = 2.18$), and with no statistically significant difference [$F(1, 40) = 0.116$, $p = 0.736$]. In both posttest conditions we had three programming tasks with an increasing difficulty level.

In the first task of the first posttest condition, the performance of the guided group and the unguided group were almost equal (means: $G_G = 1.33$, $G_{UG} = 1.35$), with no statistical significance shown in one-way ANOVA analysis [$F(1, 42) = 0.005$, $p = 0.995$]. In the second task, the means for the groups were also nearly equal (means: $G_G = 1.44$, $G_{UG} = 1.5$), with no statistical significance in one-way ANOVA analysis [$F(1, 41) = 0.042$, $p = 0.839$]. In the third task, the guided group performed slightly better (means: $G_G = 2.3$, $G_{UG} = 2.06$), but with no statistical significance shown in one-way ANOVA [$F(1, 42) = 0.880$, $p = 0.353$].

The total performance between the unguided and guided groups in the first posttest condition was: (means: $G_G = 1.72$, $G_{UG} = 1.63$), with no statistical significance between the condition means in one-way ANOVA test [$F(1, 41) = 0.242$, $p = 0.626$], and thus, there was no difference in the learning outcomes between the group that received guidance and the group which did not receive guidance.

In the second posttest condition, the groups were switched and the following scores for the three learning tasks were achieved. In the first task the guided group performed better (means: $G_G = 1.32$, $G_{UG} = 1.24$). In the second task the unguided group performed slightly better ($G_G = 1.34$, $G_{UG} = 1.4$). In the third task the guided group performed better ($G_G = 2.22$, $G_{UG} = 1.90$). Total performance for the second posttest condition was $G_G = 1.62$, $G_{UG} = 1.51$. There were no statistically significant differences between group performances in either of the learning tasks or in the total performance in the second posttest condition. The results of the one-way ANOVA analysis for the first task was [$F(1, 45) = 0.118$, $p = 0.773$], for the second task [$F(1, 45) = 0.059$, $p = 0.809$], for the third task [$F(1, 45) = 2.061$, $p = 0.158$], and for total performance [$F(1, 45) = 0.499$, $p = 0.483$].

With our positive experiences from the code-camp sessions, the performance results struck us with a surprise. We were left to hypothesize between various explanations for the reasons why the groups performed equally well. The most plausible explanation is that students indeed do learn equally effectively under guidance and outside of guided environments, and that our qualitative results from participant observation and student feedback were misleading. Further research is, however, needed for resolving the dissonance between the qualitative results and the quantitatively measured learning outcomes.

While exploring why our qualitative results suggested better learning outcomes that did not materialize, we also propose research on alternative hypotheses. Firstly, due to resource limitations, the tests had to be conducted on a pen-and-paper format, which is different from hands-on computer-based work with the exercises. Perhaps we tested the wrong thing: If we learn-by-doing, perhaps we should test-by-doing also. Secondly, while in our observations the students succeeded well, and they clearly started to capture effective problem-solving process for solving programming tasks, perhaps our intervention was not deep enough to change students' learning and test-taking habits. Similar phenomena have been observed in other contexts also: In another study researchers found out that it took years for change in learning styles to show up in test scores [15].

In the workshop situation it seemed clear to all the researcher/teachers that many students started to understand certain learning tasks and perform well in them, such as in understanding how a for-loop works. Despite their apparent mastery of the concept and skill, in the exam, the same students failed to solve similar tasks that they had successfully completed in the workshop sessions. This might result from an imbalance in *constructive alignment* between the learning environment and the assessment tasks [16, pp. 95]. In the future, we will consider the possibility to develop test-while-doing practices instead of pen-and-paper exams.

VI. DISCUSSION

Over the course of development of programming education at Tumaini University in Tanzania, we have begun to utilize an action-research approach to systematically test

the impact of educational interventions. We have designed several pedagogical approaches, and studied their outcomes using the mixed-method approach. By utilizing ideas from successful pedagogical approaches, such as the XA-method, we developed and tested a model where students work on their homework in a guided, safe, and relaxed environment, and where teachers are available for active student-teacher collaboration, continuous feedback, and student support.

The results of this study were contradictory: while there was no significant difference in the learning outcomes between guided and unguided groups, the observation notes, as well as the opinions of researchers, teachers, and students all spoke highly in the favor of guided learning. There are many open issues in this particular learning environment which pose opportunities for further research. In the following we propose a list of open hypotheses for further studies of learning programming in this particular context of education.

- 1) Students have too little practice:
 - a) Students do too few independently done (home) exercises.
 - b) There are too few guided exercises.
- 2) We fail to teach students effective learning strategies (e.g., students do not trust in their own ability to create code but they try to memorize code snippets).
- 3) The styles of programming education that we have introduced are not well aligned with students' epistemological positions.
- 4) We test the students' learning wrong. (If we want them to learn-by-doing we should test-by-doing)
- 5) Students try to adapt to each individual teacher's characteristics (in terms of questions posed, proper answers, cues for support etc.) and they would benefit from more variety in teaching/practice styles.
- 6) We fail to shift the students' focus from the syntactic level to the semantic level.
- 7) Students' English language skills are lacking (the university's official teaching language is English, though).
- 8) Some other programming language (currently Java) would produce better results.
- 9) Students rely on group work in a subject that is essentially an independent "craft" type of subject.
- 10) Due to nationally acknowledged deficiencies in basic education [17], teaching of abstract thinking in primary and secondary school level is inadequate.

Based on the positive experiences gained from guided learning, our recommendations for future activities include extending the guided learning activities by training top performing students from previous class to work as assistants. As guided learning did not produce worse results than unguided learning, the guided approach could be deepened to cover the whole course. In future, more focus should be put on the possibility of switching to test-while-doing instead of paper-and-pen exams. Programming is a challenging topic to teach worldwide. Thus, many of the open issues and challenges identified by this research may be relevant in other educational

contexts also.

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Work in Progress: Supporting Latino and English Language Learners' Written Communication Skills

A Research-Based Pedagogical Intervention

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Abstract—This paper reports preliminary findings from a qualitative study of a research-based pedagogical intervention in a freshman-level course for engineering majors. In this intervention, engineering instructors collaborated with an applied linguist in education to design activities to improve writing skills, an important professional skill in engineering. Development of effective writing skills is challenging for students, and particularly for Latinos and English Language Learners (ELLs). This challenge can be effectively addressed with meaningful writing tasks and appropriate pedagogy. Preliminary findings show improved communication and interpersonal skills among students.

Index Terms—Latinos in engineering, English Language Learners (ELLs), project-based learning, effective writing.

I. INTRODUCTION

It is widely accepted that engineers must be able to communicate effectively. Simultaneously, research on academic writing and second language writers has focused on the unique challenges that academic writing in a second language entails [1]. This paper reports preliminary findings from a qualitative study of an intervention in a required freshman-level course for engineering majors in an institution where the vast majority of engineering undergraduates are Latinos. Instructors in engineering collaborated with an applied linguist in education to integrate research-based pedagogical approaches as the instructional framework for the intervention. The intervention supported student teams in writing how mathematics topics connect to engineering applications.

II. SETTING

The University of Texas at El Paso (UTEP) is a minority four-year institution with an undergraduate enrollment of 1,711 in the College of Engineering. UTEP is located on the U.S./Mexico border and its demographics reflect that of the community it serves (76 percent are Latino). In El Paso, 76% of households speak a language other than English at home, with the vast majority speaking Spanish. Many UTEP students, even those not classified as ELLs, are Spanish speakers.

III. THEORETICAL FRAMEWORK

Appropriate pedagogical support is essential for developing engineering communication skills, and includes feedback and purposeful reflection integrated with an interactive instructional approach [3,4,5,6]. Enhancing

writing in a university course is important for a number of reasons, such as its ability to assess and promote students' understanding [7]. Moreover, authentic writing assignments, such as writing applications for internships, can serve to situate learning [8] and construct new understanding [4,5].

Research with ELLs points to the importance of meaningful participation as crucial to developing engineering communication skills. For example, Vickers [9] draws on language socialization and a situated learning framework to show how participating in a community of practice can be essential for ELLs where more proficient peers and the instructor can scaffold ELLs' learning while designing engineering projects.

Our intervention was informed by this prior research and our aim was to guide Latino and ELL students in developing a disciplinary discourse of engineering in a second language.

A. Inquiry-Based Teaching and Learning

In our design of this pedagogical intervention, we also integrated inquiry-based approaches for creating a dialogic environment and opportunities for constructing new understanding. Thus, we needed to engage learners in meaningful tasks to situate their learning [10,11] where novices have more opportunities to learn discipline-specific practice through social interaction with those more expert [11]. Thus, in our design, we infused situations where our students could interact with engineering research professors and graduate students in engineering research laboratories.

We employed project-based learning (PBL), a particular form of inquiry-based instruction, since PBL has more sustainable outcomes than other approaches to learning in terms of retention and skill development [12]. More important, it creates an environment for stimulating improvement of written communication skills. In PBL, learners drive the learning goals and construct their understanding through investigation and development of a project in answering a driving question [12]. In our intervention, teams of students were each given a mathematical concept, such as transformative functions or least squares, with the driving question: How is this applied in engineering?

B. Description of Intervention

The project was titled Mathematics Connections Project (MCP) and was framed as an opportunity to write a paper for high school students to explain how a mathematical concept is applied to engineering. The instructors engaged student

teams in researching, writing, and editing the assignment using an iterative process to improve their writing. Their investigation entailed interviewing faculty in engineering research labs and conducting library searches of relevant papers. Then they synthesized into one sentence what they had learned and brainstormed supporting ideas, generally three to four. These ideas were assigned to each group member who wrote an explanatory paragraph related to the synthesized statement. After peer edits of individual paragraphs, the team merged all paragraphs into one paper, which was individually edited and merged into a single paper for further group editing. This incorporated individual accountability, a key element for effective teams [13].

IV. ABOUT THE RESEARCH DESIGN

The questions guiding our research were: (1) In a PBL course, how do freshman pre-engineering students develop 21st century engineering skills and dispositions? (2) What are the benefits to student written communication skills in a PBL course with explicit focus on writing and the writing cycle? We collected data from field notes of participant-observation, written assignments, focus groups, and written learning reflections. These data were analyzed to identify patterns of writing development across the semester.

V. PRELIMINARY FINDINGS

Preliminary findings emerging from the data analysis were that Latinos and ELLs benefited from (a) participating cooperatively in meaningful tasks and (b) focusing on communication explicitly.

A. Participating Cooperatively in Meaningful Tasks

Students' cooperation in writing the MCP allowed them to understand the value of clearly communicating engineering applications of math concepts, and group communication with a team of peers. Cooperative groupings allow peers opportunities to socialize each other [10] into engineering discourse through immediate feedback or peer critique on performance. Thus, a written task, such as writing an email to a professor to seek an interview or writing drafts of a formal research paper, can permit ELLs to receive feedback from the professor and/ or from their peers.

To exemplify and illuminate how the cooperation unfolded in the whole class, we present the case of one student team consisting of two Latina females, Daniella and Clara, who gave consent to participate in this project and are identified with pseudonyms. Daniella is English monolingual, and Clara is Spanish dominant student who is proficient in English. The math topic assigned to these two students for their MCP was matrices.

Daniella and Clara's initial joint draft drew strongly from math content sources and began with "*A matrix is a rectangular system of numbers organized into rows and columns.*" It goes on to list 13 kinds of matrices without any analysis and a brief mention of engineering applications. Finally, a basic matrix is copied and pasted on the draft.

In the next cycle, they were asked to conduct further research on engineering applications. They contacted and interviewed an engineer on the engineering application of matrices. To prepare for writing the second draft, students read and peer reviewed each other's drafts. They received feedback on the following sentence written by Clara: "*There are many different types of matrices and there are many different ways of solving them.*" Peer reviewers asked that the sentence be changed to remove the repetitive noun phrase. Their second draft included the actual applications their interviewee mentioned, with appropriate citations. Whereas the first draft drew strongly on published sources, their second draft drew strongly on the interview and focused more on applications.

Research suggests that feedback from a more proficient peer is essential to develop second language proficiency [3]. Thus, the example shows that, while the feedback that Clara received was not substantial (it does not change the central meaning of the sentence), it could still be beneficial for her as she masters the English language. Importantly, the writing task is embedded in a meaningful context directly related to engineering content [3], rather than in a de-contextualized grammar review.

B. Focusing on Communication Explicitly

We found that freshmen engineering students indicated valuing communication as central to the work of engineers. For instance, students had to contact a researcher through email to seek an interview. Their emails often had to undergo several drafts because students were accustomed to writing only informal emails to their peers. In their reflections, students noted that it was important to write clearly and professionally to professors. For some students, like Daniella, contacting a professor was a new experience and in her reflection, she wrote the following:

Writing emails that are professional and will receive a response along with doing a research project that requires one to take the given topic and relate it to the real world is not so simple. During the process of writing, rewriting, completely starting over and then writing emails, I learned that an email . . . must be to the point, no ranting on about things that may not be important to the reader.

Daniella's reflection demonstrates her realization of the importance of writing a well-crafted text to achieve its purpose. Moreover, she contextualizes writing an email as part of the work of researching her topic on matrices and achieving her end purpose—becoming an engineer. She continues her reflection with the following excerpt:

During the process of developing the math connections project, I did not just learn about my math topic, matrices and how they are used throughout the engineering field, but also about the do's and don'ts of emails and interviews.

In sum, she began to see that the work of engineering includes learning math and its applications to engineering. In addition, she makes the connection to researching through a

variety of published and original sources, such as personal interviews.

In addition, students experienced the way in which team building can become a valuable resource to solve problems, in this case writing the MCP paper. Clara added in her reflection the following:

I learned how to work in teams too. We always tried to do the things together, that way the contribution of us three could be fair . . . I not only learned things from the research we did but I also learned many things from my teammates.

VI. DISCUSSION AND CONCLUSION

An important professional skill in engineering, effective written communication is even more challenging for Latinos and ELLs. However, meaningful writing tasks related to engineering and cooperative grouping [4,7] are part of providing appropriate pedagogical support for peer review, peer socialization, and scaffolding [9]. Academic literacy experts have argued for several years that becoming proficient in a specialized disciplinary discourse not only involves control of language but also an acceptance of the values and beliefs implicit in disciplinary discourses. Students might see the value of using language in a new way “if they recognize and understand the sorts of socially situated identities and activities that recruit the social language, if they value them or, at least understand why they are valued” [14, p. 23].

As Daniella’s reflection suggests, students began to see the importance of writing in the context of a whole host of experiences related to engineering. She situated writing in the context of interacting with research engineering professors, conducting investigations, and interacting with her group. For Latino students and in particular ELLs, explicit attention to how a text is composed focuses their attention to the language resources they need for conveying the intended meaning and gaining control of the second language [3,15].

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Predictive Models on Improvement of Spatial Abilities in Controlled Training

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Abstract— Improving spatial ability in the academic curriculum is crucial for engineering degrees. Prior research has shown that spatial abilities can be trained; that's why in this work we propose several kinds of short duration trainings aimed to improve those abilities. We have established a ranking based on the improvement rate that the student may reach knowing his starting level before undertaking training. These trainings take place before starting the academic course so students don't receive theoretical or practical contents of Graphic Engineering during the week. Before training and after its completion, the level of spatial ability is measured through validated tools for this aim. We perform a statistical analysis obtaining the gains from higher to lower levels of spatial skills acquired through each training (videogame/ augmented reality/ sketching/ descriptive geometry). With data from all training, the curves have been set up by least squares (linear, exponential, algorithm, potential and polynomial). The most suitable predictive model for all cases is the linear one.

Keywords— engineering education; spatial skills; training courses; best practices; introductory courses.

I. INTRODUCTION

La Laguna University as a pioneer and innovating center offers several training programs for improving the spatial ability of students belonging to all degrees in every engineering field of higher education [1,2,3]. These trainings aim to improve those spatial abilities in a short time (always less than 10 hours) and until now they have been based in tools supported by several technologies or devices (smartphones, iPads, augmented reality, videogames, notebooks, etc...). During training, orthographic normalized views from elements and pieces are used. We are not only looking for improvement of the student's spatial ability but for his motivation and satisfaction prompted by the job done as well. During the last few years, several experimental tests have been carried out for validating each one of these trainings [1,2,3], and actually they have been broadly implemented in the curriculum of the Graphic Design subjects at the start of the semester [4].

Development of spatial skills by engineering students is directly linked to future success in their professional work [5,6,7], and is critical for understanding the contents of engineering graphics subjects [8]. This capability can be described as the ability to picture three-dimensional shapes in

the mind's eye. Acquiring this ability can be done through an indirect process by means of Engineering Graphics subjects where students perform sketching tasks, create and read orthographic and axonometric projections [9].

Some studies demonstrate that spatial abilities can improve by means of specific training. These abilities, in engineering area, can improve with multimedia exercises, 3D software and other technologies used in graphic engineering [7,10,11].

In this paper, we present the results obtained by several groups of engineering students so each one of them have undertaken a different kind of training. All groups enjoyed significant difference in their spatial abilities and from this point onwards, we may establish a ranking of trainings and a prediction model for each one of them, so every students' level can be found according to the kind of training performed.

II. THEORETICAL FRAMEWORK

There can be no doubt that spatial ability is one of the components of human intelligence as this is backed by countless lines of research [12, 13]. There is not, however, any clear agreement on the sub-skills that this component is made up of. McGee [14] distinguishes five components of spatial skills: Spatial Perception, Spatial Visualisation, Mental Rotation, Mental Relation and Spatial Orientation. Some of the most widely accepted theories are the paper by Lohman [13] and the Meta-analysis conducted by Linn and Petersen [15], which identifies three kinds of spatial skills: *Spatial Perception* that requires participants to locate the horizontal or the vertical in a stationary display while ignoring distracting information. *Mental Rotation* involves the ability to imagine how objects will appear when they are rotated in two or three-dimensional space. *Spatial Visualisation* refers to the ability to manipulate complex spatial information when several stages are needed to produce the correct solution. Researchers from the fields of psychology [16] and geometry [17] simplify this classification into two components:

- Spatial Relation “The ability to imagine rotations of 2D and 3D objects as a whole body”
- Spatial Visualization “The ability to imagine rotations of objects or their parts in 3 spatial dimensions by folding and unfolding”.

A. Measurement of Spatial Skills

There are a large number of tools available for measuring spatial abilities but using this latter classification, in this work we chose two tests, one for each of the main categories outlined above, to enable us to quantify the values of the spatial ability:

- Mental Rotation Test (MRT) for spatial relations [18].
- Differential Aptitude Test - Spatial Relations Subset (DAT: SR) for spatial visualisation [19].

B. Spatial skills: an overview

Differences in spatial skills between men and women have been studied in many studies, which suggest that men have the edge over women in mental rotation tasks [15, 20, 21]. On the other hand, some authors have suggested that these differences may be influenced by the different social status of the people concerned [22], or by environmental and socio-cultural aspects [23]. Knowledge of the relation between the regular tasks that men and women carry out and spatial abilities would therefore be a good indicator. Some studies done along these lines [24] conclude that videogames may be a tool to improve these abilities.

Spatial skills can improve with specific training. The methodologies used may differ, depending on the area of application (pen and paper sketches, Isometric sketching, multi-media platforms, on-line platforms, video games, virtual reality, augmented reality, specific software, physical materials, etc.). Contents such as descriptive geometry, orthographic views, three-dimensional modelling, etc., have been used in engineering in order to improve the spatial abilities of students. Sorby [25] and Alias, Black and Gray [9] used a traditional graphics course on sketching activities, orthographic projection, isometric drawing. S.E. Wiley [26] concluded that 3D solid models and animation may help in developing visual perception abilities. Martin-Dorta, Saorín & Contero [3], compare the effect of several different methodologies for improving spatial abilities. Dünser et al [27] conclude that augmented reality is a highly useful tool for training spatial abilities. Rafi, Samsudin & Said [28] demonstrate the effect of virtual reality based training on improving the spatial abilities of men and women.

III. TRAININGS FOR IMPROVING SPATIAL ABILITY

In this work, we analyze six different trainings. Didactic material and proper tools have been developed for planning and designing a training series of short courses where the spatial abilities needed by engineering students may be improved. The course's contents introduce the students into the basic knowledge for sketching systems (except those based on videogames).

A. General description and trainings' programming.

The training has one week duration and starts on Monday. The first action before undertaking training is providing the students belonging to each training group with the MRT and

DAT-5:SR tests for measuring their levels of spatial ability. Later, each group performs the training proposed during five days. Every day, the series of exercises planned will be resolved in two hours, except the last day which is dedicated to an evaluation of one hour. All training end on Friday and have nine hours duration. The students rest on weekend so the following Monday they are provided with the MRT and DAT-5:SR tests once again for measuring their new levels of spatial ability and finding out the gain acquired.

For training the spatial ability, the activities proposed require performing spatial tasks mentally which are measured in the spatial tests (Puzzles, Figures' rotation, Block, Intersection, Blocks' rotation, Assemblies).

B. Trainings based on videogames.

Two trainings were designed for developing spatial abilities through videogame's use. One of them was configured for being completed on a PC (21 students) meanwhile the other was set for performing it on a Nintendo DS games console (14 students). The training consists on playing according to plan the different modes of the 'Tetris' videogame available for both PC and Nintendo DS versions (Figure 1). The training duration is nine hours. The choice of the videogame Tetris was conditioned for accomplishing the following requirements:

- It's a game that requires geometric figures and shapes.
- It allows performing operations of rotation and movement of figures.
- The spatial tasks that should be performed in the game will be related to both spatial ability components: spatial relations or spatial visualization
- The same videogame should have its own version on both platforms: PC and Nintendo DS.
- Possibility of using the tactile pen on Nintendo DS platform.

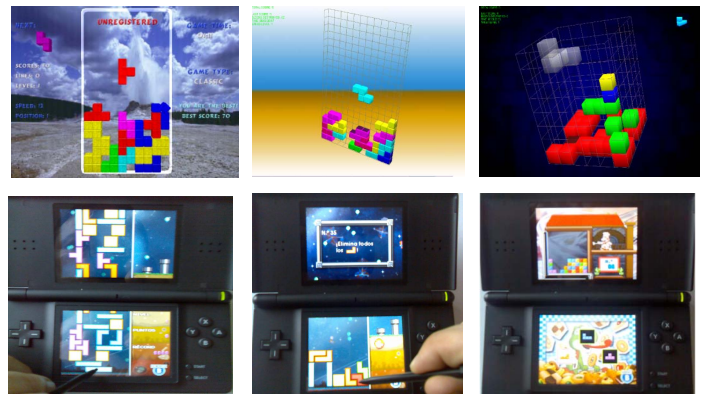


Figure 1. Tetris videogame modes on PC y NDs platforms.

C. Training based on descriptive geometry.

The problem that the student usually finds while studying descriptive geometry's contents is facing static graphic sketches on paper or any web platform which don't offer the possibility of following the solution sequence in a 3D dynamic way.

The aim of descriptive geometry is transforming the 3D objects into 2D projections. For training based on descriptive geometry, we have developed a viewer which allows performing the exercises' sequence in 3D being controlled and manipulated by the student. The 3D space may be rotated to any point of view with a simple movement from the mouse.

The viewer shows descriptive geometry (points, straights, planes, polyhedral figures...) and the solution sequence through the dihedral system's method. Besides, the projections of elements belonging to the projection planes are available for consultation.

This fast course or training has been taught in two versions according to the methodology used. One version is based on master classes through blackboard explanations where 21 students attended (group DG) and another through master classes and computer viewer support which provides the student with greater learning autonomy (group DG-3D). On both cases, the theoretical content is the same as a 65 pages book format.

The book fulfills a double condition: it's a manual for the students so they may be able to understand the basics of the dihedral system besides being a manual for those who have spatial vision difficulties but can develop it through spatial reasoning. The contents of the course are shown on table I.

TABLE I. CONTENTS OF DESCRIPTIVE GEOMETRY TRAINING

| | |
|----|--|
| 1. | Introduction. Sketching systems. |
| 2. | Dihedral system. Point, straight and plane sketching. |
| 3. | Location of a straight line and point over the plane. |
| 4. | Intersection of planes and straight lines with other planes. |
| 5 | Parallelism and perpendicularity 5.1 Parallelism of straight lines. 5.2 Parallelism of a straight line and plane. 5.3 Parallelism of two planes. 5.4 Perpendicularity of a straight line and a plane. 5.5 Plane perpendicular to a straight line. 5.6 Perpendicularity of planes. 5.7 Perpendicularity of straight lines. |
| 6 | Minimum distances. |
| 7 | Polyhedrons - Hexahedron projections. Study of three characteristics positions of a tetrahedron respecting the HP. - Tetrahedron projections. Study of three characteristics positions of a tetrahedron respecting the HP. |

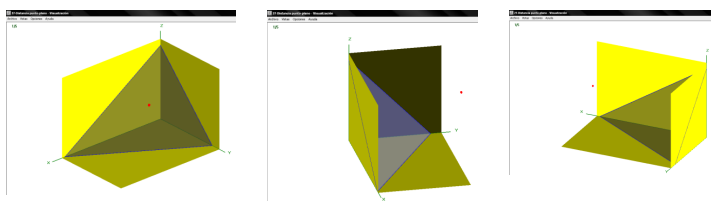


Figure 2. Dihedral system 3D viewer.

D. Training based on hand sketch based orthographic views.

Several authors have designed courses for developing spatial abilities of students through classic activities of Graphic Design (objects' sketching by normalized views/ isometric perspectives) and sketching techniques [7, 25]. This strategy

allows teacher to develop the student's spatial ability while introducing them to Graphic Design contents.

Following the same strategies that in previous courses, a printed exercise manual is designed containing a compilation of exercises about pieces in different categories according to difficulty levels for working over the sketching systems by orthographic views and perspectives. This course (Traditional Exercises –ET) or training has been performed by 29 students and its structure has five levels of growing difficulty where each level has several kinds of exercises for working on the sketching of objects through orthogonal views.

E. Training based on augmented reality

The new generations of students pay more attention and are more interested in contents when teachers use CAD tools for performing exercises, multimedia material for explanations, web resources, virtual tutorships, forum's communication... (everything related to Web 2.0) and show lesser motivation or even boredom at exercises performed with pen and paper through traditional graphic design tools [29].

The augmented reality application developed for this kind of training needs a book containing fiducially marks which encode the 3D virtual models that the application contains. Over each page there are a couple of marks that encode the proposed exercise in that page. When the camera captures that marks, the AR system may sketch over a main mark the 3D model matching the exercise on that page.

The student can turn the mark with his hands and see the model from any point of view. In this training, a new variable is added consisting on mind and hands coordination for visualizing the desired point of view. The training/course have been performed by 24 students with a five levels structure and a duration of two hours for each one, except level 5 (evaluation) where six exercises must be completed in just one hour without any kind of help about the models (*knowledge, comprehension, application, analysis-synthesis, and evaluation*).

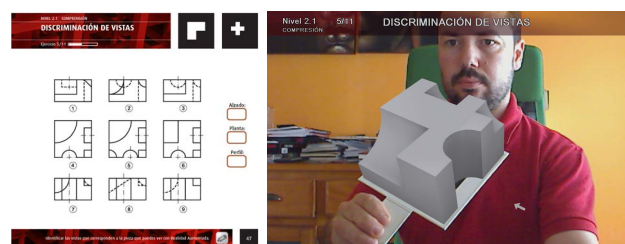


Figure 3. Exercise Sample with Augmented Reality

F. Control group and overall student's population

Each sample group is composed by freshmen students belonging to La Laguna University degrees. At the moment of performing this study, a control group has been taken into account, composed by 25 students from the overall population that have not undertaken any training.

IV. RESULTS AND RANKING

In first place, we made sure that spatial abilities belonging to every group are analogue. Having that in mind, the ANOVA is carried out and the results obtained show that all groups have analogue MRT and DAT starting levels. Each training achieves an improvement of spatial ability although values vary accordingly. However, we consider certain limitations in this study due to huge standard deviations among groups as shown on results due to the lack of detection of significant differences between groups. Possibly groups may be different but our sample used is too small for causing that difference to become significant.

TABLE II. DESCRIPTIVE GEOMETRY TRAINING CONTENTS

| *(SD) des. Std. | Pre- test | | Post- Test | | Gain MRT | Gain DAT5:SR |
|-------------------------|-----------------|------------------|-----------------|------------------|-----------------|-----------------|
| | MRT | DAT5:SR | MRT | DAT5:SR | | |
| VideoGame PC n=21 | 20.76 (8.01) | 37.76 (9.33) | 27.48 (9.03) | 45.46 (5.85) | 6.72 (4.54) | 7.70 (5.09) |
| VideoGame NDS n=14 | 12.43 (5.73) | 40.78 (6.37) | 22.79 (9.19) | 46.07 (5.34) | 10.36 (4.76) | 5.29 (3.76) |
| DG n=21 | 20.81 (7.40) | 31.29 (10.41) | 27.76 (8.81) | 39.43 (9.36) | 6.96 (6.68) | 8.14 (5.32) |
| DG-3D n=19 | 17.32 (9.56) | 29.53 (8.44) | 26.42 (8.33) | 38.53 (5.55) | 9.11 (7.83) | 9.00 (4.37) |
| AR n=24 | 19.67 (7.91) | 29.17 (7.29) | 27.71 (7.83) | 38.46 (7.05) | 8.04 (5.31) | 9.29 (4.08) |
| ET n=29 | 19.79 (7.62) | 28.48 (9.48) | 28.76 (8.79) | 37.10 (9.00) | 8.97 (5.41) | 8.62 (6.25) |
| Control Gr. n=25 | 17.44 (9.82) | 28.40 (10.17) | 22.08 (9.94) | 33.52 (11.77) | 4.64 (4.36) | 5.12 (7.13) |
| Tot.Population N=445 | 18.65 (8.35) | 29.41 (9.18) | | | | |

For checking out if the improvement of training is significant, we use t-Student considering as null hypotheses H_0 the fact that average values of spatial ability don't vary when the course ends meaning that 'students who undertake the course don't develop their spatial abilities'. In every case, the result of comparing the average pre and post test values through t-Student series in paired tests point out that the difference is significant, so it can be stated that courses have provided an improvement from the statistic point of view. For assessing the improvement values, a covariance analysis is performed (2-way ANCOVA). The ANCOVA method allows us to eliminate the difference of pre-test scores between groups and the adjusted post test scores, revealing the real effects of the experimental treatment. So, it eliminates the possible memory effect. As a reference, the control group is taken with a pre/post test difference of zero points and it's adjusted to a new post test value. This way, we may be able to compare the groups knowing the post-test adjusted value. This statistical procedure tested the interaction between training conditions (all groups). The dependent variables, co-variants and independent variables were post-test measurements, pre-test measurements and training condition respectively. The suitability this analysis' usage was tested by assessing the analysis through a statistical model containing interaction terms between the co-variants (pre-test mean scores of MRT and DAT-5:SR) and the independent variables for assessing the assumption of homogeneity between gradients.

A. ANCOVA results for MRT and DAT-5:SR.

The ANCOVA table breaks down the variability of post-test into contributions due to various factors. Since Type III sums of squares have been chosen, the contribution of each factor is measured after removing the effects of all other factors. According to the results of the Co-variance Analysis for Post-MRT, there is a statistical difference between the training courses and the control group, all p-value ≤ 0.05 , thus there are differences in the levels of spatial abilities depending on the kind of training undertaken. Similar results were obtained for the Post-DAT-5:SR as there is statistical significance between the different kinds of training (all p-value ≤ 0.05).

TABLE III. ANALYSIS OF ANCOVA MRT. EFFECT BETWEEN TRAININGS.

| Source | Squares sum type III | Gl | Quadratic average value | F | Sig. |
|-----------------|-------------------------|-----|-------------------------------|---------|------|
| Corrected model | 10078.932(a) | 8 | 1259.866 | 43.033 | .000 |
| Intersection | 3183.330 | 1 | 3183.330 | 108.732 | .000 |
| Pre_MRT | 9147.987 | 1 | 9147.987 | 312.465 | .000 |
| Course type | 416.148 | 7 | 59.450 | 2.231 | .034 |
| Error | 5240.558 | 179 | 29.277 | | |
| Total | 144496.000 | 188 | | | |
| Total corrected | 15319.489 | 187 | | | |

TABLE IV. ANALYSIS OF ANCOVA DAT-5:SR. EFFECTS BETWEEN TRAININGS.

| Source | Squares sum type III | Gl | Quadratic average value | F | Sig. |
|-----------------|-------------------------|-----|----------------------------|---------|------|
| Corrected model | 10919.574(a) | 8 | 1364.947 | 65.769 | .000 |
| Intersection | 3351.098 | 1 | 3351.098 | 161.470 | .000 |
| Pre_DAT-5:SR | 7446.425 | 1 | 7446.425 | 358.800 | .000 |
| Course type | 375.025 | 7 | 53.575 | 2.581 | .015 |
| Error | 3714.910 | 179 | 20.754 | | |
| Total | 320173.000 | 188 | | | |
| Total corrected | 14634.484 | 187 | | | |

B. Real gain values for MRT and DAT

The tables V and VI show the correction of the mean post-test value for each kind of course. Column B shows the value of the gain for all courses in comparison with the control group.

TABLE V. REAL GAIN MRT VALUES AT EACH TRAINING

| Parameter | B | Typical error | T | Sig. | 95% confidence interval. | |
|--------------|-------|------------------|--------|------|--------------------------------|---------------|
| | | | | | Min. value | Max. value |
| Intersection | 6.927 | 1.381 | 5.017 | .000 | 4.203 | 9.651 |
| Pre_MRT | .869 | .049 | 17.677 | .000 | .772 | .966 |
| AR | 3.694 | 1.550 | 2.383 | .018 | .635 | 6.753 |
| ET | 4.634 | 1.481 | 3.129 | .002 | 1.711 | 7.557 |
| DG | 2.754 | 1.610 | 1.711 | .089 | -.423 | 5.932 |
| DG-3D | 4.449 | 1.647 | 2.702 | .008 | 1.199 | 7.699 |
| PC | 2.510 | 1.610 | 1.559 | .121 | -.667 | 5.687 |
| NDS | 5.060 | 1.823 | 2.776 | .006 | 1.463 | 8.657 |
| CONTROL | 0(a) | . | . | . | . | . |

TABLE VI. REAL GAIN OF DAT-5:SR VALUES FOR EACH TRAINING

| Parameter | B | Typical error | T | Sig. | 95% confidence interval | |
|--------------|--------|---------------|--------|------|-------------------------|------------|
| | | | | | Min. value | Max. value |
| Intersection | 13.015 | 1.415 | 9.199 | .000 | 10.223 | 15.807 |
| Pre_DAT5 | .722 | .038 | 18.942 | .000 | .647 | .797 |
| AR | 4.385 | 1.302 | 3.367 | .001 | 1.815 | 6.954 |
| ET | 3.524 | 1.243 | 2.834 | .005 | 1.070 | 5.977 |
| DG | 3.825 | 1.353 | 2.827 | .005 | 1.155 | 6.495 |
| DG-3D | 4.193 | 1.387 | 3.023 | .003 | 1.456 | 6.930 |
| PC | 4.768 | 1.395 | 3.418 | .001 | 2.016 | 7.521 |
| NDS | 3.609 | 1.592 | 2.266 | .025 | .467 | 6.751 |
| CONTROL | 0(a) | . | . | . | . | . |

C. Adjusted average values for Post-MRT and Post-DAT

The tables VII and VIII show the average values for MRT and DAT, obtained by each group after performing the training.

TABLE VII. ADJUSTED POST-MRT AVERAGE VALUES

| Course type | Average | Typical error | 95% confidence interval | |
|-------------|-----------|---------------|-------------------------|------------|
| | | | Min. value | Max. value |
| AR | 26.648(a) | 1.106 | 24.466 | 28.831 |
| ET | 27.589(a) | 1.007 | 25.602 | 29.576 |
| DG | 25.709(a) | 1.186 | 23.368 | 28.050 |
| DG-3D | 27.404(a) | 1.243 | 24.952 | 29.856 |
| PC | 25.465(a) | 1.186 | 23.124 | 27.805 |
| NDS | 28.015(a) | 1.476 | 25.102 | 30.928 |
| CONTROL | 22.955(a) | 1.083 | 20.817 | 25.092 |

TABLE VIII. ADJUSTED POST-DAT-5:SR VALUES

| Course type | Average | Typical error | 95% confidence interval | |
|-------------|-----------|---------------|-------------------------|------------|
| | | | Min. value | Max. value |
| AR | 41.142(a) | .941 | 39.285 | 42.998 |
| ET | 40.280(a) | .862 | 38.579 | 41.982 |
| DG | 40.582(a) | .996 | 38.616 | 42.547 |
| DG-3D | 40.950(a) | 1.053 | 38.872 | 43.028 |
| PC | 41.525(a) | 1.011 | 39.529 | 43.521 |
| NDS | 40.366(a) | 1.254 | 37.891 | 42.841 |
| CONTROL | 36.757(a) | .927 | 34.927 | 38.586 |

V. RANKING AND PREDICTION MODELS

The real gain values of each training, obtained from tables VII and VIII are arranged in table IX so all trainings are arranged in table IX so their ranking can be observed according to the gains obtained in the development of spatial ability.

TABLE IX. COURSES' RANKING FOR IMPROVEMENT OF SPATIAL ABILITY.

| RANK | Gain MRT | RANK | Gain DAT-5:SR |
|-----------|-------------|-----------|---------------|
| 1° | NDS 5.060 | 1° | PC 4.768 |
| 2° | ET 4.634 | 2° | AR 4.385 |
| 3° | DG-3D 4.449 | 3° | DG-3D 4.193 |
| 4° | AR 3.694 | 4° | DG 3.825 |
| 5° | DG 2.754 | 5° | NDS 3.609 |
| 6° | PC 2.510 | 6° | ET 3.524 |
| CONTROL 0 | | CONTROL 0 | |

We propose a mathematic model for predicting the result of post-test measurements for all trainings according to the student's pre-test spatial ability level. So, according to the MRT and DAT each student have, it's possible to find out which level may be reached later if he performs a certain course.

With the paired data of pre/post test scores belonging to each course, the adjustment of different curves by least-squares and is chosen the most suitable expression to the data known (linear, exponential, logarithmic, potential or polynomial). The coefficient of determination R2 identifies the curve's adjustment goodness of fit.

These adjustment models of the different curves for each course. The following adjustment models for each course's different curves (y=post-test ; x=pre-test) are exposed with the most suitable choice shaded having in mind the correlation coefficient's value and the model's simplicity.

TABLE X. PREDICTIVE MODELS FOR TRAINING AUGMENTED REALITY

| MRT_RA | | R2 |
|-------------|--|------|
| Linear | $y = 0.7644x + 12.676$ | 0.60 |
| Exponential | $y = 14.574e^{0.305x}$ | 0.59 |
| Logarithmic | $y = 10.854\ln(x) - 3.4218$ | 0.55 |
| Potential | $y = 7.2746x^{0.4512}$ | 0.59 |
| Polynomial | $y = 0.0233x^3 - 0.6623x^2 + 8.0668x - 11.707$ | 0.63 |

| DAT-5_AR | | R2 |
|-------------|-------------------------------|------|
| Linear | $y = 0.8107x + 14.812$ | 0.70 |
| Exponential | $y = 19.587e^{0.0225x}$ | 0.70 |
| Logarithmic | $y = 19.28\ln(x) - 25.868$ | 0.65 |
| Potential | $y = 6.1273x^{0.5453}$ | 0.67 |
| Polynomial | $y = 0.15x^2 - 3.13x + 44.59$ | 0.73 |

From the prediction's point of view, the coefficient of determination shows the variability percent between the y variable (after test) that may be explained by the x variable (prior to test). A linear prediction model is proposed in every case because of the model's simplicity and similar magnitude to every other model according to the R2 adjustment.

TABLE XI. OPTIMUM SPATIAL ABILITY PREDICTION MODELS FOR DIFFERENT KINDS OF TRAINING.

| Course | | Regression models |
|----------------------|-------|---|
| AR based | MRT | Post-MRT = $0.7644 \cdot \text{Pre-MRT} + 12.676$ |
| | DAT-5 | Post-DAT = $0.8107 \cdot \text{Pre-DAT} + 14.812$ |
| Traditional Exercise | MRT | Post-MRT = $0.9132 \cdot \text{Pre-MRT} + 10.684$ |
| | DAT-5 | Post-DAT = $0.7333 \cdot \text{Pre-DAT} + 16.216$ |
| DG-3D | MRT | Post-MRT = $0.805 \cdot \text{Pre-MRT} + 11.593$ |
| | DAT | Post-DAT = $0.5835 \cdot \text{Pre-DAT} + 21.144$ |
| DG | MRT | Post-MRT = $0.8626 \cdot \text{Pre-MRT} + 10.581$ |
| | DAT | Post-DAT = $0.7736 \cdot \text{Pre-DAT} + 15.225$ |
| NDS | MRT | Post-MRT = $1.4395 \cdot \text{Pre-MRT} + 4.8947$ |
| | DAT | Post-DAT = $0.7348 \cdot \text{Pre-DAT} + 16.104$ |
| PC | MRT | Post-MRT = $0.9755 \cdot \text{Pre-MRT} + 7.2233$ |
| | DAT | Post-DAT = $0.5628 \cdot \text{Pre-DAT} + 23.796$ |

VI. CONCLUSION

While starting the academic year, students are proposed several short courses for developing spatial abilities. In courses

based on performance of sketching exercises with pen and paper format there is a risk of students quitting because of boredom, lack of motivation and unattractive tasks, that's why all contents and developing task should be supported by an attractive platform which may attract their attention while keeping them interested while following training.

Aiming that tasks do not become a routine so students lose interest on both training and the technology used, the training should be of short duration, with different kinds of exercises and many ways to use the tool so the students will not repeat the same kinds of exercises and consider that tool as repetitive. Dealing with it this way, the tool used for this training may favor the student's commitment to the course.

- The linear model is the most suitable choice for predicting the improvement of spatial abilities one individual may have, regardless of the training performed.
- The training with videogames is the strategy which most improves the spatial abilities, but doesn't contribute knowledge about Graphic Design content so they don't provide any learning to students.
- The training with augmented reality can be performed autonomously as material designed allows this possibility.
- The use of 3D tools improves attention and motivates student for working on Graphic Design contents.
- A short duration course of roughly 10 hours, aimed to develop the spatial ability on engineering students provides a huge improvement on spatial vision's levels.

As a pending future work, the validation of these predictive models will take place. So, the spatial ability levels will be measured predicting the level achieved through a certain training. Afterwards, that value will be compared to the one obtained once training is complete.

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Work in Progress: Update 2012 on the iCollaborate MSE Project

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INTRODUCTION

Abstract—The overall objectives of the research performed in the iCollaborate Materials Science and Engineering [MSE] project are to measure if improvements in student learning outcomes, student engagement, and successful course completion rates are possible if the structure in a basic materials engineering course is transformed from primarily deductive practice to an Information Communication Technology (ICT) enabled inductive teaching and learning environment. There are two overarching components of our project. The first component required the transformation of the course structure from deductive practice to inductive practice. This element is supported by research results in STEM education and educational theory based on cognitive and social constructivism. The second component is the ICT support as there is an additional research base that supports connections between ICT enhanced collaborative learning, distributed cognition, and enhanced student outcomes. We propose that ICT support combined with immersion in an inductive teaching and learning environment will improve student outcomes more than either singular component case.

The capabilities of the iPod Touch allowed us to build applications (apps) that utilize different multi-media formats. Eight different MSE apps have been built so far. The apps facilitate and support daily collaborative learning opportunities that target specific student learning objectives that are known to be challenging. Bi-weekly in-class, low-stakes quizzes help the students evaluate how well they are building their own knowledge base. Three kinds of data sets will be used to evaluate our research. Data set one is from deductive practice. Data set two is with inductive practice. The third data set, which we are now collecting, is similar to data set two, but with ICT support.

This work-in-progress paper will describe the project, its theoretical base, the apps, experiences with the deployment of the devices, and focus group findings. The National Science Foundation is supporting the project (NSF CCLI #0941012).

Keywords—Collaborative learning; ICT enabled inductive teaching; iPod Touch applications; Materials science and engineering; Low-stakes quizzing; MSE apps.

The objectives of the iCollaborate MSE project are to understand whether student learning outcomes, commitment, and success are enhanced if the course structure is transformed to an ICT enabled student-centered, inductive teaching environment. Because of its personalizable, multi-touch user interface, we chose the 4th generation iPod Touch as our ICT device. There are two overarching components of our project. The first component required the transformation of the course structure from deductive practice to inductive practice. This element is supported by research results in STEM education and educational theory based on cognitive and social constructivism; and, there is a substantial body of evidence that favors the inductive teaching approach [1]-[8] and a summary of this evidence has been reported elsewhere [9]-[10]. This component of the project has been successfully implemented. The second component is the ICT support as there is an additional research base that supports connections between ICT enhanced collaborative learning, distributed cognition, and enhanced student outcomes [11]-[14], which also has been reported [9]-[10]. We proposed that ICT support combined with immersion in an inductive teaching and learning environment will improve student outcomes more than either singular component case.

The multi-media format of the iPod Touch allowed us to build applications (apps) that present information in a variety of formats: lists, graphs, visuals, and audio. The following apps have been built: Vocabulary, Concept Questions, Tune-Up, Basic Knowledge, Material Properties, MSE Convert, Composites Calculator, and we are building the content for the completed MSE Knowledge Tools application. These apps are designed to facilitate and support daily collaborative learning opportunities that target specific student learning objectives that are known to be challenging, (also reported elsewhere [9]-[10]). The materials within the applications are conceptually contained so that while exploration and higher order connections are encouraged, the students are not overwhelmed with too much data or have no contextual basis for judgments.

Bi-weekly in-class, low-stakes quizzing help the students evaluate how well they are building/reconstructing their own knowledge base. The results from the low-stakes quizzes are used to identify the problems and concepts that the students

are still struggling with after the mini-lectures and collaborative work, and are subsequently covered once more in the lecture portion of the class. The students see this as a highly effective way to facilitate their own learning, as well as way to compare their own outcomes to the outcomes of their peers. From the faculty perspective, the remaining outstanding learning objectives are clearly identified in this process and succinctly move the course toward a very robust continuous improvement loop.

Focus groups were used as formative assessment tools to help us evaluate and understand the perceived effectiveness of the targeted collaborative work, the low-stakes quizzes, and the iPod apps from the student perspective. While student teams were engaged in their ICT enabled collaborative exercises, most students wanted an additional, personal device to continue their studies beyond group work. We found that students consider iPods as personable devices.

STUDENT PERCEPTIONS - FOCUS GROUP RESULTS

Two groups of students (alpha and beta) have provided focus group feedback, thus far, for the project. A third focus group was recently recruited to further the development and effectiveness of the apps deployment cycles. In the alpha deployment, the apps were not all that well integrated into the course activities, and we had just made the shift to all collaborative learning, peer learning, and low-stakes quizzing. We felt this deployment was for more us to understand how the students would react to the devices and for us to understand how to deploy them, rather than for data collection purposes. In the beta deployment, the apps were much more integrated into the course, but most importantly, the collaborative learning and the low-stakes quizzing were well integrated into the course. Interestingly, the student feedback (perceptions) from the two cycles of deployment was consistent. While the students often complained about the in-class, low-stakes quizzes during the class sessions, they rated them as the most effective of all the pedagogical strategies employed in the course. More than 90% of the students find the low-stakes quizzes of value, and can understand the alignment among the various course components [10]. The students also feel the quizzes encourage them to complete the collaborative work on time and keep up in their course work. The students are indeed correct in that completing the collaborative work is necessary to do well on the quizzes, but the quizzes are designed to provide individual accountability and mastery. While the students may not understand these complexities, they almost universally agree (perceive) that the low-stakes quizzes help them master course outcomes.

The students rated the collaborative work as the second most effective pedagogical strategy in the course [10]. While the ratings for the collaborative work was slightly less (2%-5%) on average [10], the differences are perhaps more about perception as the low-stakes quizzes provide more immediate feedback and count for more in their overall course grade. And, there is no chance to redo the work in the quizzes. Here student feedback is consistent with other work on low-stakes retrieval effectiveness [15].

Based upon an initial assessment of our learning outcomes data (exams and projects) we believe that the combination of the targeted collaborative work and low-stakes quizzing does improve student outcomes. Previously, we did not see learning gains with low-stakes on-line quizzes in a deductively taught course with traditional homework assignments.

Initially, we were disappointed that the students were rating the new iPod apps of lower use than the other course strategies [10]. Do the students really prefer taking an in-class quiz, rather than using new MSE specific iPod apps to facilitate their learning? In order to find out, we recently convened our third focus group. The results from that focus group provided much insight as to why the student perception was that the apps are less effective tools than the other pedagogical approaches in the class. First, even though the iPod apps provide immediate feedback on their own outcomes, the apps do not provide any comparison data regarding the performance of their peers. Students want to know how many of their peers are struggling with similar concepts. In retrospect, this is obvious. The students want the apps to be “operationalized” in the same way as the low-stakes quizzes and collaborative work are. In class, we discuss the problematic student learning outcomes one more time in lecture after we review the results of the quizzes or collaborative work. We need to do the same when we are reviewing the results from the apps! We also found that many students will not generally complete all the app work unless they receive some reward for it (also not surprising). The reward should match all the other course work, and the students must also perceive the completion of the apps as essential to their success. Third, the students have an overabundance of course resources and, many students choose to optimize their time with the reward. The highest achieving students complete the apps regardless, as do the students who are struggling the most in the course. It is the students in the middle who are choosing to use the apps less. We have found successful course completion rates and retention rates have gone up after the iCollaborate approach has been implemented, which is accompanied by an overall rise in course GPA and scores on exams (which will be outlined in a future paper). The number of high achieving students remains the same. But, as expected the iCollaborate pedagogical has a much more meaningful change in outcomes for the students who traditionally struggle with the course.

CONCLUSION

The iCollaborate MSE project has successfully created an innovative approach to inductive practice where most of the known STEM education best practices are present (plus ICT support). The project has created 8 MSE apps for the iPod Touch. The next phase of the project will be to modify the apps to provide peer comparison data/difficulty level along with the individual group outcomes. We must add a sufficient reward structure within the course to stimulate iPod app use.

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Work in Progress: Engaging New PIs Using an Electronic Mentoring System

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Abstract— Success as a Principal Investigator (PI) of a National Science Foundation (NSF)-funded project requires both project management and change leadership skills, disciplinary knowledge, and familiarity with the project itself. Because gaining the skills of management and leadership involves either first-hand or vicarious experience, new PIs might struggle to find the best course of action when facing a difficult situation. While individual mentoring could enable new and prospective PIs to acquire these skills, arranging a mentor for all new PIs is not feasible. In addition, prior work has indicated a preference in faculty for gaining knowledge informally (e.g., using case studies) from mentors who have experienced similar situations rather than in more formally assigned partnerships. Thus, we seek to understand whether a many-to-many electronic mentoring website is an effective method to aid new and prospective PIs in a range of NSF programs in developing project and change management skills.

Keywords—component; electronic mentoring; community of practice; principal investigators

I. INTRODUCTION (HEADING 1)

Successful Principal Investigators (PIs) utilize skills in both project management and change leadership in addition to their disciplinary and project-based background. However, developing these skills takes time and experience, so new PIs may find it difficult to decide on the best course of action in a complex situation. While individual mentoring would be a way of gaining these skills, arranging a mentor for all new PIs is not feasible. In addition, prior work [1] indicated a preference in faculty for gaining knowledge informally (e.g., using case studies) from mentors who have experienced similar situations rather than in more formally assigned partnerships. Thus, we seek to understand whether a many-to-many electronic mentoring website is an effective method to aid new and prospective PIs in a range of National Science Foundation (NSF) programs in developing project and change management skills.

The National Academy of Engineering (NAE) has developed a website that will provide many-to-many electronic mentoring for new and prospective PIs. The Principal Investigators Garnering Useful Information on Developing

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[Project] Effectiveness site (<http://govpiguide.org/>) includes information valuable to new and prospective PIs from the Advanced Technological Education (ATE), Transforming Undergraduate Education in STEM (TUES), Robert J. Noyce Scholarship (Noyce), and Research on Gender in Science and Engineering (GSE) NSF programs. Although the final development process is ongoing, several features are active.

II. WEBSITE FEATURES

The 28 Video Scenarios show the experienced PIs from discussing fictionalized situations that new PIs might encounter. The scenarios were written based on interviews with 49 veteran PIs so they include some aspects but no details of those the PIs themselves experienced, allowing for frank discussions without identifying individuals or institutions. The Video Scenarios fall into one of five broad topic categories: Staffing, Partners, Finance, Communications, or Donors. For each scenario, the interviewee answered three guiding questions, with each answer broken out into a separate video to allow website visitors to choose what information on which to focus. The three guiding questions were:

- What additional information do you wish you had and what assumptions are you making?
- Given the information provided, what advice do you have for the principal investigator? Please be explicit about the assumptions you are making and how they are influencing your guidance.
- How would you advise a new prospective principal investigator to avoid the indicated situation?

Each Video Scenario page includes 2-4 PIs responding to each of the three questions, and users can sort by question, respondent, NSF program, or topic categories as they search for information related to their own situation and tailor their electronic mentoring to their own needs.

In addition to the Video Scenarios, the site contains Leadership Perspective videos, in which experienced researchers, faculty members, and NSF program officers who discuss topics of potential interest to users. Sample topics include avoiding common problems among new PIs, overcoming resistance, diversity, and assessment and evaluation. Like the Video Scenarios, the Leadership Perspective videos are approximately one minute long, which

presents new information in a short, easily-processed form that provides the viewer with the awareness needed as a basis for further research on that topic [2]. The videos also have associated transcripts.

Several other tools support the development of on-line communities. The website supports RSS feeds and users can create their own resource library (e.g., documents to share, external web sites, recommendations on consultants, etc.), personalize their home page, chat live with other users (both new and experienced PIs), and share links and bookmarks. Other features include the ability to establish a new community, invite others to join, keep a common calendar within a community, discuss proposal ideas or other topics of interest, and share documents. Finally, users can post photos (for example, of activities at PI meetings) and contribute to a blog.

Although users will be required to log-in, membership is free and all aspects of the site will be available to all users. Users will join one of the networks (ATE, TUES, Noyce, or GSE) as their primary association, but will be able to join the other networks as well.

III. EVALUATION

An evaluation form has been posted on the site and users will be encouraged to provide feedback about their experience. The survey asks general questions (e.g., overall impression of

the site) as well as more specific questions on the utility of various PI GUIDE aspects (e.g., usefulness of the social networking capabilities; quality and helpfulness of the videos). We also ask whether the site has increased their knowledge of project management and change management and how they plan to use that knowledge in the future. In an effort to maintain continuous improvement, we also ask respondents to list any additional resources, information, links, or features that would be useful additions to the PI GUIDE website.

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Work in Progress: The University of Texas System Louis Stokes Alliance for Minority Participation: A State-wide Initiative to Promote STEM Undergraduate Research

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Abstract— For 20 years, nine institutions in the University of Texas System and five partnering community colleges have collaborated to promote STEM undergraduate research through the Louis Stokes Alliance for Minority Participation (LSAMP). The primary programmatic activity of the Alliance is its Summer Research Academy (SRA) which has engaged a total of 1,565 undergraduates. Of these, 242 have been supported within the last five years. The Alliance has also partnered with the US Department of Energy to support a number of faculty and student teams (FaST) to engage in research at several national laboratories. Since 2003, 37 students and four faculty members have participated in this effort. This paper will describe both the SRA and FaST. Data on program participation and success will be discussed. The Alliance is now posed to expand its effort to include research abroad. The general direction of the Alliance for the next five years will be discussed.

Keywords—undergraduate research; STEM; National Science Foundation

PROJECT HISTORY AND ACTIVITIES

The University of Texas (UT) System Louis Stokes Alliance for Minority Participation (LSAMP) became a coordinated effort in 1992 with leadership that consisted of presidents and provosts from the entire UT System. The objective of the first phase was to increase the number of STEM undergraduate degrees that were awarded to underrepresented minority (URM) students. Phase II focused on increasing the number of community college students transferring to four-year universities in the STEM disciplines; the initiative to increase BS production continued. Phase III saw a shift in objectives when the primary goal became an increase in the number of students entering into STEM MS or Ph.D. programs following receipt of their undergraduate degree. Phase IV was inceptioned in 2007 and the focus continued to be graduate degree promotion but was expanded to include international travel/research experiences.

The primary activity of the UT System LSAMP is the annual Summer Research Academy (SRA). The SRA is an

eight-week program in which undergraduate STEM majors work on an intensive research project with a tenured or tenure-track faculty member at one of the nine UT System campuses. The SRA is intended to be an exchange program in which the students have the opportunity to engage in research outside of their home institution to preview another UT System campus's programs and environment. The participating students work as part of a research team under their faculty mentor's supervision on a cutting-edge STEM project. Students at each of the campuses also participate in a series of developmental workshops, videoconferences, laboratory trainings, and other meetings to enhance their research experience. They learn how to create conference-style research posters and present their work locally at the end of each SRA. The annual UT System LSAMP Student Research Conference, held in the fall semester gives the SRA students the opportunity to gain more presentation experience and to share their research findings with a national audience.

Since undergraduate research is the proven method of the UT System LSAMP to increase minority student graduation, we have partnered with the Department of Energy to offer faculty and students from our partner campuses the opportunity to participate in the Visiting Faculty Program (VFP), formerly the Faculty and Student Teams (FaST) initiative, at one of the US National Laboratories. As part of VFP, each faculty member will lead a team of 2-4 undergraduate and/or graduate students at a national laboratory. The team will work on-site at the national laboratory as part of a larger research group on an established project. The team will be hosted and mentored by a research scientist housed at the lab and will perform their specific research for 10 weeks. In the past, the UT LSAMP has sent teams to Argonne National Laboratory, Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, and most recently, Oak Ridge National Laboratory. The teams may originate from any campus in the UT System and the lead institution (UT El Paso) submits a NSF proposal on their behalf to secure the funding and manage the grant.

National Science Foundation (HRD-0703584)

PROGRAM SUCCESS

For almost 20 years, the UT LSAMP has been one of the premiere research programs for undergraduate students in the UT System. Over 1,500 STEM students have conducted meaningful research as participants in the SRA and have developed professional skills through the various activities offered as part of the SRA experience. Project goals have been met and exceeded during the duration of the grant.

Since its inception, the UT System LSAMP has tracked enrollment of and degrees awarded to URMs in STEM disciplines by partner institutions. The results achieved to date are extremely encouraging. Enrollment has grown steadily from 8,367 in Fall 1991 to 17,593 in Fall 2009. This is an increase of 110% with respect to 1991 LSAMP baseline data. Similarly, the number of baccalaureate degrees awarded annually to underrepresented minorities in STEM disciplines has increased from 575 in AY 1992-1993 to 2,004 in AY 2009-2010. The rise is an unprecedented increase of 351%. This increase in degree production has consistently placed four institutions in the Alliance among the Top 10 in the nation for awarding undergraduate degrees to Hispanics in Engineering, Education, Nursing, and Business to name a few. In 2009, STEM fields accounted for 22.1% of UT System degrees awarded as compared to the national public university average of 18.4%.

A large range of STEM majors is represented by SRA alumni with the most common being Biology (21%), Electrical Engineering (10%), Computer Science (9%), Mechanical Engineering (9%), Chemistry (8%), and Mathematics (8%). The majority of students in the VFP have been from various engineering fields and chemistry.

LSAMP'S FUTURE

In October 2011, the UT LSAMP submitted a fifth proposal to the NSF for funding as a Model Senior Alliance to conclude the work it has done for 20 years. This proposal will continue best practices and will address three primary objectives: 1) enhancing the UT System SRA to ensure that a significant number of students, including veteran students, participate in a sequence of research experiences, starting with on-campus training and culminating with a UT System summer undergraduate research exchange, a national laboratory opportunity, or a research abroad capstone experience; 2) ensuring that URM students who are co-enrolled in partnering community colleges and universities complete their STEM associate degrees and advance towards their baccalaureate degrees; and 3) creating synergy among closely related NSF-funded projects-e.g. S-STEM, STEP, REU, and AGEP- at each one of the Alliance's partnering institutions to create pathways to success for URM STEM students. The proposal also included the addition of two community colleges to the Alliance: Tarrant County Community College District and Tyler Junior College.

The Alliance's plan for the next five years, which is derived from an analysis that looks at internal strengths and weaknesses and external opportunities and threats, is to provide STEM students continued opportunities to perform research at UT System universities, the US Department of Energy's national laboratories, and various international research sites.

CONCLUSION

Based on NSF's goal to diversify the STEM workforce and include more URMs in academia, the UT LSAMP's mission is more important than ever before. The global research community continues to grow and the demand for competent undergraduate and graduate students will continue to increase in the United States. The UT LSAMP is in the unique position to make a positive change for URM involvement at the undergraduate and graduate research level. The UT LSAMP's work to improve the number of URMs graduating with STEM degrees and continuing on to graduate school is also directly in line with the Texas Higher Education Coordination Board's "Closing the Gaps" initiative. This plan includes four focus areas: 1) student participation in higher education, 2) student success in college, 3) excellence in teaching, and 4) high quality research and scholarship. Because of this, the UT System LSAMP will help insure that talented students from diverse backgrounds will have the support necessary to earn bachelor's and, ultimately, doctoral degrees in a timely fashion and become future leaders in STEM disciplines both in Texas and across the nation.

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Peering at the peer review process for conference submissions

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Abstract— For many scholars conference papers are a stepping stone to submitting a journal article. However with increasing time pressures for presentation at conferences, peer review may in practice be the only developmental opportunity from conference attendance. Hence it could be argued that the most important opportunity to acquire the standards and norms of the discipline and develop researchers' judgement is the peer review process - but this depends on the quality of the reviews. In this paper we report the findings of an ongoing study into the peer review process of the Australasian Association for Engineering Education (AAEE) annual conference. We began by examining the effectiveness of reviews of papers submitted to the 2010 conference in helping authors to improve and/or address issues in their research. Authors were also given the chance to rate their reviews and we subsequently analysed both the nature of the reviews and authors' responses. Findings suggest that the opportunity to use the peer review process to induct people into the field and improve research methods and practice was being missed with almost half of the reviews being rated as 'ineffectual'. Authors at the 2011 AAEE conference confirmed the findings from the 2010 data. The results demonstrate the lack of a shared understanding in our community of what constitutes quality research. In this paper in addition to the results of the above-mentioned studies we report the framework being adopted by the AAEE community to develop criteria to be applied at future conferences and describe the reviewer activity aimed at increasing understanding of standards and developing judgement to improve research quality within our engineering education community.

Keywords—peer review, research quality, engineering education research.

I. INTRODUCTION

For many new scholars, a conference paper is the first way to try out an idea on those who should be able to offer informed opinion. A common practice is to turn conference papers into journal articles in the light of feedback received on the initial presentation. However, with ever decreasing time to present and have discussion at most conferences, the comments

of anonymous reviewers of the submitted paper may be the only developmental help many authors get from conference attendance. We argue that with this in mind reviews of conference papers need to be taken seriously and not treated as a mere formality to meet government and/or institutional requirements to be regarded as a research publication. It is therefore worth asking just how well conference reviews are performing this developmental role.

II. BACKGROUND AND MOTIVATION

Arguably, the most important opportunity to acquire the standards and norms of the discipline and develop researchers' judgement is the peer review process [1] – but this depends on the quality of the reviews. 'Good' feedback has been identified as being timely, specific and relevant [2], yet often reviews lack these basic qualities. Reasons for poor feedback include the quality of feedback is generally not assessed, lack of time or the reviewers available do not have the required expertise. This may also be because reviewers see their role as a gatekeeper rather than for quality improvement or development. For example, in 2011 the authors received a review for a research paper investigating peer reviews that stated:

I personally do not think that it is the reviewer's role to be friendly, or provide training to naïve researchers. Most important seems to assist the editor in deciding whether a paper is acceptable or not for publication (i.e. screening).

With the advent of various forms of online publishing the peer review process has recently come under scrutiny [1], particularly as the process functions as a kind of censorship, deciding what personnel and whose views are deemed acceptable in any scholarly society. Needless to say, we are not interested here in this gatekeeping function. Rather we want to focus on the way that peer review can and ought to be a *conversation* among people with similar intellectual interests for the purposes of improving understanding and expressing (and where necessary altering) community standards and opinions.

It has been well demonstrated that there are many ways in which peer review fails its developmental function [3] including through restricting the dissemination of new ideas, excessive in-group gatekeeping and inconsistency [1, 4]. Origgi [5] has argued that an important function of the review process is a “*conversation in slow motion*” amongst scholars in order to improve, disseminate and develop their ideas and we argue that such a conversation is much needed in the emerging field of engineering education research. Academics engaging in this field frequently have to argue for the rigour and significance of their work [6]. While some of the necessity for this argument is a result of institutional resistance to the pursuit of educational research by engineers, some of it arises from a perception (sometimes accurate) that conference presentations and published work in this still emerging field are not of the highest quality. There are only a small number of graduate students undertaking engineering education research dissertations at Australasian universities. Hence, most researchers in this field were trained in quite different paradigms than those that underpin educational research. Bridging the epistemological divide between technical training and the more social science of education continues to be problematic for some [7]. Improvement requires not only developing knowledge of the relevant research theories and methods, but for novices to develop their judgement about what is acceptable practice in the field [8]. Conferences are important times and places to share strategies and to encourage more systematic and well grounded research.

The current review process does not encourage conversation to change ideas on both sides, but is more often a hurdle to be overcome for publication. We believe that work in our field can be improved by conversations, debate and publication, but we want to know what role peer review currently fulfils and we want to consider what kinds of mechanisms are likely to maintain and improve standards while allowing the conversation to go on. Finally we want to consider how such mechanisms might be instituted in this community of engineering education research.

The Australasian Association for Engineering Education (AAEE) has been actively pursuing improvement in engineering education research quality, including examination of the quality of the peer review process. In this study we were investigating whether peer review as practiced in the AAEE annual conference has a developmental function for authors. Papers submitted to this conference are double-blind peer reviewed, however the review criteria are currently subject to change at the discretion of the local organising committee. We were interested in authors’ assessment of the impact of reviews of their paper, and the quality of the reviews themselves. Preliminary studies were conducted using the 2010 data [9]. These studies were repeated in 2011 to confirm the findings of the previous year. We were also looking for evidence of shared understanding between authors and reviewers of the standards required for research. In 2011 we decided to specifically investigate the authors’ judgement of the quality of their own paper and whether academic rank is a reliable indicator of expertise in engineering education research. The intention of these studies was to inform the design of a developmental process for reviewers. This paper reports the

2010 data with the new 2011 data, describes the adopted strategy for improving the peer review process, and outlines the future work proposed to continue this line of research.

III. METHODS

Authors who submitted a paper to the 2010 and 2011 AAEE conferences were invited to assess the usefulness of the reviews they received. The online tool SPARK^{PLUS} [10] was used to collect and store authors’ responses. In line with ethical practice, when authors initially logged on they were asked to indicate their agreement to their responses being used in this research.

In the analysis that follows for the 2010 AAEE conference we considered only the reviews of papers that were accepted into the ‘Research’ category (n= 66 reviews: two each for 33 papers), since clearly expressed criteria were provided for these papers and were available for authors and reviewers from the beginning of the review process. These criteria are listed in [9]. The 2011 conference did not have an explicit research category so responses from authors of all papers were considered, including authors whose papers were rejected (n = 74 reviews: two each for 37 papers).

Three types of data are included in this paper:

- authors’ assessment of their reviews (2010 & 2011)
- the research team’s analysis of the reviews (2010 & 2011)
- authors’ self assessment of their reviewed paper (2011)

A. Authors’ assessment of their reviews

In 2010 23 authors (70%) from the research category responded to the invitation to assess and comment on their reviews and we have considered all of these here. The online tool used to collect these assessments comprised a set of open-ended questions about the impact of the review.

Author responses were entered into NVivo [11] and coded for recurring themes using the constant comparative method [12] to build up a codebook for analysis. The coder was a graduate student who had not been involved in the original review process although he had been a co-author on one of the papers submitted. He did not submit an author response and thus represents someone with experience of the community but no prior involvement in the review process which might have biased his reading of the texts. He was trained in content analysis methods [13] and results were discussed with the other researchers on the project to establish a shared understanding of the content of the categories. The categories established through this process to describe the reviews are:

- Counterproductive (CP)
- Ineffectual (I)
- Cruel to be kind (CK)
- Positive impact (PI)
- Future impact (FI).

The content of these categories is described in more detail in [9].

In 2011 authors were invited to rate their reviews against these categories using the question and rating scale shown in Figure 1. All authors received information about the categories in the rating instructions.

Figure 1. Authors' ratings screen for 2011 reviews

B. Analysis of the reviews

We were surprised by some of the favourable ratings authors awarded their reviews in 2010. To benchmark these ratings, we developed a content analysis of the reviews, using the same method as for the author's responses, to gain a more objective description of them.

The reviews of the 23 authors who participated in this research in 2010 were analysed by the graduate student using the method outlined in Section A above. In coding the reviews the explicit advice within each review was examined to determine whether it fell into any of the following five major categories:

- Gaps in logic
- Typographical/grammar errors
- Inadequate data handling
- Identifying relevant literature
- Quoted from paper under review

In 2011 another member of the research team used the same categories to code the reviews of those authors who responded in that year to the invitation to assess their reviews.

C. Authors' self-assessment of their reviewed paper

In 2011 authors were invited to rate their own paper according to the same scale used by reviewers for the 2011 AEE conference:

- 3 Unsuitable for this Conference
- 2 Strongly Reject Paper
- 1 Weakly Reject Paper
- 0 Borderline Paper
- +1 Weakly Accept Paper
- +2 Strongly Accept Paper
- +3 Strongly Accept + Worthy of Best Paper Nomination

The statement and rating scale is shown in Figure 2. As well as rating their paper, 2011 AEE conference authors were asked to identify their paper's strengths and weaknesses.

Figure 2 Authors' self-assessment rating screen

IV. RESULTS AND DISCUSSION

A. Authors' assessment of their reviews

Not all authors took the opportunity to comment in writing on their reviews, but the comments from those who did in 2010 were analysed into the categories in Table I. Note each author response was allocated to only one (the most dominant) category.

TABLE I. CATEGORIES OF AUTHOR RESPONSES TO OPEN-ENDED QUESTIONS

| | 2010 Reviews % (n = 30) | 2011 Reviews (authors) % (n = 37) |
|-------------------|-------------------------------|---|
| counterproductive | 10 | 9.5 |
| ineffectual | 47 | 26 |
| Cruel to be kind | 3 | 9.5 |
| Positive impact | 33 | 43 |
| Future impact | 7 | 12 |

Counterproductive reviews were those which authors felt were actual impediments to improving their paper, either because the tone of the review was too carping or the reviewer had misunderstood the work. The high number of ineffectual reviews is of particular concern in the light of the present discussion calling for reviews to have positive impact and improve future work. In the eyes of the authors at least, the unhelpful reviews outnumbered the helpful ones.

While the 2010 data was categorised by researchers from author comments, in 2011 authors were asked to directly rate their reviews as best fitting into one of these categories. Each author was asked to rate each of their two reviews and 28% of authors (37 of 132) responded. While there is a pleasing reduction in the number of reviews assessed as ineffectual by the 2011 authors, this reduction is not statistically significant ($p = 0.07$). There is a corresponding increase in the number of reviews assessed as having some impact whether that impact is likely to be immediate (i.e. improving the paper being reviewed) or for future research projects. The results listed in Table I suggest that in the view of authors, the reviews in 2011 were more useful than those in 2010.

B. Analysis of the reviews

As described in the methods section, explicit comments in the reviews were coded into five categories listed in Table II. Table II also shows the number of reviews that contained explicit advice in each category for both of these conferences.

Although the provision of criteria in 2010 was meant to make it clear to reviewers what the expectations of the conference organizing committee were, only 4 reviewers made explicit reference to them. Instead reviewers seemed to respond to the papers on the basis of what they decided was important (Table II), such as grammatical errors.

Gaps in logic were identified with advice such as “*lack of alignment between the research question, the literature cited, the data and the analysis*”(2010) or the fact that “*conclusion is not related with the results of this study*”(2011). While this is potentially helpful advice, a lack of specificity was often apparent. New scholars may need to be told what alignment looks like for instance, or at least what the reviewer means by alignment. There is very little difference in the number of comments in this category from the 2011 reviews compared to the 2010 reviews.

TABLE II. CATEGORIES OF EXPLICIT ADVICE GIVEN BY REVIEWERS

| | 2010 Reviews % (129 comments from 46 reviews) | 2011 Reviews % (135 comments from 74 reviews) |
|---------------------------------|---|---|
| Gaps in logic | 30 | 28 |
| Typographical/grammar errors | 26 | 18 |
| Inadequate data handling | 21 | 21 |
| Identifying relevant literature | 13 | 10 |
| Quoted from paper under review | 9 | 10 |
| Other | | 13 |

The attention to typographical errors in 2010 was a surprise but is in line with journal review practice. While there are fewer comments in this category from the 2011 reviews than the 2010 reviews, the difference is not statistically significant ($p = 0.116$).

Reviewers' comments on data handling tended to be more specific, drawing attention to ways to improve tables or what extra information could be added to clarify or support the author's argument, for instance. For both the 2010 and 2011 reviews, 21% of comments related to inadequate data handling.

Similarly, where reviewers drew attention to specific sources in the literature we expected that this would help improve not only the paper under discussion but future work as well. There were examples such as “*Make a direct connection to the Bradley Review and the government response, so all readers can understand the importance of this study and how it could relate to their institution*” (2010) and others giving actual citations. Relatively few (13% in 2010 & 10% in 2011) pointed out where authors might go in the literature to improve their argument.

Quotation from the paper under review was in our opinion another form of specificity in advice but only 9% (2010) and 10% (2011) of the reviews identified the actual words in the paper that were of concern. If the aim of review is partly to improve practice, then reviewers need to be specific about how to do so and make clear what was wrong and how it could be corrected.

In 2011 review statements that did not align with any of the existing categories were aggregated into an ‘other’ category. The ‘other’ category consists of 1 comment that the paper concerned does not fit any of the conference themes, 8 comments regarding the 6 page limit being exceeded (6% of all

comments) and 8 comments (6% of all comments) saying that the paper is/is not a ‘research’ paper or is a ‘show & tell’ paper and some include why the reviewer has that opinion e.g. “*The paper is lacking robust research methodology, and objective measures and evaluation of the outcomes*”(2011). In 2010 only the reviews of papers in the ‘research’ category were analysed while for 2011 reviews of all papers were analysed as there was no specific research category. The similarity in the proportion of all comments across the five categories between the 2010 and 2011 conferences confirms the initial 2010 findings that, in general, reviews did not provide useful information to authors and did not demonstrate good feedback practice by being specific. Yet Table I shows that authors perceived the 2011 reviews as more helpful than the 2010 reviews.

This perception is difficult to understand as apart from the slight reduction in focus on typographical and grammar errors, there is no significant difference in the distribution of comments between the two conferences. We did observe that there were some one line reviews for 2010 papers such as: “*Overall a good paper presenting an interesting evaluation of collaborative learning*” whereas the 2011 reviews were generally longer and there were no one line reviews. De-identified information from the 2010 reviews was discussed with delegates in an open forum at the 2010 conference and we could speculate that this attention to the review process may have encouraged the non-trivial reviews in 2011. However, as noted above our analysis of the reviews found them no more helpful for influencing quality research than in 2010.

C. Authors' self-assessment of their reviewed paper

Sixty authors of papers submitted to the 2011 AAEE conference responded to the invitation to self-assess their paper and rate it on the same scale used by the reviewers. The range of ratings used by authors varied from -1 (weakly reject paper) to +3, while reviewers' ratings were in the range from -2 (strongly reject paper) to +3. Figure 3 shows the difference between the authors' self rating of their paper (S) and the average of the reviewers' ratings of the paper (R). As shown in Figure 3, 18% of authors rated their paper at exactly the same level as the average of their reviewers ($S = R$). For 45% of authors there was a difference of 1 or less between their rating and the average of their reviewers, while for 37% of authors this difference was greater than 1. Overall 75% of authors rated their paper higher than the average of the reviewers' ratings for their paper.

Examining the academic rank of authors who rated their paper the same as the average of their reviewers and those with a self rating more than 1 category higher or lower than the average of their reviewers showed that there is no discernible link between academic rank (Lecturer/Senior Lecturer/Associate Professor/Professor) and whether the author could accurately predict the average of their ratings from reviewers. These results confirm the findings reported in [14] that for their medical journal “*characteristics such as higher academic rank...failed to predict higher-quality reviews*”. This is not surprising as many members of the engineering education community in Australasia earn their PhD in engineering before they develop an interest in engineering

education or indeed in engineering education research. In contrast some of the more junior members of our community may earn their PhD in engineering education research. This has the consequence that their academic rank may not reflect their expertise in this area.

Not all authors that rated their paper also identified the paper's strengths and weaknesses – in fact there were 33 responses from the 60 authors that rated their paper. These strengths and weaknesses nominated by authors were compared to the strengths and weaknesses identified by their reviewers to investigate if authors and reviewers agreed. In our estimation some high-quality reviews were unappreciated by the authors as they did not understand comments referring to frameworks, research methods and qualitative analysis.

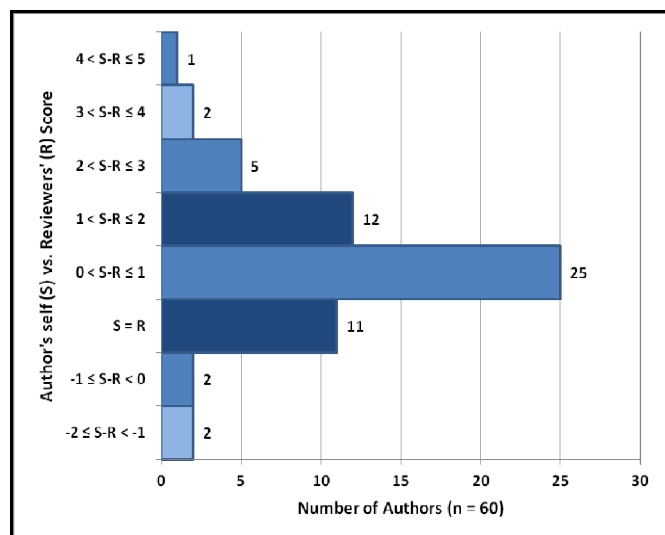


Figure 3. Authors' self-rating of paper (S) compared to the average of the reviewers' ratings of the paper (R)

Most reviews (58%) commented on the issue that the author had identified as a strength, and most of these reviewers (63%) agreed with the author that this was a strength, the remainder thought the paper was weak in the identified aspect. The authors' nominated weaknesses were identified by 36% of reviewers, with 52% of reviewers commenting on weaknesses other than those identified by the author.

This variability between authors and reviewers in terms of both rating papers and identifying strengths and weaknesses of the papers may not necessarily be a reflection of the authors' expertise and judgement, since some recognised experts differed significantly from their reviewers. It could also be an indication of the reviewers' (lack of) expertise. These results indicate that the academic rank of authors and reviewers is not a reliable indicator of the quality of conference papers submitted or reviews written about these papers.

The results reported in this paper (author ratings and comments from their reviews and their self-rating of their papers compared to the reviewers ratings) demonstrate that there is not a shared understanding in the AAEE community of what constitutes quality research in engineering education. Establishing such a shared understanding is important if engineering education is to continue to develop as a credible

research domain. Dialogue on research is as important for establishing a shared understanding of the required standards as it is in establishing the standards for assessing student learning outcomes. The UK-developed Assessment Manifesto [15] urges a move to the establishment of appropriate forums for the development of a shared understanding of standards across multiple communities:

Assessment is largely dependent upon professional judgement and confidence in such judgement requires the establishment of appropriate forums for the development and sharing of standards within and between disciplinary and professional communities.

Consequently any developmental process for reviewers should be designed with an opportunity for discussion between the participants about research standards.

The three inter-relating aspects of the peer review process: review criteria, reviewers, and authors need to be addressed if we are to have any confidence in peer review contributing to ongoing research quality. With this in mind the AAEE Executive tasked the authors of this paper to develop reviewing criteria that can be applied for all future AAEE conferences, and to devise a reviewer developmental process for AAEE members.

V. ADOPTED STRATEGY TO IMPROVE PEER REVIEW

The process of developing reviewing criteria for future AAEE conferences was focused around the use of a Delphi panel [16]. This panel was convened to establish reviewing criteria for future AAEE conferences. The authors and the Chair of the 2012 AAEE conference reworked the Journal of Engineering Education (JEE) criteria to better fit the Australasian community and then sought comments from twelve researchers of varied experience (nine Australian and three international) on these reworked criteria. The first round of Delphi panel responses has been incorporated into restated review criteria. These restated criteria were then distributed to the Delphi panel for further comment. At the time of writing we are waiting for responses to these criteria

Reviews using these criteria will then be written for several example conference papers so that members of the AAEE community will have exemplars to indicate not just the criteria to use, but also the expected standards of writing about research and practice that meet those criteria. These exemplar reviews will be available via an electronic site (discussion forum, blog or wiki) where AAEE community members can familiarise themselves with the criteria and standards and participate in discussion of engineering education research. This site will augment but not replace standard peer review which will still be necessary for institutional reasons.

All members of the AAEE community (both authors and reviewers) will then be invited to participate in a collaborative peer review activity that will be designed according to the framework outlined in [17], as follows:

- Individual: Participants review and provide feedback on an exemplar paper using the chosen criteria

(entering their reviews into the online tool SPARK^{PLUS})

- Collaborative: Participants are able to anonymously compare the reviews to each other and explore the reasons given for different ratings by other participants. An open review discussion forum will be made available to seek clarification and/or debate differences etc.
- Confirmation: Participants confirm their understanding by rating and providing feedback on another exemplar paper using the chosen criteria (entering their reviews into SPARK^{PLUS})

At least one round of these activities is planned to be completed before the review process commences for the 2012 conference.

VI. FUTURE RESEARCH

These results suggest that the academic rank of authors and reviewers does not correlate with the quality of conference papers submitted or reviews written about these papers. The authors of this paper suggest that whether an author is likely to develop expertise in this domain will depend on whether and how strongly they identify themselves as an engineering education researcher.

Identity theory [18, 19] will be used as the lens to analyse the interactions between authors/reviewers on the discussion forum, and authors' responses to reviews of their paper/s. Identity models are ways of thinking about educational research which appear to either enable or constrain the acquisition of research expertise [20]. Interviews with individuals who display attributes of various identity models within the Australasian engineering education community will also be used to investigate any link between professional identity and development of research expertise.

VII. CONCLUSIONS

This study provided contradictory results between authors' perceptions of their submitted papers, their reviews and analysis of the usefulness of the same reviews. This indicates that there is little shared understanding in the Australasian engineering education community of what we mean by quality research in engineering education.

The study confirmed the results of Callaham and Tercier [14] that academic rank is not a reliable indicator of the quality of a paper or a review written on it. This is not surprising in our community since most members were not trained in educational research methods [7]. However this is no reason not to work towards improving the expertise of the community and the Australasian Association for Engineering Education is committed to improving the knowledge and expertise of its members with a collaborative peer review development activity. A critical component of the proposed process is the opportunity for discussion which is necessary to establish a shared understanding of standards.

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Work in Progress: A Model for Facilitating Problem Based Learning

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Abstract— This work in progress reports preliminary findings from a study of six teams in a well-established Problem Based Learning (PBL) curriculum. As PBL gains popularity in engineering curricula, it is increasingly important to understand faculty roles in order to best prepare faculty for this type of teaching and to effectively design meaningful learning environments. Because PBL facilitation requires skills and techniques that differ markedly from traditional content-delivery modes, engineering faculty need a clear model to describe their roles and practices in such an environment. To develop such a model, we employ the theory of cognitive apprenticeship to analyze audio-video recorded sessions of PBL in engineering.

Keywords—problem-based learning; facilitation;

I. INTRODUCTION

Problem-based learning (PBL) is growing in popularity in engineering classrooms. Some of this growth may be attributed to the changes in ABET accreditation in 2000. In particular, the change to outcomes-based criteria for accreditation has put more focus on the ways students learn to apply knowledge, design, and problem solve, as well as on professional skills such as team work, communication and life-long learning. In response, many engineering departments have engaged in strategic curriculum reform, and PBL is often seen as an effective strategy to achieve these desired outcomes. Additionally, recent conferences and journals dedicated to PBL, as well as increased publications on PBL indicate that interest in PBL is on the rise, particularly in engineering [1].

PBL fosters student agency to promote development of content knowledge, cognitive skills and professional skills. The pedagogy is student-centered such that students engage in self-directed small-group learning guided by a facilitator [2-3]. Much PBL research has examined student outcomes, and a meta-analysis of such studies shows that students achieve the expected outcomes as well or better than students in traditional classrooms [4]. Additional research shows that students in PBL classes have a deeper understanding of content, retain this knowledge longer, and are better able to transfer their knowledge to other situations [2, 4]. Research has also begun to focus on the ways that PBL might promote student motivation and increase student retention in engineering programs [5]. However, despite the many demonstrated benefits, PBL is still not a widely used pedagogy in engineering.

Barriers to implementing PBL in engineering may be associated with faculty training and support, student transition from lecture based to self-directed learning, designing effective problem statements, and concerns over content coverage. An instructional model for PBL in engineering would be useful to guide faculty in effectively implementing PBL in their classrooms [2, 6]. Such a model is the long-term goal of the research presented here. As a first step, we identify and describe facilitator roles in an engineering PBL classroom. While there are suggested practices for facilitators, little research has examined how facilitators enact their roles [7]. One such study has examined faculty-reported practices in project-based capstone design courses, which share many features with more traditional PBL approaches [8, 9]. Yet much work remains to be done to better understand these practices in engineer PBL environments. We begin closing this gap through a longitudinal examination *in situ* of facilitators working with students over a seven week period, utilizing cognitive apprenticeship theory to address the research question [10], *How do faculty foster the transformation from student to apprentice engineer in PBL engineering course?*

II. THEORETICAL FRAMEWORK

Cognitive apprenticeship is a framework, developed by [10], as a tool to design learning environments. It includes four main elements – *content, method, sequencing and sociology*. Since our goal focuses on understanding how facilitation happens, we focus on the *method* element, which refers to the ways in which the instructor promotes the development of students' learning. *Method* has six components - modeling, coaching, scaffolding, articulation, reflection and exploration. General definitions for these components are:

- Modeling – teacher performs a task so that students can observe
- Coaching – teacher observes and facilitates while students perform a task
- Scaffolding – teacher provides supports to help the students perform a task
- Articulation – teacher encourages students to verbalize their knowledge and thinking

- Reflection – teacher enables students to compare their performance with others
- Exploration – teacher invites students to pose and solve their own problems

The first three methods are used to help students develop cognitive understanding and the next two support meta-cognition. Instructors use the last method to guide students to independently explore using their knowledge in other contexts. Importantly, these components occur independently, but not in a rigidly specified sequence.

III. METHODS

To describe facilitator roles, we studied a well-established PBL program in a first year engineering course. We observed six PBL groups multiple times over a seven-week period; the six groups were facilitated by five different instructors. Observing students over time as they worked through assigned problems enabled us to analyze facilitator roles and how these roles changed as students progressed in self-directed learning skills. The observations were recorded (audio and video), transcribed, then analyzed using qualitative coding with codes developed from the cognitive apprenticeship framework. The six components of cognitive apprenticeship served as *a priori* codes, but we allowed the data to inform the operationalized definitions for the codes and the appropriate sub-codes.

As an example, we started with the general definition of *coaching*, in which instructors observe and facilitate while students perform a task. Initially, we examined the transcripts for instances where the instructor provided input to the students while they were working. Then we collected these coded segments and looked for commonalities and differences that could be used to define the code and sub-codes. For coaching, the emerging definition focuses on instructors prompting students to make decisions to follow or not to follow a particular path in the problem solving process.

IV. PRELIMINARY FINDINGS

Preliminary results suggest that modeling, coaching, and scaffolding are of primary importance in the PBL process, though coaching was the strategy used most often by the facilitators who were observed. This technique is very student-centered, such that the students are working on a problem and determining the path to a solution; the instructor is in the background. The instructor observes the students as they progress; when she sees that they have come to a decision point and are unsure about how to move forward or have chosen to proceed down a path that is not productive, she poses a question to help them continue to progress. For example, students designing an experiment to test a body fat analyzer had to select an analyzer for their experiment. A few students suggest buying the cheapest one, while others had different ideas. The instructor questioned the students: *“What’s the advantage to buying a cheaper one over a better one?”* The students had come to a decision point and had trouble moving forward, so the instructor provided a question that led the students to evaluate their choices.

Importantly, to support continued student development, the prominence of each strategy changes with time. Final results from this project will enable us to provide distinct examples on what each of these activities look like in a real and tangible way that is specific to an engineering context yet transferable to different engineering content or subjects.

V. CONCLUSIONS AND FUTURE WORK

Preliminary, findings from this work provide a strong foundation for the longer-term goal of developing a model for implementing PBL in engineering classrooms. This is the first of three critical components of a workable model:

1. Identify and describe the roles of the facilitator in fostering student learning,
2. Describe the intersections of facilitation and the students’ roles in their learning processes, and
3. Determine barriers faced by faculty in implementing PBL.

Once the first item is complete, we will turn our attention to items two and three. Our data set is sufficiently rich to complete this task. In addition to the observations currently being analyzed, we have longitudinal interviews with student participants and observations and interviews from another first-year program where PBL was implemented experimentally. This full data set provides an opportunity to analyze students’ roles in their learning process. The implementation of PBL at the second site provides us with great insight into the barriers faced by faculty when implementing PBL.

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Modelling Remote Laboratories integrations in e-Learning tools through Remote Laboratories federation protocols

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Abstract—An educational remote laboratory is a software and hardware tool that allows students to remotely access real equipment located in the university as if they were in a hands-on-lab session. Federations of remote laboratories have existed for years: they are based on enabling two universities to exchange remote laboratories directly, without registering students of the latter on the former university. Integration of remote laboratories on Learning Management Systems (LMS) or Content Management Systems (CMS) have also been addressed in the past, enabling institutions to delegate the authentication or authorization of the experiments to the LMS/CMS. However, these integrations are usually achieved in an ad hoc way, integrating each particular laboratory to a LMS/CMS. This contribution studies the use of federation models to integrate remote laboratory management systems in LMS/CMSs, since both approaches (integrating a laboratory on an external electronic learning tool, and integrating a laboratory on other laboratory) are essentially equivalent. The contribution defines two case studies to evaluate this approach, showing how this integration is achieved on a LMS (Moodle) and on a CMS (Joomla).

I. INTRODUCTION

An educational remote laboratory is a software and hardware tool that allows students to remotely access real equipment located in the university, as if they were in a hands-on-lab session. Federations of these remote laboratories have existed for years, as well as integrations of remote laboratories in Learning Management Systems (LMS), developed to integrate the remote laboratories on institutional platforms. However, these integrations were mostly done in an ad hoc way, binding a particular laboratory to an LMS and focusing on the integration itself.

The contribution of this paper is to model and evaluate how a general federation model for remote laboratories can be used to support third party consumer systems such as LMSs, CMSs or e-learning tools. Since the discussed federation model is focused on simple rules (priorities, access) for third-party

agents consuming laboratories -regardless they are remote laboratories or other kind of software- it becomes reusable for the integration of other e-learning tools. With this approach, the remote laboratory will still establish particular rules for each system and for each external institution. Furthermore, the provider university can establish high level rules (e.g. University A grants 10,000 accesses on Laboratory 1 to University B) and the consumer university can decide to let their users consume it through different technologies (e.g. different LMSs or remote laboratories) without notifying the provider.

In order to evaluate this contribution, a federation model is defined and implemented on an existing open source remote laboratory called WebLab-Deusto¹, enabling two universities to share laboratories through this remote laboratory. The federation protocol has been implemented in an LMS (Moodle), so users can consume the laboratories and educators can select which users can access which laboratories. Finally, the federation protocol has been incorporated to a CMS (Joomla) through an extension. The feasibility of this approach to support heterogeneous web environments is described detailing the differences over existing e-learning integration approaches.

This paper is structured as follows: section II explains the federation model, section III describes the existing integration of remote laboratories in LMS/CMS, section IV discusses the approach proposed, and section V describes case studies, focusing on Joomla (CMS) and Moodle (LMS). Finally, section VI sums up the conclusions and draw the future work.

II. FEDERATION OF REMOTE LABORATORIES

This section details what is a federation of remote laboratories and its relevance.

¹<http://www.weblab.deusto.es/>



Fig. 1. Remote laboratory

A. Remote laboratories

A remote laboratory is a software and hardware tool that allows students to remotely access real equipment located in the university. Figure 1 represents the essentials of a remote laboratory: a student connects -normally through a web browser- to a physical, real laboratory deployed in the university. There are a wide range of remote laboratories in the literature for different engineering and sciences fields: robotics, electronics, chemistry...

Every remote laboratory manages at least a subset of the following features: authentication, authorization, scheduling users to ensure exclusive accesses -typically through a queue or calendar-based booking-, user tracking and administration tools. However, most remote laboratories are developed aiming a particular setting (a laboratory for robots based on PIC18, an electronics). So the focus is usually achieving that the particular setting is available through the internet.

B. Remote Laboratory Management Systems

As many features of remote laboratories are common among them, Remote Laboratory Management Systems (RLMS) arised. RLMSs were focused on providing the required common tools for remote laboratories, and managing the common features. Examples of these systems are: MIT iLabs² [1], Labshare Sahara³ [2], VLCAP [3] and WebLab-Deusto [4]. Each RLMS can manage different concurrent experiments. They provide tools for establishing which users can access which experiments, tools for reporting teachers which students did what and when, and other administrative tools. For instance, if a RLMS supports a new feature, such as LDAP (a directory protocol used to authenticate and authorize users), automatically all the experiments developed with that RLMS will support it.

In order to do so, RLMSs usually provide some guidelines or even APIs that allow experiment developers to create new experiments. For instance, WebLab-Deusto provides an web service interface for experiment developers and working libraries for a wide range of software technologies, both for server (Python, Java, .NET, LabVIEW, C++, C) and client side (JavaScript, Flash, Java).

The advantage of using these RLMSs is that they speed up the development process of remote laboratories. Teachers aiming to create a remote laboratory do not need to work on scheduling, authentication, authorization, etc. but focus on making the experiment available through the Internet. If a new version of one of these RLMSs is released and comes with

more features, the developed experiment will automatically include them.

C. Federating remote laboratories

A unique characteristic of remote laboratories when compared to traditional laboratories is that the distance of the student to the real equipment is not an issue, so remote laboratories can be shared with other institutions. This sharing can be managed in a direct, simple way: the *provider university* (the one where a remote laboratory is located) creates accounts of users of the *consumer university* (the one interested in using the provider university's equipment for their students). Students of the consumer university directly access in the provider university and the provider university does all the work: it authenticates the user, authorizes him to use the laboratory and provides the laboratory.

There are multiple problems with this solution. First, the provider university must create and manage the user accounts of all the interested consumer universities. In a complex scenario, where a wide variety of consumers exist -such as foreign universities and even secondary schools that simply do not speak the provider university's language-, this approach does not scale. Second, the management of this approach is cumbersome: consumer universities would need to notify providers every change, and local databases or protocols such as LDAP would not be available. Third, the consumer university cannot carry a proper accounting of the uses performed: it must trust the provider university. If both institutions come to an agreement where users of the consumer university can access up to 10,000 times, there will be no way for the consumer university to audit this if the provider university at some point says "you have already the limit".

In order to handle these and other problems, a two-side model is required (see figure 2), where both universities have the same RLMS that manages this sharing. The consumer university can authenticate and authorize local students, and once authorized, the local RLMS will contact the provider university and request a slot. This way, the provider university does not need to manage students and courses of the consumer university, and the consumer university can track all the requests performed to the provider university, being able to track students and audit the overall use.

In this sense, MIT iLabs have been effectively sharing remote laboratories around the world for years [1][5]. Different universities can use the MIT iLabs RLMS to develop, maintain and share their remote laboratories with other universities. In the federation model defined by the iLabs Shared Architecture (ISA), two types of remote laboratories can be shared: batch laboratories (using queues) and interactive laboratories (using a calendar-based booking system).

However, this mature architecture lacks a feature relevant to this contribution, which is *transitive federation*. Transitive federation refers to the capability of re-sharing a remote laboratory to a third university. For instance, one university could share 10,000 accesses to other university, and this other university could split these 10,000 accesses on two: the

²<http://ilab.mit.edu/wiki/>

³<http://www.labshare.edu.au>

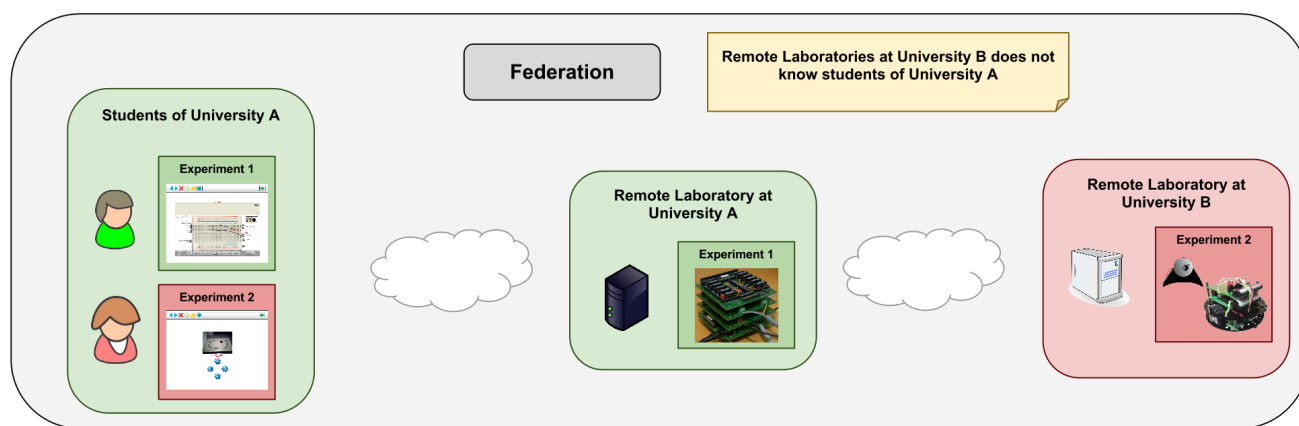


Fig. 2. Federation of remote labs. Students registered in the federation

first 7,000 being exclusive for their students and the other 3,000 might be re-shared to a third university interested in consuming that laboratory. This would work in the same way a real market works, where prices adapt to the offer, demand and required quality of service. The RLMS used in this contribution (WebLab-Deusto) defines a federation model which supports transitive federation, as well as load balance among different copies of the same experiment distributed through the federated universities.

D. Relevance

The federation of remote laboratories has a major role on engineering and sciences education. It makes possible for students of one university to access hands-on-lab sessions of other universities through an institutional RLMS and through agreements among the institutions involved. Furthermore, secondary schools connected to local universities can transitively access laboratories of federated institutions.

Indeed, the interest on federation of remote laboratories is growing. The Labshare project survey [6], made on all 34 Australian universities offering undergraduate engineering programs, reflects that interviewed executives were more interested in getting involved for the pedagogic merits of the remote laboratories, and were more inclined on initially being laboratory consumers than providers. Indeed, the European Union Commission will invest 60 million euro in research actions, projects and network of excellences in Technology-Enhanced Learning (TEL), under the objective ICT-2011.8.1 of the call FP7-ICT-2011-8. One of the target outcomes is precisely supporting a European-wide federation and use of remote laboratories and virtual experimentations for learning and teaching purposes.

III. EXISTING INTEGRATION OF REMOTE LABORATORIES IN LEARNING / CONTENT MANAGEMENT SYSTEMS

Proper integration of remote laboratories on LMSs is an active field of research. The relevance of this field is that, as detailed in [7], there are several services duplicated between remote laboratories and learning management systems. The

administration and user experience would increase if they were merged. Both systems usually support user authentication, authorization, group management, administrative tools, user tracking, and even scheduling. Some integration approaches suggest to delegate all these services to the LMS, but some of these services will still be at least shared, such as scheduling (especially when federation systems arise) or user tracking (since some interactions with the remote laboratory might occur outside the scope of the web browser).

In order to integrate remote laboratories and LMSs, [8] discusses the usage of SCORM and [9] implements an architecture around it. This technology is designed to be supported by different LMSs and indeed multiple LMSs have implemented different versions. However, since it is a client-side technology and therefore it cannot contain any server code, it does not support a secure way to exchange credentials, ensure reservations or return results to the LMS.

Other approach is to develop an ad-hoc plug-in to include a particular remote laboratory on a LMS[10]. This approach is common in the literature, and sometimes it is implemented by just copying or exchanging the users among both systems. Within the field of integrating remote laboratories on electronic tools appears the integration of remote laboratories on CMSs. In [11], the remote laboratory relies on Joomla to perform all the administrative tasks. This approach is interesting since it does not duplicates all the tasks referred in [7]. However, it is an example of an ad-hoc integration which does not support the integration of other remote laboratories neither the integration on other CMSs.

IV. DISCUSSION

Most integrations among remote laboratories and LMSs or CMSs are ad hoc integrations of one particular LMS/CMS to a particular remote laboratory. The target of these integrations is to delegate the tasks for authentication, authorization, user tracking and scheduling to the LMS/CMS. This delegation is the same delegation described in section II as the target of federation models: the consumer remote laboratory will manage the authentication, authorization and user tracking,

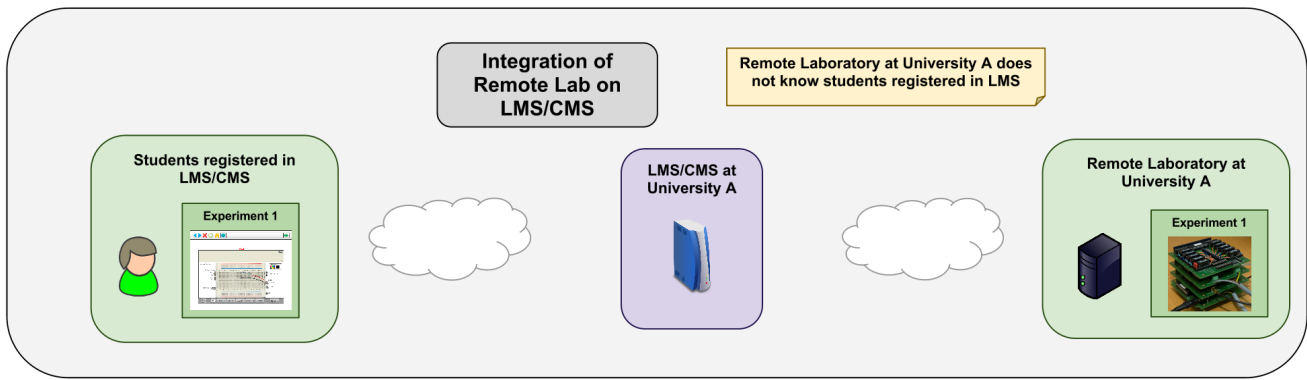


Fig. 3. A LMS/CMS can act as a federated node consuming the federation protocol

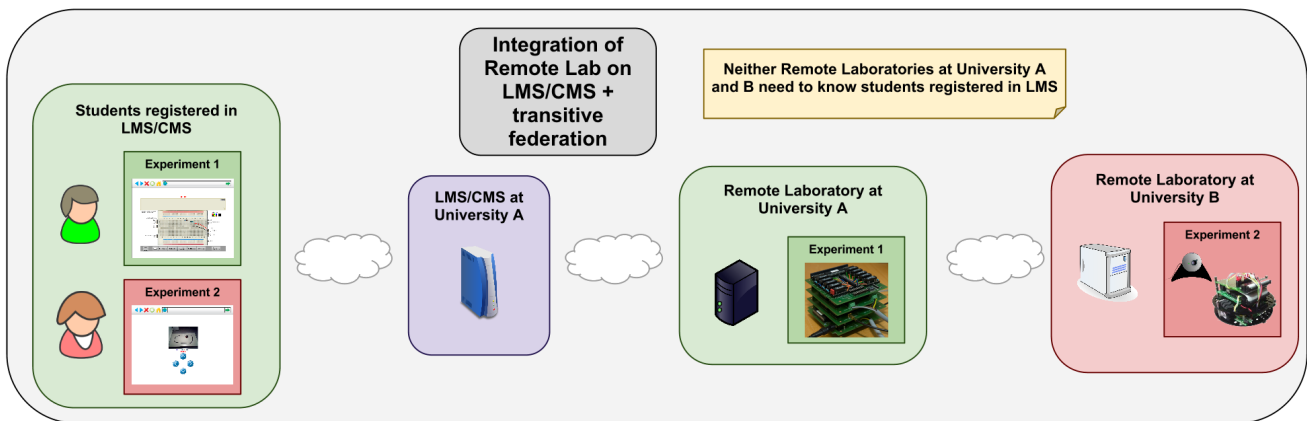


Fig. 4. If the federation is transitive, the LMS/CMS will still be able to consume remote laboratories in other universities

while the provider remove laboratory will be in charge of enabling the interaction of the user with the experiment.

The key concept introduced in this contribution is that the remote laboratory integration on LMS/CMSs is essentially equivalent to the integration of two federated remote laboratories. Thus, a LMS/CMS could be considered an external consumer of the federation protocol of a RLMS. As described in figure 3 and compared to figure 2, the LMS/CMS acts as a federated node, even if it is in the same university as the remote laboratory. This way, the student in the figure will access through the LMS/CMS to the remote laboratory.

The relevance of this concept is that it simplifies notably the integration of both systems. Under this approach, the LMS would not need to exchange user information, or use standards such as OAuth or Single Sign On protocols to effectively perform reservations in the remote system. If the protocol is simple enough, different systems can adopt it, since the interface only needs to provide three actions:

- Listing of possible experiments (so administrators of the LMS/CMS can choose who has access to what)
- Reserving the remote experiment
- Usage retrieval (to be stored in the LMS/CMS database)

It is worth mentioning that if the federation model does not

support transitivity, the LMS will not be able to consume remote laboratories on other universities through the institutional remote laboratory. This means that in the example of figure 3, students registered in the LMS will be able to use experiments located in University A. But, if no transitivity is supported, and if the remote laboratory of University A was federated with one of University B, students registered in the LMS would not be able to use them. The only way to achieve this would be registering also the LMS in University B. However, given the transitivity property of the federation model supported in WebLab-Deusto, figure 4 becomes possible without expliciting all the contracts and subcontracts.

V. CASE STUDIES

For the sake of clarity and evaluation, two case studies are presented. They describe sample integrations in a LMS (Moodle) and a CMS (Joomla) of the remote laboratory WebLab-Deusto. WebLab-Deusto is a remote laboratory used for the latest 8 years by over 1,000 students in 12 different courses in the University of Deusto. WebLab-Deusto supports federation with other instances of WebLab-Deusto in a transitive way, and this federation protocol is indeed being used with local

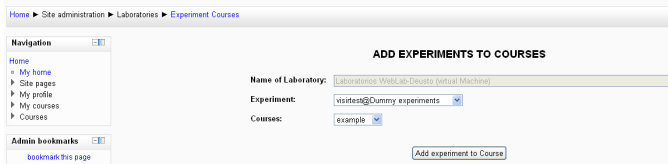


Fig. 5. Admin granting permissions of an experiment on a course

secondary schools ⁴.

While both Moodle and Joomla use the same technology (PHP) and therefore some code is reused (the federation protocol client), the same code has been implemented in other kinds of systems. WebLab-Deusto experiments can be consumed from iLab systems through the federation protocol of WebLab-Deusto: iLab acts as a federated node that interacts with WebLab-Deusto. As part of the european *e-pragmatic* project, a commercial LMS is also integrating WebLab-Deusto using .NET and it will be used in the context of the project.

The federation protocol of WebLab-Deusto requires a web service with the following methods:

- System authentication → The consumer system will call the *login* method to authenticate the institution, providing the institution ID and password.
- Available experiments retrieval → The consumer system will call the *list_experiments* method to retrieve the list of experiments available for the consumer system. The provider university can choose through a permissions system to what experiments the consumer system will be able to access.
- Reserve an experiment → The consumer system will call the *reserve_method* to request a reservation and start on a queue.
- Check the state of a reservation → The consumer system will call the *get_reservation_status* to know the current state of the reservation requested, such as the position in the queue or if it has already been assigned. The consumer system is free to cancel the reservation at any point if a similar resource was found during this process in other university. Finally, it will provide a URL that the user will be able to use to consume the laboratory.
- Usage retrieval → The consumer system will call the *get_experiment_uses* to get what messages were exchanged among the user and the final remote laboratory. The system may respond that the final user cancelled the request or that it is still running so the consumer must request again some minutes later.

A. Moodle

A Moodle plug-in using the federation protocol has been developed. In the Moodle system, different RLMSs can be registered. The connection data will include the URL of the remote system, and a single username and password, identifying the university. Three roles are defined:

⁴<http://weblab.colegiourdaneta.com/>

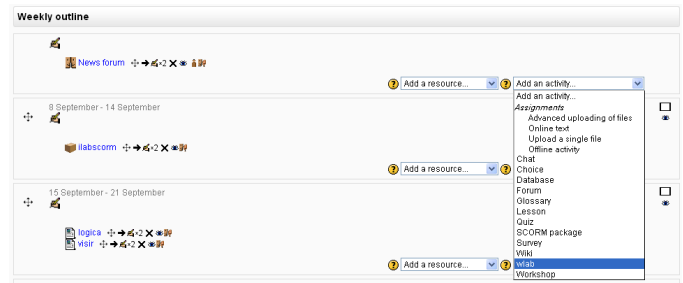


Fig. 6. Teacher adding a remote lab as an activity for a course

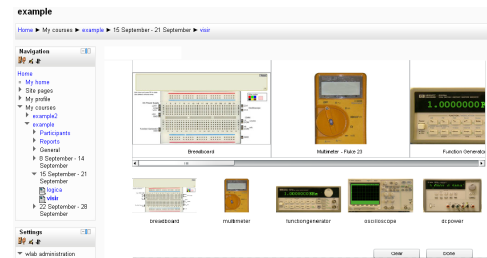


Fig. 7. Student running an experiment

- **Administrators:** Administrators can associate courses to experiments. As shown in figure 5, they can define that the course “Electronics IV, Electronics Engineering can access the VISIR experiment in University A”. In order to do this, the plug-in use the *list_experiments* method detailed above.
- **Teachers:** Teachers of courses with associated experiments are automatically allowed to add accesses to laboratories as Moodle activities to the course. In the menu shown in figure 6, in the second step they will choose among the associated laboratories. They can add, remove or hide the activity as any other Moodle activity.
- **Students:** Students of courses with associated experiments can automatically use the experiments (see figure 7), once teachers have created the activities. Whenever a student requests an access, the plug-in will perform the request in the name of the student, using the university credentials.

Only moodle administrators can define which courses have access to each external remote lab. The management becomes simple: every teacher added to a course through the Moodle administrative tools can automatically manage the associated laboratories. Every student enrolled in a course can use the laboratory. Remote laboratories do not need to exchange any user information (credentials, full name, etc.) with the LMS.

B. Joomla

A plug-in for Joomla using the federation protocol has been developed (live demo ⁵). The schema used for this integration was simpler, with only two roles involved:

- **Administrators:** they will manage which groups have access to what remote experiments. This is done through

⁵http://www.weblab.deusto.es/weblab_joomla/

| User Menu | | Group | Experiment Name | Category Name | Launch |
|--------------------------------|--|-------|-----------------|-------------------|--------|
| » Your Profile | | 14 | ud-logic | PIC experiments | Run |
| » Experiments of WebLab-Deusto | | 14 | visir | Visir experiments | Run |
| » Site administrator | | | | | |

Fig. 8. List of experiments available for current user

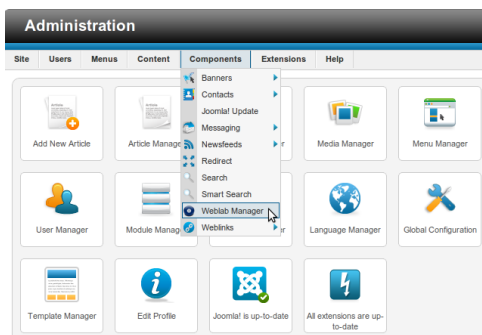


Fig. 9. WebLab-Deusto manager in the Joomla Administration panel

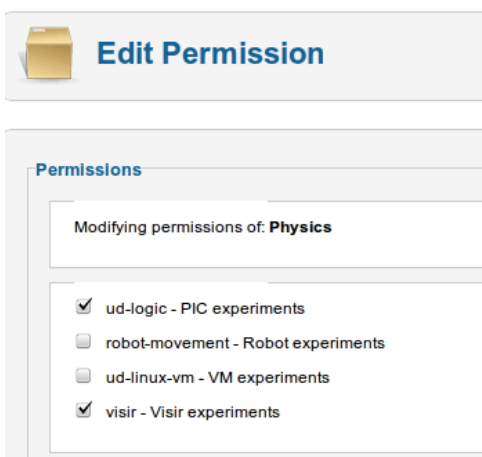


Fig. 10. Permissions editor for each group

the standard Joomla's administration site (see figures 9 and 10).

- **Users:** there is a link where every user can see what experiments can be run. This way, users who are members of groups with associated experiments will see those experiments and they will be able to start using any of them (see figure 8).

As in the Moodle case, users and administrators of Joomla use the standard tools provided by the framework. In this case, authentication and group membership is managed with the standard tools. The plug-in only needs to define which groups can access which laboratories, as well as provide a small component to start the reservations. The remote laboratory does not need to exchange credentials or register students.

VI. CONCLUSIONS AND FUTURE WORK

This contribution shows a novel approach for integrating remote laboratories on LMS/CMS, using the federation model of remote laboratories. The impact of this contribution is not restricted to the users of those remote laboratories that support federation -especially to those that support a transitive federation model-, but to every remote laboratory which aims to be integrated into a LMS/CMS. This is so since this feature will automatically be available for laboratories integrated in a Remote Laboratory Management System (RLMS) that supports this federation model. For instance, the integration of VISIR on WebLab-Deusto [4] makes VISIR benefit from this integration, as seen on figure 7. Furthermore, the integration model proposed does not need to exchange information related to particular students, neither it requires to constantly synchronize this information, becoming a simple approach to be implemented. Indeed, the contribution details the integration of a LMS (Moodle) and a CMS (Joomla), showing how the integration of other LMS/CMS could be done.

Regarding future work, the Moodle plug-in is expected to be used with students of the University of Deusto during the next course, and support for other LMS -in particular, the "LRN" LMS, used in UNED- is under development. At the time of this writing, it still misses the retrieval of usage data. It would be desirable that other RLMSs provided new or supported existing federation interfaces to evaluate the proposed integration approach with more remote laboratory systems.

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Increasing Access to Engineering

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Abstract— Based on research, constructing a program to increase accessibility for students with financial need, and diversity of students graduating with engineering baccalaureate degrees requires multiple components and partnerships to recruit, retain and graduate students. This paper describes how a program at Texas A&M University was initially constructed, how it has evolved, and what influences on student success have been observed.

Keywords—engineering students, diversity, recruitment, retention

I. INTRODUCTION

Earning an engineering degree is a route from high school graduation to many fascinating, financially attractive career paths; however, for many academically talented students with substantial financial needs and diverse backgrounds, access to undergraduate engineering programs is becoming increasingly difficult, in part due to rapidly increasing costs of undergraduate education, both in the United States [1, 2] and worldwide [3]. Designing programs to address this challenge involves multiple elements. Specifically, plans should address twin challenges of recruiting and retaining engineering students who have the academic qualifications to complete an undergraduate engineering degree, but have hurdles in addition to the cost of higher education that deter them from considering or choosing to enroll and complete this degree. Thus, recruiting and retaining academically talented students with substantial financial needs and from diverse backgrounds requires a comprehensive program. The intent of this paper is to offer the programmatic response that one engineering college has developed for these challenges and indicators of the extent to which these responses have addressed these challenges. For the purposes of the paper, results will be presented only for students that the university and the college have supported financially using funds from the S-STEM program of the National Science Foundation (NSF), who will henceforth be referred to as S-STEM scholars. The S-STEM grant intends to increase the quantity, quality, and diversity of the engineering workforce in the state, the US, and globally through enabling academically talented and financially needy students to obtain a baccalaureate STEM degree. It should be noted however that the programmatic elements discussed herein are available to a wider range of students than those receiving funding from the NSF S-STEM program.

II. LITERATURE BACKGROUND

Considerable research has been done on challenges faced by entering students from populations who historically have not sought degrees in science, technology, engineering, and mathematics (STEM) disciplines, or engineering more

specifically, in numbers consistent with their representation in the general population [4-6]. Research indicates that increasing the number and diversity of engineering majors will call for financial assistance for academically talented African American and Hispanic high school students whose families do not have the financial resources to fund the rising cost of a college education. Research and internal findings at Texas A&M University indicate that students with high financial need often will enroll if tuition and fees, and room and board, are covered by scholarships and grants. This finding is particularly applicable to the targeted groups of first-generation and traditionally underrepresented potential students. This includes studies on retention in STEM disciplines [e.g., 4] and in engineering alone [e.g., 7, 8]. Further, based on this research, many programs have been developed to recruit and retain one or more segments of these STEM students [9-12]. However, each institution that launches or redesigns programs to improve recruitment and retention of one or more segments of these engineering students must do so within a set of constraints that includes the history of the institution, profiles of students who traditionally have attended the institution and successfully completed their engineering degrees, the mission and characteristics of the institution, and characteristics and needs of populations from which the institution primarily recruits.

III. COLLEGE OF ENGINEERING PROGRAM BACKGROUND

The college of engineering has been refining and improving a two-pronged recruitment-retention plan to recruit, retain, and graduate diverse students. This section overviews these efforts, while details are provided in the following two sections.

To recruit diverse engineering students, the college has many different programmatic elements, but the focus for this paper is the set of components that directly involve collaborations with 12 strategically selected high schools. Program recruitment components include summer camps and visits to campus, focused on these selected high schools. The program also involves support during the application process, receptions hosted by industry partners for admitted students and their families, and scholarship awards. When considerable resources (human and financial) have been used to recruit these targeted students, it is important to also invest in their retention; therefore, Texas A&M University has also developed a retention program with an overall goal of creating a community of scholars. These components focus on student support strategies such as living learning communities, course clustering, industry interaction, student professional society involvement, and student career placement. It also includes elements to address difficulties in transitioning to the university environment and help students develop study and time management skills. More detail will be provided below on the

recruitment and retention efforts to provide information that may be useful to other institutions.

In terms of how recruitment and retention efforts have influenced student success, this paper focuses on students supported with funding from the NSF S-STEM program. Since 2001, Texas A&M University has received a series of three grants (totaling \$1,270,000) from NSF to support scholarships for financially deserving, academically talented, and first-generation engineering students. Criteria used for the most recent S-STEM scholarship awards include a family income level below \$60k, a combined SAT of 1300, US citizenship or permanent resident status, and a minimum score of 65 in the university Freshman Scholarship Awarding Scoring Model (FSASM) that considers academics, adversity, and curricular and extra-curricular activities. These grants have provided up to two years of partial funding for students majoring in various engineering disciplines and computer science.

The first NSF-supported project resulted in first-year retention of 87.2% (compared to college-wide retention of 70%) and an average first-year GPA that was 0.3 points higher than the college average. The second project served 53 first-generation and low-income students (29 Hispanic, 1 African American, 11 women). Retention of these students was very encouraging, with 95% of S-STEM Scholars continuing their studies in engineering for their first two years of the project, compared to a 71% retention rate for all entering engineering students in the College. The third project is serving 57 low-income and first-generation students (35% of recipients were first generation and the numbers include 12 Hispanic, 3 African American, and 14 women students). To date, first-year retention for the third project has been 85.7% (compared with a college average of 74%), with a first-year GPA above 3.0.

What were elements that have contributed to the success of these students, and how were decisions made to arrive at these elements? The following two sections on recruitment and retention will address multiple components in this question.

IV. RECRUITMENT

Need for programs to attract underrepresented students to STEM fields became more acute following a series of Supreme Court decisions which limit the ability of higher education entities to use race in university admissions (*Regents of the University of California v. Bakke*, *Grutter v. Bollinger*, *Adarand v. Peña*, *Hopwood v. Texas*). In response to these factors, the engineering college decided early in program development that it would need partners to address manifold challenges associated with recruiting and admission. Texas A&M University reached out to high schools and partnered to provoke and sustain student interest in studying engineering.

Description of the recruitment component at Texas A&M University will be framed in terms of the following questions to be addressed by a university interested in forming and sustaining collaborations with high schools for the purpose of improving the recruitment of diverse students: (A) What are criteria by which a university can identify collaborators? (B) How will collaborators who satisfy these criteria be identified? (C) How will unproductive partners be identified and handled? (D) How

will potential students be recruited? and (E) What factors contribute to successful collaborations? Addressing these questions is the focus of the following subsections.

A. What are criteria for identifying collaborators?

Over the years, the engineering college had worked with a number of high schools through many programs. From these programs, the college constructed a list of high schools that were potential collaborators. To reduce the list to a manageable number, the college first used ratings by the state educational agency. The agency had rated some high schools across the state as academically unacceptable (due to results of state mandated testing), and the college removed these high schools from consideration. Next, the college, with its interest in increasing enrollment of African American and Hispanic students in engineering, focused on high schools with large minority populations. Also, high schools chosen had high percentages of students with significant financial need. Third, because engineering students need to be academically prepared, the college focused on high schools that offered advanced (honors or AP) courses in mathematics and science. Finally, the college did not include geography as one of its criteria. Although this decision increased travel demands on college personnel, the college thought it was important not to limit potential participation based on the ease with which an institution could be reached. Eventually, interest in collaborating with Texas A&M University would be a critical factor in determining partners, but interest would be ascertained in the next step, described in the following section. In summary, state educational agency ratings, student enrollment demographics, mathematics and science course offerings, and interest were the four criteria utilized to identify potential partner high schools.

B. How will collaborators be identified?

Starting with the above criteria, the college identified an initial list of school partners across the state, from which it intended to select 12 high schools. From this list, the college ordered the list in terms of which high school would be contacted first. Ordering was done by the average SAT score of graduating seniors, highest first. With the ordered list, college personnel visited the first school on the list, described the program, asked about interest, and attempted to evaluate the level of interest. After the visit, both potential partners would gauge likely interest in collaboration. Some high schools were interested and willing to commit, others were not. If the school was interested in participating and willing to put forth effort to partner, they remained on the list. If not, they were removed and number 13 on the list was moved up, and so on. Eventually, the college selected 12 high schools.

The list of potential partners is not fixed. Each year, Texas A&M and the 12 partner high schools evaluate the program. The University is interested in the level of engagement by each high school. For example, did a high school select the expected number of interested students? How qualified to study engineering at Texas A&M were the identified students? Did the juniors participate in the summer program? How many of the identified students applied to Texas A&M? Also, each high school evaluated its participation. Based on this evaluation,

Texas A&M has replaced some high schools due to low level of engagement, and added other high schools to the list.

High schools are interested in whether participation provides an additional, viable pathway for its students to attend college, particularly in engineering. Each wants a sufficient number of its students to express interest in applying to Texas A&M, apply to the university, and see them accepted. The “sufficient number” varies across the high schools, but each high school monitors the results to decide, in part, whether it will continue to participate in the program.

C. How will potentially qualified students be identified?

When the high school partnership program was started in 2008, each partner school was asked to identify a total of 12 junior and senior students using the following criteria: (i) academic performance, (ii) interest in engineering, and (iii) enrollment in advanced math and science courses. As the program evolved through evaluation and experience, some changes have been made. Since 2011, a partner high school is asked to identify its 12 seniors and 12 juniors who are US Citizens and have: (i) expressed interest in engineering, (ii) demonstrated a strong work ethic, (iii) shown academic excellence in advanced math and science courses, and (iv) have a minimum Math SAT of 550 (or equivalent). The minimum MATH SAT score was added, in part, because the college started requiring a 550 MATH SAT score for admission into engineering. The high school would then work with the identified students to encourage their interest in engineering and application to Texas A&M University.

D. How will potential students be recruited?

Each high school encourages its selected students to participate in the full range of Texas A&M recruitment activities. High school juniors attend a four-day residential summer program on the university campus to learn more about the institution and engineering. It is offered to students for minimal cost (\$100/student) and provides prospective engineering students with opportunities to experience engineering team design projects first hand under the direction of engineering faculty members. Also, students are invited to visit and tour the campus (including the living learning community discussed below). They meet with college representatives and current engineering students to discuss career prospects in engineering and why high school students might want to consider studying engineering. Sessions provide information about what would be necessary to succeed in engineering. Finally, the college invites seniors, together with their families, at each partner school who are admitted to a reception hosted by engineering industry (usually at their place of business) where the students can interact with working engineers, as well as college and university recruitment personnel.

Since its inception, both partners worked to improve the program based on input from both partners and observed outcomes. Since 2011, the engineering college has added an ambassadors program for these high schools that involves sending current engineering students from these high schools to visit their schools at least once a year and share their college experience. In fall 2012, the high school partners requested,

and the college has provided, Skype sessions with information on different engineering majors for their junior students.

E. What factors contribute to successful collaborations?

At least two major factors contributing to successful collaborations are: (1) Program support at the K-12 institution and (2) Institutional (university) support for the program through staff support and scholarship funds.

Each partner institution identified a teacher/counselor who led the support of the program. The lead teacher or counselor is expected to collaborate closely with Texas A&M staff and to have a good understanding of the program goals and components. The lead teacher or counselor is familiar with the college’s admission requirements, works closely with other teachers to recruit qualified students for the program, and encourages targeted students to actively participate in the program. The engineering college has several opportunities to meet with teachers who support this program and get their feedback on the value of this program for their school and how this collaboration supports their goals.

Commitment and impact of the program has varied across the 12 partner high schools. In one school, the teachers drove for several hours to bring the students to the summer camp. At another school, the teacher brought the students to the engineering open house while he was on crutches. For these two high schools, we have observed a significant improvement in recruitment (200% and 900% higher than before program was established). In several other schools, moderate increases in recruiting their students have been observed, while there are a few schools with almost zero change on recruitment. However even at these schools, administrators and teachers report they value this collaboration and that it benefits their students.

Institutional (university) support, in the form of staff support and scholarship funds, is also essential for the success of the program. At the college level, staff support organizes campus visits for high school seniors designed specifically for each partner school. These visits include presentations, lab tours and interactions with current engineering students from their high school. In addition, college staff members coordinate local receptions for seniors (who have been admitted into the engineering college) and their families. These receptions are hosted by industry partners at a location close to the high school, and students are eligible to win scholarships provided by the industry sponsor and university financial aid office. Finally, college staff members maintain regular communications with all targeted students and provide support during the application and admission process. Recruiting is staff-intensive, thus requiring institutional support to maintain.

V. RETENTION

Although there has been considerable research on retention in engineering and there are many engineering retention programs, the authors have not uncovered foundations or methodologies that guide development of a new retention program. For its design, the engineering college now uses the fourteen (14) components of the Meyerhoff Program [13] as a starting point for constructing a framework for a retention program: (1) Financial aid, (2) Recruitment, (3) Summer bridge

program, (4) Peer study groups, (5) Tutoring, (6) Summer research internships, (7) Mentors, (8) Program community, e.g., Meyerhoff scholars live in the same residence hall, living-learning community, (9) Minority Access to Research Careers (MARC) program, (10) Personal advising and counseling, (11) Program values, (12) Faculty involvement and commitment, (13) Family involvement, and (14) Administrative involvement and public support.

Of these fourteen components, components 1-9 may be categorized as programmatic components; i.e., they are concrete initiatives that a retention program can implement. When the Meyerhoff Program began in 1988 [10], program designers included these elements. Components 10-16 may be categorized as cultural components; i.e., they are components that have developed around the program during its history. For example, when the Meyerhoff program was initiated, program designers could not have prescribed faculty involvement and commitment; they have taken steps to cultivate this component, but the degree to which it would occur had to wait until the program was sustained for several years.

Using this framework and considering its resources to invest in retention of engineering students, the engineering college has designed a retention program with the following components: (i) Scholarships, the college has raised funds for scholarships from many sources, (ii) Summer bridge program, (iii) Engineering living learning community, (iv) Course clusters, i.e., engineering students take multiple first-year courses together, (v) Assessment of incoming proficiency in mathematics and placement in first mathematics course, (vi) Assessment and development of knowledge and skills for self-regulation of learning, (vii) Mid-semester advising, (viii) Monthly seminars, and (ix) Community-building activities.

Description of the retention component will address the following questions: (A) How will the students be supported financially? (B) How will the students be academically supported to achieve success in engineering when many of these students have traditionally lacked strengths in important factors such as strong mathematical backgrounds, study skills, self-directed learning, etc.? (C) How will the students be socially and culturally supported to achieve success in the university environment?

A. How will the students be supported financially?

"The availability of financial aid at both the undergraduate and graduate levels impacts students' decisions to enroll in post-secondary education, choose a specific major, and complete a degree" [14]. In addition to financial aid as a factor in recruitment, financial need also plays a role in retention. The higher the financial need of a student that is not met by scholarships or family resources, the greater the likelihood that the student will not be retained in engineering. Therefore, the first component of the college retention program is to reduce unmet financial need of its students. At Texas A&M University, the Office of Scholarships and Financial Aid identified top candidates for the scholarships associated with the program from the pool of all freshman engineering students with a valid scholarship application and a completed FAFSA. To select students, both with financial need and likely to succeed in engineering, university financial aid utilizes a

detailed scoring model (Freshman Scholarship Awarding Scoring Model) that captures academics, activities, and adversity.

For the S-STEM program, over the past three years, the college awarded sixty (57) scholarships with award levels ranging from \$1,500 to \$10,000 per year. Students were eligible to receive a renewal award for their sophomore year if they remained in engineering and were in good academic standing (Grade Point Average of 2.75 or higher). Eight awardees came from the high schools selected in the recruitment program described above, two in 2009, two in 2010 and four in 2011. The college would like the numbers of awardees from the targeted high schools to be greater and continues to work with the high schools to achieve that goal.

B. How will the students be academically supported?

Several components of the retention program that emphasize academic support are described below.

1) Summer Bridge Program: Based on a survey of engineering department chairs, summer bridge programs are being implemented at 45% of engineering programs [15]. Often, they support students during the transition from high school to college, and frequently they are intended to strengthen their academic backgrounds. At Texas A&M University, the summer engineering program focuses on mathematics, physics and engineering study skills. Participants take 3 credit-bearing courses for a total of 6 hours and "engage in community-building activities with their peers, upper class students, and university faculty and staff" [16].

All S-STEM scholars receive a letter encouraging them to apply for the summer bridge program designed for at-risk engineering students. Priority admission is given to S-STEM scholars and students who attend partnering high schools. S-STEM Scholars usually have high Math SAT scores, because of the intent of the program and the selection criteria. Nevertheless, the engineering college thinks they would benefit from components of the summer bridge program for physics and study skills as well as transition to university life.

2) Assessment of Incoming Proficiency in Mathematics and Placement in First Mathematics Course: Success in first mathematics course in engineering programs at Texas A&M has been established as a crucial predictor of retention in engineering [17]. However, high school grades and SAT scores have limited use in predicting success in calculus. Preparatory courses taken in college have some ability to predict success in calculus. For example, students who entered calculus with lower grades in prerequisite courses were not generally successful [18]. Furthermore, while commercially available placement tests have been very effective for placement in lower level mathematics courses, many universities have found them less effective in placing engineering students into the calculus sequence [19, 20]. More colleges are using locally developed placement exams along with high school performance and standardized test scores [21, 22]. Placement exams are used not only to predict success, but to place students in courses where they are most likely to be successful [21, 23]. At one college, approximately 80% of students who took the recommended course or an easier one were successful over a period of five

years. Researchers concluded that a “well-designed in-house placement test geared towards [their] curriculum is a simple and powerful tool for placing incoming students in an appropriate mathematics course” [21, p. 32].

Students entering Texas A&M as engineering majors take a Mathematics Placement Exam (MPE) to determine whether they should take Calculus I or a preparatory pre-calculus course. According to available student data, many students do poorly on the MPE even though they had several advanced mathematics courses in high school, including AP Calculus. Analysis of data over a period of years shows that students who attain a raw score of 22 (out of 33 questions) or above have at least a 70% probability of success in the first engineering calculus course (course grade of A, B, or C).

3) *Course Clusters so Students Take Multiple First-year Courses Together in the Same Sections*: Since 1992, Texas A&M has offered first-year engineering courses in clusters, and participation in these engineering course clusters has been correlated with improved retention in engineering, including women engineering students [24]. Course clusters are another form of learning community, one in which efforts to promote belonging, are organized around students seeing each other multiple times during the week in common course sections [25, 26]. At Texas A&M, the most common form of engineering cluster courses consists of linked sections of Introduction to Engineering I and II, Calculus I and II, and University Physics I and II, in the first and second semesters, respectively. Another form of engineering course clusters groups a study skills course with one or more of the trio of courses: calculus, engineering, and physics. S-STEM Scholars and students from the partner high schools who were calculus-ready were invited to participate in course clusters. Unfortunately, the 2011-2012 cohort was not enrolled in course clusters, partly due to reduction in college funding.

4) *Monthly Seminars*: S-STEM Scholars participate in a non-credit, monthly, one-hour seminar. The seminar is designed to develop good study and time management skills. Also, they showcase successful former student engineers, faculty and staff from diverse backgrounds as guest speakers. Seminar topics include: transitioning to college, engineering study skills, goal setting and time management, effective communication, career choices, leadership, and team building.

5) *Assessment and Development of Knowledge and Skills for Self-regulation of Learning*: In addition to developing knowledge and skills in mathematics, physics, engineering, and other subjects, engineering students must often also improve the tactics needed to learn new content. Self-regulated learning is thought to play a role in success of engineering students [27]. Further, two studies, one at Penn State and another at Texas A&M, failed to discern any improvements in knowledge and behaviors associated with self-directed learning [28, 29]. Therefore, one component in the retention program intends to improve knowledge and skills for self-regulated learning.

To help students understand their current knowledge and behaviors with respect to learning, S-STEM Scholars take the Learning and Study Strategies Inventory (LASSI) [29] in their first monthly seminar of the year. The assessment is administered and interpreted by the student counseling

services. Students are advised during subsequent workshops to address areas of improvement needed in regards to learning and study skills via a one-on-one counseling session. Informal observations of and conversations with S-STEM Scholars suggest the learning and study skills component does not yet have an observable improvement in how students address their learning, e.g., they do not begin studying for an exam until the night before.

6) *Mid-Semester Advising*: S-STEM Scholars meet with their departmental advisors during the fourth week of classes as an early intervention tactic to discuss their academic progress. At midterms, students whose GPA is below 2.0 are required to meet with their academic advisor again to develop an action plan to improve their grades.

C. How will students be socially/culturally supported?

Social and cultural support is provided at Texas A&M University primarily through a living-learning community. Also note that this is a program providing significant academic support, which is woven into the design of the community (hence living AND learning). “Participation in some form of learning community is positively related to student success, broadly defined to include enhanced academic performance, integration of academic and social experiences, positive perceptions of the college environment, and self-reported gains since starting college. The effects are somewhat stronger for first-year students” [30]. Encouraged by positive influences on student success by learning communities, in particular living-learning communities, the engineering college formed a living-learning community for women engineering students as early as 1992 [31]. In 2006, the college established a living-learning community for 400 first-year engineering students (about one-third of the entering engineering students). Based on positive feedback from participants, the college has sustained the community and continues to explore ways to improve the experience and results and has grown the living-learning community to 600 students [31].

The engineering college provides several programs to support student academic success and connection with engineering. Students participating in the living-learning community have access to free on-site peer tutoring sessions in mathematics, physics, freshman engineering courses and chemistry (Sunday thru Thursday, 6 – 10 PM) as well as supplemental instruction [32] sessions in mathematics. Tutoring and supplemental instruction are offered within the residence hall used for the living-learning community. In addition, living-learning community students have opportunities to engage in the freshman team projects with NASA or the city utilities group. Finally, there are about fifty upperclassman engineering students with a GPA of 2.75 or higher who are housed in the dorm and they either work as resident assistants or support social events with engineering faculty. In 2010-11, we logged more than 2,691 help tutoring sessions in the dorm. The first-year retention of the fall 2010 living-learning cohort was 83% compared to 76.9% of the college. In 2010-2011 and 2011-2012, 9% and 41% of the S-STEM Scholars participated in the living-learning community, respectively.

All S-STEM Scholars are invited to apply for and participate in the engineering living-learning community for engineering students via an official award offer letter.

CONCLUSIONS

A multi-pronged approach has improved recruitment, retention, and graduation of a greater diversity of engineering students. Collaborating with high schools to attract diverse students to engineering has been critical. Further, implementing a multi-component retention program is necessary to help retain these students. Recruitment and retention programs require resources by both the college and high school, and it is important that all involved have a clear understanding of how this partnership supports their goals. The NSF S-STEM program has been an important component in developing a program for students who may not have considered Texas A&M University or an engineering degree within their reach.

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Evaluating the Effectiveness of the Use of Teaching Materials in Video Format in Distance Learning Environments

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Abstract - Projections indicate that video will be responsible for 90% of network traffic until the end of the decade. Considering the high cost of media production and, mainly, the high consumption of network resources for applications that explore it, it will be extremely important to monitor such use, preventing against wrong or distorted views of this consumption. Within this scenario, it is necessary to develop mechanisms and tools that provide a clear vision of video effectiveness consumption, as well as the measuring of "viewer engagement". What tools can be developed to evaluate such consumption? What should be measured, i.e., which are the parameters and metrics necessary, and how can we obtain them, in order to measure the effectiveness of video applications use, for example in engineering courses and distance learning environments? These are some of the questions considered in this paper, especially evaluated within a scenario of video usage for teaching/learning purpose.

Keywords - video delivery, viewer engagement, distance learning.

I. INTRODUCTION

Many systems are designed to provide educational materials in video format for distance learning environments, as well as support material and learning material. The production of these videos requires a sophisticated infrastructure and a team to manage the entire process: the recording of videos, their edition, and the delivery process. Given the fact that this process requires time and an expensive production, it is important for educational institutions to assess the real benefits of using video in teaching and learning environments.

Statistical surveys show the increase in use of Web videos for multiple purposes, whether for entertainment, information dissemination, education or training. In addition, prospective studies indicate that such use will continue to grow, reaching much higher numbers than the bandwidth occupied by the transmission of data at the end of this decade. [1].

In this context of strong growth in video consumption it is necessary to develop mechanisms and tools that can measure the real use of video streams. For this purpose, the monitoring of the following is considered:

- **Video transmission:** In order to understand precisely which requests are met and for how long they are met. Often, when a video is requested, one session is established, but for a momentary network problem, the video stream may not be received by the requester, who will then place his or her request once again. **If the transmission** system uses the number of sessions to account for its cargo of use, there will be a misjudgment. In other situations, the video may have been only reproduced partially, because the user has closed the connection. Also, being aware of the quality of service (QoS) transmission [16], such as delay, delay variation (jitter), and bandwidth consumed, is relevant to the operation and maintenance of the transmission network. All these situations need to be planned in order to get a closer view of the video quality users are receiving.
- **Video Reproduction:** In this area it is important to evaluate video stream reproduction, which can be influenced by different factors, as it may have different users' QoE (Quality of Experience) [16], and consequently the levels of engagement with the content ("viewer engagement") [15] [12] may vary. To estimate such subjective parameters, we can evaluate for example, the quality of the playback video (using the comparison of signal to noise ratio, NSR, the original video with the video received), the degree of user satisfaction, or user behavior during reproduction.
- **Absorption of the video content:** We wish to evaluate the degree of absorption of knowledge through this media consumption, as well as engagement with the subject. The concept of "viewer engagement" can be used in many ways, considering aspects such as usage scenario, age, or user's cognitive characteristics, or by verifying the degree

of involvement, using interactive tools and social networks to disseminate information or feelings about watching the video. In our case, we are more focused on education scenarios, with engineering and computer students. Considering this, one possibility is to compare students' opinion about a video explanation, for instance, and their results in formal evaluation.

Different scenarios may require distinct techniques to assess the quality of video streams and extent of absorption of video contents. Educational scenarios demand different assessment techniques from those used in commercial environments. Likewise, the metrics for evaluating the level of information comprehension may also be different. For example: in producing a marketing video, an advertising campaign of a particular company often makes use of techniques to increase the viewer's attention, where one possibility is to increase the frequency of changing scenes, [13] and this strategy may not be effective in educational environments. In marketing field the effectiveness of a visual element used can be measured by the growth of sales. For a movie, the producer can measure its acceptance by verifying ticket sales.

In the learning process, the effect of audiovisual content should be measured considering the degree of absorption and the ability to address issues related to the object of study. Distinctions can be considered when the public belongs to different age or social groups, because the cognitive perception and interpretation of information may vary depending on age and environment [11].

Some research shows that video use in teaching can be as effective as a live class, reaching satisfactory educational goals when the involvement and motivation are maintained [9] [10]. In this sense, it is extremely important for an educator to have reliable information regarding student's involvement, in a way that it will be possible for him/her to trace a connection between said involvement and student's performance.

This shows that necessary definitions must be established in order to provide actions that can develop content more aligned to student's expectations and cognitive profiles, thus improving knowledge absorption and making learning activities more attractive and thus more efficient. Furthermore the results of such evaluation will allow educational institutions to plan the financial and technological infrastructure necessary for the delivery of educational materials. Therefore, in order to obtain these parameters it is necessary to define appropriate metrics with which to measure them [14] [15].

II. RELATED WORK

Projections indicate that by 2012, video use will represent half the consumption of network in the world, already surpassing the P2P traffic, currently the most responsible for network traffic. By the end of the decade, projections indicate that this percentage will fit about 90% of the network bandwidth [1].

Currently, connected TV content providers invest many resources in mechanisms that capture information from viewers, developing applications that encourage them to provide more information about their characteristics, preferences and opinions. From there, databases are built in order to carry out various analyses, which should give the advertisers the necessary feedback in order to direct programming to the user's interest. [6].

Another important concern of advertising professionals is the use of new rich media, to ensure awareness among new generations. However, there is some concern about the lack of consistent metrics to gauge the ROI (return on investment) for investment in the development, production and dissemination of media [7].

On the other hand, based on usage statistics mentioned above, this idea of measuring the impact and ROI of media can be extended to other scenarios where it is also important to check user's interest and engagement in the content offered. We can, for example, use the same for educational environments, or distribution systems or even web video IPTVs. This concept can also assist in the operation and maintenance of network infrastructures, to verify the effectiveness of video consumption, and consequently the consumption of network resources.

So far, few academic papers in monitoring and evaluating video consumption field have been published. Studies found, which will be discussed below, can be classified into: studies on cognitive engagement in TV ratings, user engagement with the consumption of Web videos, and videos using the method of teaching / learning.

In television, Smith [12] makes a study of viewer's involvement and interest with respect to the dynamism of a scene, showing that the increased frequency of changing scenes and semantic association with humorous or unexpected elements, activate cognitive engagement. This study considers the influence of alpha waves and their role in the brain region which processes visual functions. Liebes [13] categorized spectator's involvement with soap operas, and concluded that relating to a character of the plot leads to a greater interest in the show. Sawahate [16] developed another study focused on evaluating TV cameras, used to detect eye-gaze in order to measure viewer's engagement with the content offered and correlate it with the absorption of knowledge. Milliken [14] studies the potential of UGOV (User-Generated Online Video) tool, which allows video generation. These videos are posted on YouTube to check the contribution of regional identity in their consumption, level of involvement and engagement of Internet users. Engagement, in this case, is measured using a questionnaire that includes, for example, questions about frequency of application use, how much a user learned, how a particular video changed user's opinion on a particular subject, and how many comments posted on social networks were related to the concerned video.

In another study, conducted by Bardzell [15], physiological measures, such as heart rate and respiration per minute, were used to measure the emotions caused by the most

popular videos. They also used strategies such as emotional **tag** (user indicates their emotional state by choosing emoticons), space for adding a text review and logging the user actions with respect to the video (pause, stop, browse the timeline of video (seek), etc.). The work uses triangulation to analyze results obtained, crossing information, relating them to perception and emotional experience, preferably video, as well as contextual factors.

Another work that deserves attention, as it deals with an educational context, is the article written by a group at Microsoft Research. The article's aim is to test the effectiveness of a video annotation tool, which provides video and synchronized slides, and space to include participation textual support [9]. The tool was tested for learning purposes in group work, and also with individuals, showing that there was excellent absorption of educational content with its use. Another study presents a tool that defines the best place to put ads in a video [3]. The evaluation was done subjectively, using as parameters the relevance of the site, comfortability and user satisfaction.

III. REQUIREMENTS

The functional requirements which direct all activities considered within the scope of the project are:

- Data collection: providing mechanisms that enable the collection of information from different data sources (such as data servers, transmitters, applications, video players);
- Reception and data persistence: receiving the information collected and persisting it properly so it can be analyzed;
- Analysis: providing mechanisms that enable the analysis of collected data, extracting information that can be used to improve video distribution service, the application that makes use of this service, or even the production of content.

A. Technical Requirements

Among the technical requirements we can enumerate:

- Technological Independence: The goal is to enable the collection of information from video distribution systems. The service must be as independent as possible from the technologies used in the elements to be monitored;
- Weak coupling: The service must be easily integrated into applications to be monitored, in order to facilitate their use;
- Scalable: The service must be scalable to meet growing demands for monitoring;
- Flexibility: It should support the monitoring of any parameter, enabling different scenarios and meeting different interests.
- This will allow the service to be used in contexts and scenarios not originally provided,

enabling high reuse;

- Modular architecture: it must be based on layers with well-defined roles, thus facilitating the service operation and maintenance. That is, a module can be improved or changed without affecting the other modules.
- Insurance: Mechanisms that ensure protection from improper actions against the service should be provided.

B. Premises

The following assumptions are being considered in the project:

- Designing a comprehensive model: In the design process, create a solution that addresses the requirements presented in the best way possible. The goal is to specify a complete monitoring and analysis, that goes beyond not only the prototype to be designed, but also the original purpose of the project. Several other usage scenarios could be explored. For example, adding data mining tools, which will allow the verification of trends or usage pattern behavior in a given video application. Another example is: from the tools implemented we may identify, for instance, that a certain group of people tends to be more interested in a topic-specific knowledge. Another possibility of use would be to incorporate geolocation tools to extract regional behaviors, such as concentration of users of a particular video service in a specific region.
- Prototype Development: the prototype will be developed to meet as many requirements as possible. Initially, the focus will be on features that make up the core of the service, then the service will be extended gradually, through improvements and developments of each of the modules in the system.

These requirements and premises are based on the high video exposure, which brings forth the effectiveness of this consumption. The idea is that the greater the possibility of interaction with the video element, as well as with other tools (social community and evaluation, for example), the better we can monitor these actions, based on the video application, service and software components, allowing the measurement of the engagement, ie, the consumption effectiveness. This idea is illustrated in figure 1.

IV. PARAMETERS AND METRICS

In order to allow the video engagement assess, it is necessary to monitor user interaction with the video application. We

consider four groups of parameters, indicated with the following metrics:

Transmission Parameters - Monitored based on the video transmitter usage:

- Delay;
- Jitter;
- Bandwidth consumed;
- Number of open sessions;
- Percentage of CPU used.

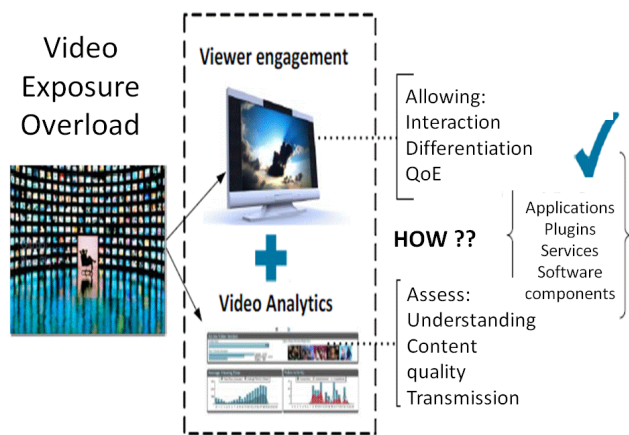


Figure 1: Framework for video applications

Video Player Parameters – monitored based on user interaction with video player:

- Mouse actions;
- Windows focus;
- Pause, fast forward, rewind
- Use of Comments tool;
- Interaction with social network tools (facebook, twitter).

QoE – check the level of user satisfaction proposing a poll;

- Related to video content quality;
- Related to video quality;
- Related to transmission quality.

Content Absorption – check how much user has learned watching video content:

- Evaluation based on test learning validation;
- Other activities to check content absorption (debates, work groups, etc).

V. SYSTEM DESING

With these parameters and metrics in mind, it was possible to design a monitoring system, which is composed by 4 modules, as showed in figure 2.

- Server module: monitors the metrics related to server;
- Application Module: responsible for metrics related to user interaction with application;

- QoE and Content Absorption Module: records the QoE and content absorption's assessment score;
- Report Module: responsible for the use of the data obtained, crossing it to allow proper result analysis.

As the purpose of this system is to monitor the learning actions and check the student's engagement to consume a video element, we chose to integrate the monitoring module to a system of teaching/learning, as LMS (Learning Manager System). Thus, we can join quickly and easily the video element to a course material, and monitor the student interactions.

Although monitoring modules are independent from any system, we choose Tidia-Ae LMS [17] to integrate QoE and Content Absorption Module, in order to build a learning context.

The video server used is VIUSP, a software for video distribution, developed in University of Sao Paulo, where monitoring server module was coupled. To implement the application module, we used a video player based on jwplayer [18], through which monitoring functionality was developed. PostgreSQL v.9, was used as database, and the framework Pentaho (Open Source Business Intelligence), which allows data manipulation and plotting graphics (like Cartesian, pie and bars), as well as data tabulation, was used to implement the Report Module.

The diagram in figure 2 show the system overview and its modules, focusing on the communication flow, where solid lines indicate the request between user desktop/LMS and LMS/Video Server; the dashed line indicates the video streaming from video server to user desktop or device and the dotted line represents monitoring of data persistence in database.

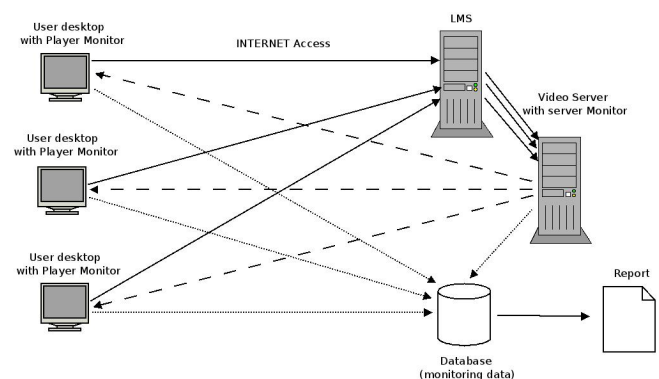


Figure 2: System overview with communication between modules indicated.

Figure 3 shows the interface of the LMS integrated with the monitoring modules. In this screen it is possible to see the video player, the text box for comments, the facebook and twitter icons, the stars that allow classification of video quality

(and consequently transmission quality), and finally, next to the video player, the tests to assess content absorption.



Figure 3: Shot screen of LMS integrated to monitoring modules

VI. USAGE SCENARIO

When a user accesses a video he/she can interact with it in different ways: evaluating it using tools provided in the application interface (chat, forum), commenting on it (by blogging, writing in a wiki or publishing comments in a public site), as well as sharing it in social networks. In addition, the user can be asked to answer several types of polls and tests about the watched video.

The use of video application to support the learning process is being considered as a baseline to guide the project development. We understand the potential of using video in this type of scenario and see that the goal is to design a monitoring service to assess the benefits of using video in this context.

Besides trying to measure how much the videos help in the learning process, we aim to enable the service to extract various other important informations, such as quality of content, level of effectiveness of a particular video on learning a specific concept, and the level of student interest in the subject.

In order to evaluate the service being developed, first we must create the following test scenario:

- Use of two groups of students. For the first group, class material will be available on video as supporting content. For the second group, this video material is not available, thus serving as a control group for testing.
- For the team using the video material, the assessment of student awareness and engagement with regard to the material will be made through a set of subjective questions, for example:
 - Evaluating the perception:
 - Overall: excellent, good, indifferent, bad, very

- bad;
 - Understanding of content: it helped a lot, helped, indifferent / did not help, made me confused.
- Evaluating the engagement:
 - Through comments made about the video;
 - Through the sharing / recommendation of the video.

Figure 4 illustrates the usage scenario.

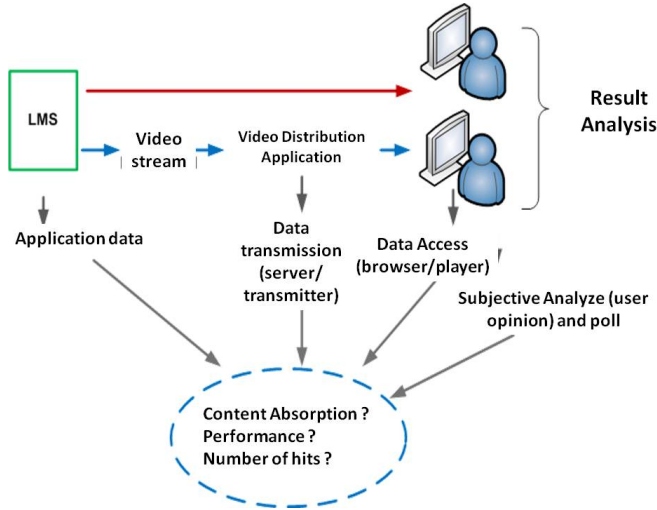


Figure 4: Learning scenario of system use

After the tests, based on the average score of each team and within the group that received the video as learning support , the variation of the grades will depend on the level of subjective evaluation, combined with evaluation of technical parameters collected (If the student had trouble watching the video due to a long buffering time or transmitter overload, for example, if he or she has watched all the content or not, interacted with the content by making a comment or engaging in video sharing/recommending)

Then, the final score of each group will be compared and analyzed, and within the group which received the video material, specific parameters will be created for the evaluations, such as the variation of grades depending on the subjective evaluation questionnaire that each student has answered. Adding to this, the technical data collected (directly related to the reception quality of the user), will also be considered. For example: difficulty in watching the video due to problems arising from the user's network infrastructure, the video application, network video transmitters, as well as analysing whether the user has watched the video in its entirety or only partially, written comments or recommended the content in any way. Thus we have a complete analysis of the user experience quality and how these factors affect student performance.

From this scenario it will be possible not only to assess the potential of the service, but also to allow extraction of information that may be useful to improve the attractiveness of the videos and content, or make it possible to adapt the content (for example, videos should not last longer than a certain time, or the absorption level drops) These are just some examples of analysis that could be made from the data collected.

VII. PRELIMINARY RESULTS

With the first tests using the monitoring system, we were able to verify its potential and observe that:

- Different generations have different interaction profiles with video application;
- Low quality video and network transmission problems discourage the student to use this material;
- Long videos discourage the students in watching them thoroughly.

Of course these observations are only preliminary, and not conclusive. During the next months, we will be working in the continuity of the tests, applying the usage scenario described above.

VIII. CONCLUSIONS AND FUTURE WORK

As presented in this paper, video consumption tends to grow in coming years and it will be increasingly important for institutions that produce and use videos in their core activities, to have metrics and parameters with which to scale the physical infrastructure and human resources needed for such use. At the same time, it becomes increasingly imperative to know the validity and effectiveness of using this type of media. Especially in teaching and learning activities, it is very important to be able to assess how much knowledge a particular material in video format was effective in building, considering a student or group of students. In engineering courses and computer courses, besides being able to offer a didactic content of a concept in a video format, it is possible to offer recorded experiments. This, of course, does not present the same didactic purpose as that achieved if a student got to perform this experiment him or herself, but can in some cases (in which this possibility does not exist), help them better visualize concepts and practices. Given these facts, it is very important to have metrics to evaluate the effectiveness of this material. We have made some preliminary tests which showed that use of video among younger students is effective. However, this kind of material requires a proper use, in order to maintain student's interest and attention. We continue

making our experiments to observe what is the best way to use video content in our engineering and computer courses.

ACKNOWLEDGMENT

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A Systematic Knowledge Pattern (SKP) for Teaching Knowledge Management

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Abstract— Knowledge Management (KM) is a new, evolving computing paradigm based on a collection of processes that govern the creation, dissemination, and utilization of knowledge. We present and discuss a novel method, Systematic Knowledge Pattern (SKP), based on utilizing innovative computing tools for teaching KM. The SKP builds on powerful computing tools employing generic logic-based problem-solving methods that provide an insight into and an understanding of common problems and knowledge processes in any area of KM. The method combines disciplinary principles, a pedagogical approach based on utilizing pedagogical patterns, and intelligent use of technology. We discuss pedagogical aspects of utilizing the method and how it can be specifically adapted to teach KM to high-school students.

Keywords- Knowledge Management, high school curriculum, knowledge pattern, pedagogical pattern, innovative computing tools

I. INTRODUCTION

Knowledge Management (KM) is a new, evolving computing paradigm based on the collection of methods and processes that govern the creation, dissemination, and utilization of knowledge [3]; it is an assortment of techniques for representing and managing codified knowledge. The field has emerged from a number of areas in computer science, notably, artificial intelligence, databases, software engineering, and information systems [11]. Researchers and practitioners in the field usually have extensive formal education in computer science/information sciences. They are involved in constructing information management systems, intelligent systems, reengineering, groupware, etc. To them, knowledge means objects that can be identified, handled, and used in knowledge systems. The objects are created and presented in terms of knowledge patterns, and processed using innovative computing tools.

Teaching KM, especially since it is a young discipline, is challenging to computing educators. Teaching and related learning strategies involve solving typical KM problems, designing systems, and understanding human behavior. Teaching should be planned to develop students' abstraction abilities and their computational thinking [17]. Since KM deals with the creation, dissemination, and utilization of knowledge, which is a complex ongoing task usually performed by a group of people, it is important to emphasize

to students the collaborative aspect of distributed and shared knowledge, using a collaborative learning approach.

The next sections of this paper relate to a novel method, based on utilizing innovative computing tools for teaching collaborative knowledge in the KM area. The first section presents the essence of KM and presents the concept of Knowledge Pattern. In the second section we discuss challenges in teaching KM and refer to the Information and Knowledge Systems (IKS) course. Thereafter we present the Systematic Knowledge Pattern (SKP), and discuss pedagogical aspects of employing it for teaching KM.

II. WHAT IS KNOWLEDGE MANAGEMENT?

Knowledge Management consists of a range of strategies and practices used in an organization to identify, create, represent, distribute, and enable adoption of insights and experiences. Such insights and experiences comprise knowledge, either embodied in individuals or embedded in organizations as processes or practices [10][11]. Knowledge management efforts typically focus on organizational objectives such as improved performance, competitive advantage, innovation, the sharing of lessons learned, integration, and continuous improvement of the organization. Business organizations are continually developing and implementing a variety of techniques and information technologies to enhance knowledge management. Knowledge management efforts overlap with organizational learning. They may be distinguished from the latter by their greater focus on the management of knowledge as a strategic asset and an emphasis on encouraging the sharing of knowledge. Knowledge management addresses the lack of sharing knowledge among members of organizations by encouraging individuals to make their knowledge explicit by creating knowledge elements, which can be stored in knowledge bases for later reuse or for participating in communities of practice [11]. Knowledge in organizations has the following components:

1. *Knowledge about customers*- the most vital knowledge in most organizations.
2. *Knowledge about Processes*- applying the best know-how while performing core tasks.

3. *Knowledge about Products and Services*- smarter solutions, customized to users' needs.
4. *Individual Knowledge*- experience and creativity of individuals in the origination.
5. *Collaborative knowledge*- collaborative information shared by several departments in the organization.
6. *Organizational insight*- insight databases that include implicit and deduced knowledge about the organization.

A. Knowledge patterns

Knowledge is one of the most important assets for any organization, and for all areas of science [9]. Whereas experience describes events in one specific context that can only be reused carefully, knowledge is usually applicable in previously unknown contexts with a fair amount of certainty [13]. The concept of knowledge patterns can be used to support practitioners and researchers in their knowledge management activities. Knowledge patterns share one way to formalize and describe lessons learned and best practices (i.e. proven experiences) about structuring knowledge, the design of KM systems, or the development of underlying ontologies. Such patterns capture aspects that positively or negatively influence the KM activities. A knowledge pattern is a general, proven, and beneficial solution to a common, recurring problem in knowledge design, i.e. the structuring and composition of the knowledge, defining metadata (information about information) and potential relationships between knowledge components [13]. The basic structure of a knowledge pattern is as follows:

Name: What is the pattern called?
Issue: What is the issue (e.g., problem) addressed by this pattern?
Q-Effect: What "knowledge quality aspects" are mostly affected by this pattern? This section clearly states whether there is a positive, negative, or neutral effect.
Solution: What suitable solutions underlie this pattern? Multiple alternative solutions may be suggested.
Causes: What are the basic causes of this pattern?

Patterns may include additional information entities such as context, examples, anecdotal evidence, or exceptions. Knowledge patterns may refer to knowledge components of an organization, as well as to semantic relations between knowledge components. The following are examples of knowledge patterns that deal with problems related to the main process in different departments: (a) the annual budget in a financial department, and (b) customer complaints in a customer service department.

Example 1:

Name: Exception in the annual budget

Issue: Exception in the annual budget issue, exception in the wages of workers in the year 2010.

Q-Effect: Wastefulness of resources.

Solution: Increasing efficiency in the work shifts, building worker profiles, incompatible workers, specialization and combining the workers in courses, and outsourcing.

Causes: Increasing earnings and employing professionals.

Example2:

Name: Faults in the customer service based on the customers' complaints.

Issue: Customers' complaints are not closed and untreated in time.

Q-Effect: Loss of existing and potential customers.

Solution: Constructing a warning system that will alert one about untreated complaints in time, and will set a time limit for making complaints.

Causes: Tunneling processes in organizations, ignorance toward an existing complaint.

III. TEACHING KNOWLEDGE MANAGEMENT

A. The Information and Knowledge Systems curriculum

The curriculum Information and Knowledge Systems (IKS) [8] was developed in Israel (2003) for high school students with average skills and achievements who might not be able to succeed in an academic study track, yet can manage to graduate in a low-level technological study track. Regarding computing studies, although above average students would usually prefer to major in computer science in the academic track [5] or in software engineering in the high-technological study track [6], average achievers may benefit more from learning how to use fluently and reflectively innovative computing tools to create and process knowledge.

The IKS curriculum integrates the area of Knowledge Management in business organizations. It deals with methods of production, collection, organization and processing storage and focuses on processes and assembling insights that derive from real problems. The curriculum deals with collaborative information and knowledge processes that investigate the nature of information and information processes [8]. The IKS curriculum derives its origins from the scientific paradigm of the future, which was suggested by Dyson [4]. Dyson distinguished between a paradigm of concepts and a paradigm of tools and asserted that tools may manufacture conceptions and not only vice versa. As an example of this trend, he described the personal computer as a technological tool that shaped the most important theories of the beginning of the 21st century [4]. A few years later, the authors of the *Science 2020 Report* [16] stated a similar vision regarding the ongoing influence of the development of computing technology regarding the way scientists perform science: "*Conceptual and technological tools developed within computer science are...starting to have wide-ranging applications outside the subject in which they originated, especially in sciences investigating complex systems*" [16, p. 8]. In particular, "*Scientific computing platforms and infrastructure are making possible new kinds of experiments that would have been impossible to conduct only 10 years ago, changing the way scientist do science.*" [16, p. 14]. In the context of knowledge management, innovative computing tools enable one to define

new methodologies for dealing with explicit, implicit, and distributed knowledge embedded in complex organizations. Based on the aforementioned ideas, the IKS curriculum enables the students to learn the essence of knowledge and knowledge management through the use of innovative computing tools. The curriculum intends to promote real-life insights by means of information, technological tools, as well as information and communication technology using the internet, sites and portals. Teaching IKS requires guiding the students in performing a continuous knowledge management process (KMP) aimed at collecting and processing knowledge about a chosen organization [9].

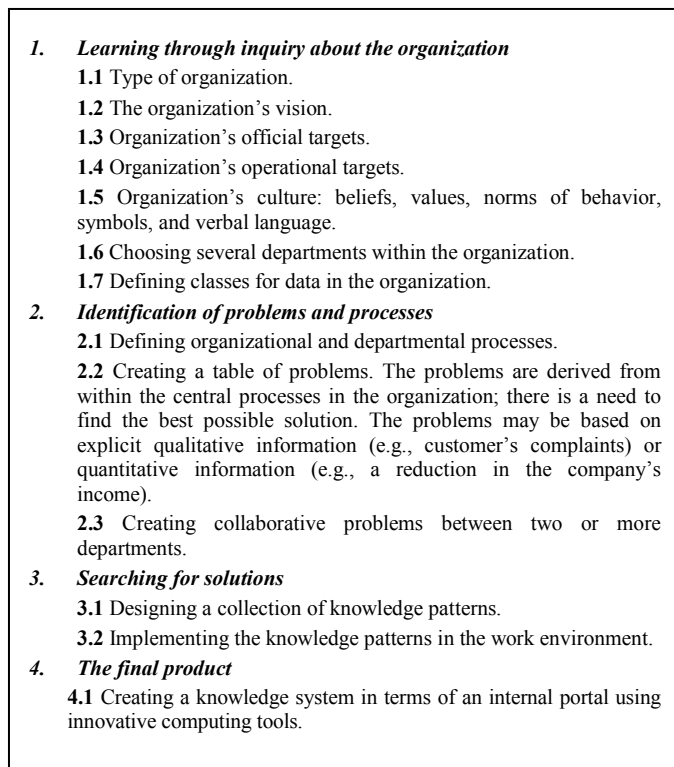


Figure. Stages of the Knowledge Management Process (KMP)

The final product of the course is an internal information business portal used as a major gateway to all enterprise resources. The portal provides information needs that are common to all the employees in the organization, such as information about the organizational structure, human resources, professional units, service units, phonebook, products, payroll, attendance, professional information, social services, bulletin board for employees, as well as integration of advanced services such as computer forms, queries, and access to personal information. Knowledge components tools assist to create the portal such as database management, SQL queries, blogs, wiki, surveys, document management, protocol of meetings, and subject trees.

B. Challenges in Teaching KM

Problem-solving processes in the KM area require abstract thinking and integrating: understanding the problem, acquiring relevant information and using tools effectively and wisely.

Combining these levels might be difficult for average students. Specifically, learning fundamentals of KM require students to develop and use skills related to various aspects of knowledge:

- (a) *Explicit knowledge*: Emerging assumptions; codifying known knowledge (information);
- (b) *Systematic and reflective processing*: Finding implicit knowledge by repetition;
- (c) *Differentiating vital knowledge*: Abstracting and focusing on the main issues;
- (d) *Sharing knowledge*: Sharing distributed knowledge and integrating it into a deduced (implicit) knowledge base to obtain insights about the organization; and
- (e) *Smart use*: Using innovative tools in an intelligent way.

These skills are required for understanding the essence of KM and for internalizing knowledge patterns discussed in class. Average students might have difficulties in comprehending the complexity of knowledge and the compound structure of an abstract problem.

These considerations motivated the first author, who is a leading teacher, to develop a suitable pedagogical approach for teaching the IKS course to students with average achievements and to establish a culture of building collaborative knowledge in class. Long-term teaching experience with average students motivated her to find ways to trigger changes in the students' approach to KM problems while gradually developing their aforementioned required skills and enhancing their problem-solving methods. This was basically obtained through reflection and investigation of different teaching methods. The outcome of this informal action research process was an innovative approach to teach KM, which builds on the power of innovative computing tools, and combines disciplinary principles, pedagogical tools, and intelligent use of technology.

IV. THE PEDAGOGICAL APPROACH

We suggest a pedagogical tool that combines three main components: (a) disciplinary (KM) knowledge, (b) innovative computing tools, and (c) pedagogical approach based on utilizing pedagogical patterns [1][2][15]. The tool, called Systematic Knowledge Pattern (SKP), features a new style of teaching and learning; it enables students to systematically organize and process explicit and implicit knowledge, and eventually to create collaborative collections of knowledge patterns for a variety of organization-related problems [13].

A. The Systematic Knowledge Pattern (SKP) model

The SKP model leads to a variety of expected solutions, and the inference of insights related to organizations. SKP attempts to provide an easy way to answer questions such as the following: What is knowledge? How to produce knowledge? How can knowledge be presented and shared in organizations? How can implicit information be retrieved from an organization? And how can the explicit information be organized in an organization?

The SKP model is organized basically as a linear process composed of components marked A-H executed in alphabetic order (Figure 2), but pragmatically, it supports an iterative

back-and-forth process owing to the possible discovery or emergence of new problems, or as a result of refining already identified problems (components E, E1 in Figure 1).

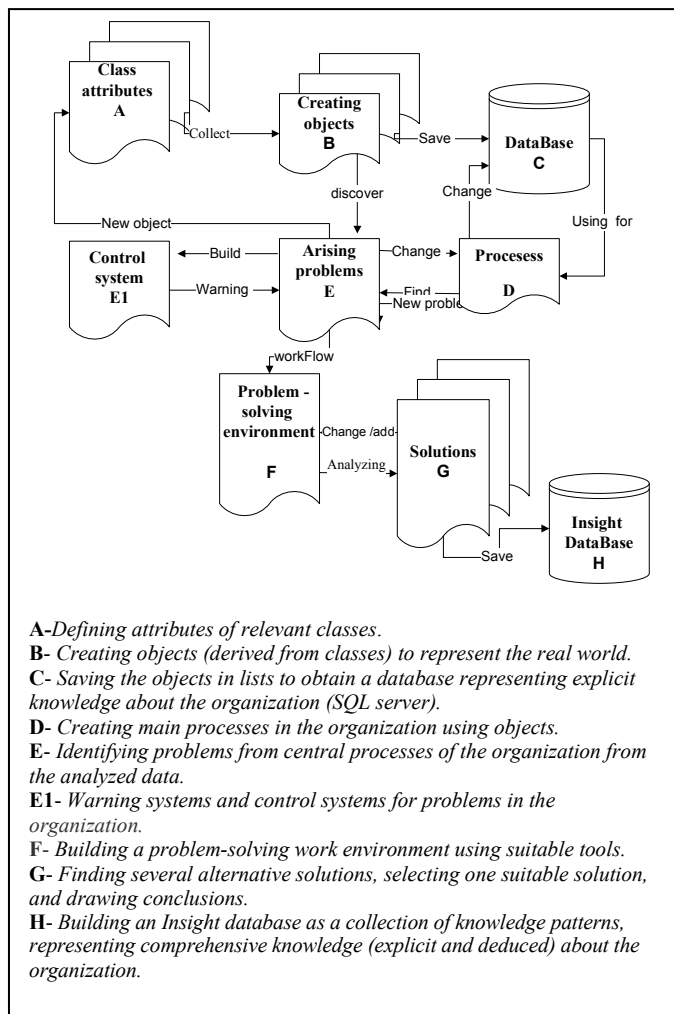


Figure 2. The Systematic Knowledge Pattern (SKP)

The SKP builds on powerful computing tools employing generic logic-based problem-solving methods that provide an insight into and an understanding of common problems and knowledge processes in any area of KM. The tools enable one to create: (a) knowledge patterns (suitable solutions for identified problems) and (b) deduced insight knowledge bases related to specific organizations. The tools support collaborative work of the students. Using tools that include components such as survey, blogs, wiki, discussions, meetings, queries, lists, and web parts, and workflows (an environment for describing knowledge patterns) enable the students to capture relevant information and to organize it in the form of knowledge patterns, thus showing suitable solutions for the identified problems. Without using such tools the student could not possibly present knowledge patterns and preserve the deduced personal knowledge.

Using SKP help the student to build a collection of insights and then translate the possible solution to a work environment. For example, a final product can be a working environment (workflow) for finding solutions. The workflow is a collection of information and knowledge tools including discussions, documents, lists, queries, surveys, and documents of conclusions, and a list of knowledge patterns.

Microsoft SharePoint 2010 [14] is a collection of tools that enable one to create sites, insights, contents, and communities. It also includes a built-in search engine. It is an example of an innovative tool for implementing computerized knowledge management processing. The tool supports collaborative working, and thus could be used for collaborative learning. Students can set up web sites to share information with others, manage documents from start to finish, and publish reports to help everyone make better decisions. The above-mentioned characteristics of Microsoft SharePoint 2010 led us to choose it as a suitable environment for teaching the IKS course. Actually, the computerized tool shaped The SKP model. Each component of the SKP is implemented using corresponding components of the computerized tool.

The SKP method suggests collaborative learning in a situation in which two or more students attempt to learn something together via a knowledge system (e.g. a portal). We believe that collaborative learning that combines pedagogic strategies with advanced technological tools can promote students' learning and their problem-solving performance. Specifically, knowledge can be attained within the class where members actively interact by sharing experiences, solving problems and better understanding processes in any area of Knowledge Management.

B. Utilizing SKP to teach KM processes

Table I describes how the components of the SKP (Figure 2) relate to corresponding stages in the knowledge management process (KMP) (Figure1).

An example of utilizing SKP in class: OSEM is one of the largest food manufacturers and distributors in Israel. We demonstrate in Table II the knowledge management process (KMP) that students should perform related to the company.

TABLE I. SKP COMPONENTS-KMP STAGES

| SKP Components | Stages of KM process |
|--------------------|--|
| A, B, C | 1.7 - Defining classes for data in the organization. |
| D, E, E1(optional) | 2.1 Defining organizational and departmental processes. 2.2 Creating a table of problems. 2.3 Creating collaborative problem between two or more departments. |
| F, G, H | 3.1 Designing a collection of knowledge patterns. 3.2 Implementing the knowledge patterns into the work environment. 4.1 Creating a knowledge system in terms of an internal portal. |

TABLE II. THE ACTUAL KMP RELATED TO OSEM

| KMP stages | SKP comp. | The actual KMP related to OSEM |
|------------|-----------|--|
| 1.1-1.5 | | Collecting information about the organization. |
| 1.6 | | Choosing departments: Financial department and client service department. |
| 1.7 | A,B,C | Classes: Client, Budget |
| 2.1 | D | Central processes - Annual budget, client complaints. |
| 2.2-2.3 | E | <p>Problem: Increase in the anomalies of the annual budget in the year 2010.</p> <p>Presenting the problem as a knowledge pattern:</p> <p>Name: Anomalies in the annual budget</p> <p>Issue: Finding the reason for the anomalies in the 2010 budget.</p> <p>Q-Effect: Waste of resources, the creation of inefficient processing in the system.</p> <p>Solution: Building a list of objects of the annual budget for 2010. Querying, excel pivots, looking for exceptional factors, building a presentation for the solution. Meeting for decisions regarding managers, departments, documents.</p> <p>Causes: Increased earnings and employing professionals.</p> |
| 3.1 | F | Construction of an environment that solves the problem. |
| 3.2 | G | Creating solutions with technological tools in the above environment, for example: querying for making management decisions, pivots in Excel, graphs, web parts. |
| 3.3 | H | Preserving solutions in the insight database. |

C. Integrating Pedagogical Patterns into the SKP model

Pedagogical patterns are intended to capture the expert knowledge of the practice of teaching and transfer that knowledge to others [www.pedagogicalpatterns.org]. They do not, however, express new pedagogical ideas, but rather, the tried and proven solutions for pedagogical problems. Communities such as the Pedagogical Patterns Project [15] have been collecting many types of patterns that can help teachers teach and students learn. Educators consider pedagogical patterns as suitable tools to document the successes of pedagogical frameworks in order to enable their reuse [7].

We decided to utilize several pedagogical patterns, some of them were originally were designed to teach computer science, and to integrate their principles into the SKP disciplinary model in order to teach knowledge management processes as follows:

Pedagogical pattern - Explore for Yourself

A person's success is based mainly on her ability to learn new concepts efficiently and to act as a team player by sharing knowledge and insights [1].

Using for SKP- Innovative KM tools are very user-friendly for the students; they give immediate feedback and thus support learning. Feedback increases the students' confidence, and encourages them to take responsibility for the learning process. Use of SKP enables the students to explore their abilities, inspires them to search for new solutions, and supports internalization of knowledge.

Pedagogical pattern – Role Play

The complexity of some concepts makes them hard to understand with only abstract explanations. Furthermore, difficulties in understanding complex concepts may frustrate the students [1].

Using for SKP - The SKP model has several components and is suitable for collaborative learning. A group of students who are working on a project divide the missions and take responsibility for each mission; this may reduce the complexity. Innovative KM tools make abstract problems and solutions more concrete. From the collaborative point of view, competition from different teams can be performed, where the team playing will be observed by the other teams.

Pedagogical pattern - Different Approaches

Every person obtains information differently, using different approaches to the same topic [1].

Using for SKP - The SKP model enables students to find solutions in different ways. The SKP is a non-linear model. Each student can use a variety of tools to capture knowledge and build some possible solutions such as an alert system, workspaces for decisions, workspaces for documents, workspaces for social events, blog, a publishing site with workflow, and more.

Pedagogical pattern - Test tube

Students are often naive about what resources are available to them. They often ask questions they could answer by themselves. While this is not bad in itself, they would be happy to know they can find their own answers quickly. Students need to learn to be effective in answering their own questions [2]. When students encounter holes in their knowledge, we would like for them to seek out an answer. Unfortunately, students often resort immediately to the "easy fix" of asking an authority for the answer [2].

Using for SKP - Students are often afraid of taking responsibility for their own learning. Searching for solutions by using KM tools (e.g., search engines) may reinforce students' independence and motivate them to find the answer on their own. The tools provide independent research for self-control. Self-control navigates the student to higher level of independent thinking for finding alternative solutions for a problem.

Pedagogical pattern - Toolbox

Let students build a tool kit in early courses for use in later courses. If well-thought out and implemented, it can be a wonderful guide to reusable software... Having a personal tool kit of reusable software components can be a wonderful help in a difficult project [2].

Using for SKP - The KM tools enable students to develop a collection of methods for solving a problem, and to accomplish a complex project effectively.

V. IMPLEMENTATION

The curriculum Information and Knowledge Systems (IKS) was developed in 2003 and has been gradually implemented since then at Israeli high schools. For the last 4 years the number of schools which choose to teach the IKS course has significantly increased. During the last academic year the IKS course was taught in 50 schools, 1-2 classes in a school, and 20-30 students in a class. The students developed final projects (an internal information business portal related to some organization) which were evaluated by external examiners, especially nominated for this task by the Ministry of Education.

During the last academic year, the SKP model was utilized to teach the IKS course to a class of twenty high school students. We conducted a pilot study aimed to check the effect of utilizing SKP on students' perception of the concept of knowledge. The students were asked to answer an open questionnaire (same, Pre and Post) that related to the essence of knowledge and basic information (data). The findings indicated that before studying the course most students could not distinguish between knowledge and data, and could not explain the difference between acquiring and using knowledge. After the course the situation was significantly different. Students grasped *knowledge* as a complex collection of inferred insights and could distinguish implicit *knowledge* from explicit *information*. Interestingly, even though students used computerized tools to deduce knowledge, they related *knowledge* to human inference processes, acquired by people (stored and processed in their brains), whereas *information* was perceived as "external" and tangible presentation of data, usually expressed in terms of computerized tools. From empirical evidence, we got the impression that after students have gained experience in building knowledge systems utilizing the SKP approach, they could more easily grasp the essence of collaborative knowledge. We further plan to conduct a comprehensive study aimed at classifying students' knowledge management processes, as well as their perception of KM concepts. Specifically, it would be interesting to investigate if and how students use computerized tools in an intelligent way to deduce new knowledge from already gained knowledge, and the way they collaborate to obtain distributed and shared knowledge.

VI. CONCLUDING REMARKS

Knowledge Management is an evolving computing paradigm based on a collection of methods and processes that govern the creation, dissemination, and utilization of knowledge. We presented here the Systematic Knowledge Pattern (SKP) based on utilizing innovative technology tools for teaching collaborative knowledge organization and processing. The tool was adapted to teach the *Information and Knowledge Systems* course to high school students with average achievements. Combining tools that create knowledge and build knowledge systematically by listing all the appropriate template broad issues in knowledge management allows students who have difficulty in organizing information and generating knowledge to understand how knowledge is created and what is known in the broad sense. Students have

to deal with abstract thinking when finding solutions to compound problems and are required to integrate distinct abstraction levels: (a) understanding the problem, (b) acquisition of relevant information; and (c) effective and wise use of tools. Students who have difficulties in abstracting information should receive guidance from an expert who has mastered KM methods, KM technological tools, and related pedagogy. The SKP, in integrating pedagogical patterns, serves as a powerful tool for the teacher in supporting students. Teaching with the tool should be based on concrete associated examples while continuously analyzing students' knowledge management processes.

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Work in Progress: Putting Control Engineering in Middle School Girls' Futures

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Abstract—The purpose of the project described in this paper is to increase the number of female students in middle school who have a basic understanding of control engineering principles and how these apply to modern engineering and technological devices. Project work is being implemented within a local girls' school in Hobart, the capital city of the state of Tasmania, Australia. Project activity has included running a series of hands-on workshops for two separate middle school classes. These workshops have introduced control engineering principles and the engineering design process. Project experiences so far are discussed and recommendations for future project work are outlined.

Keywords— *K-12 initiatives; control engineering; gender; communal goals.*

I. INTRODUCTION

It is commonly observed that there is an underrepresentation of women in STEM professions, particularly in Engineering [1-2]. This underrepresentation can be partly due to the limited understanding of the work done by engineers and the role of engineers in helping society. The literature indicates that women often gravitate towards careers that they perceive will enable them to contribute to society and help people, such as careers in the health services [2-3]. Unawareness of the communal goals that are integral to engineering, such as helping people, working with people and benefiting society as a whole, can also contribute to girls showing less interest in the profession [2]. More accurate or holistic perceptions of the engineering profession need to be encouraged in the middle school years [3]. The middle school seems to be a suitable educational setting to target as students have not yet begun selecting subjects [4]. Importantly, research indicates that students often exclude engineering as a viable career option by the age of 14 (grade 8 in Tasmania) [1, 5].

Control Engineering is usually introduced to middle and high school students through the use of robotics programs that focus on the control of actuators based on sensor inputs [5]. Additional programs involving sensor science can be used to introduce some control engineering ideas [4]. These approaches show control in a more traditional light to the methods proposed in this paper. The purpose of the work

undertaken in this project is to introduce control engineering to middle school students through a series of hands-on activities in a variety of fields. These fields include civil engineering, sound, optics, vehicles, biomedical engineering, planes, rockets and rollercoasters, among others. The remainder of this paper will outline the preliminary approach taken and our experiences so far. Recommendations to improve the program throughout the remaining project duration are also described.

II. EXPERIENCES SO FAR

Two classes, one grade 5 and the other grade 6, from St Michael's Collegiate School attended one workshop a week for four weeks. Each workshop was run by undergraduate engineering students who are part of the University of Tasmania's STEM Education and Outreach team (<http://www.utas.edu.au/stem>). Program content included two civil, one optics, and one sound engineering workshop. All activities were linked to the new Australian standards in Science. Most activities involved students working in small teams to emphasize the role of teamwork in engineering practice. The Draw an Engineer Test (DAET) [6] was used as a pre- and post-survey to gauge student understanding and perception of engineers.

The number of participants in each workshop was 21 and 24 for grades 5 and 6, respectively. In the pre-survey, half of the DAETs of each grade depicted an engineer similar to a car mechanic. Typically, these drawings showed an adult male, wearing dirty overalls using basic tools to repair an engine or motor. In the post-survey this was not drawn by any student in grades 5 or 6. Post-surveys most commonly showed civil or electrical engineers. Aspects of design, planning, teamwork, problem solving and the engineering design process were also evident in many drawings. These were all topics that were discussed across the various workshops, implying that the students did retain these important engineering concepts beyond the end of the program.

The role of communal goals in engineering was emphasized in this series of workshops. While the topic of women in engineering was never directly addressed, the number of female engineers drawn in the post-surveys increased from 2 to 10 for grade 5 students, and from 4 to 8 for grade 6. Each workshop conducted had at least one female facilitator, and

this may have demonstrated to students that engineering is not a male-only profession. The increase in female engineers drawn in the post-surveys could also be due to the revelation that engineers are not necessarily car mechanics. The students appeared to relate to engineering more once some of the basic aspects of the profession were introduced.

The DAET was accompanied by a worksheet asking students about the engineer they drew. Communal goals were not referred to at all by either grade in the pre-survey. In the post-survey, only one grade 5 student discussed communal goals such as safety and environmental considerations and societal impact. However, 10 grade 6 students made reference to these ideas. This may be related to a higher level of maturity in the grade 6 class. In general terms, the grade 5 class was also less attentive and more eager to complete only hands-on activities, so perhaps did not engage with as much content as the grade 6 students.

The civil workshops included discussions and hands-on activities that focused on water and structures. In general, these workshops were less technical than the optics or sound workshops. Control ideas were integrated into a water purification activity. After designing and constructing a filtration system, the basic control loop of input, output and feedback was introduced. It was then linked to the purification activity by discussing how the performance of a purification system determines the changes that are later made to it. Students were responsive in this section and seemed to gain a basic understanding of control concepts. Towards the end of the water engineering workshop, an industrial application was presented. Facilitators introduced a local paper mill that uses fresh river water in its processes. With the help of the facilitators, students then worked together to describe a basic system to control the temperature and quality of the water being returned to the river.

Control was integrated into the optics workshop through use of a fibre optics activity which involved students using a microcontroller-based fibre optics board. Students could control the light sequence being sent down the fibre optic cable by interacting with the microcontroller.

Students explored the basics of how sound travels through air and constructed a speaker from low cost materials as part of the sound workshop. Inputs and outputs were discussed relating to the operation of the speaker and the notion of feedback was also introduced. It was observed that student understanding of control engineering principles could have been improved by directly reinforcing these ideas in other activities throughout the workshop.

Students participating in the program were provided with a feedback form to fill out at the conclusion of each workshop. The general sentiment expressed by the students was that they did not enjoy engaging in discussion as much as participating in hands-on activities. This suggests that the standalone workshops run at the university need to be more closely linked into classroom work so that students take responsibility for their own learning, rather than just viewing the excursions as a fun activity where they are not expected to learn.

Preliminary evidence suggests that students have enhanced their understanding of what engineers do. Students have also made connections with women in engineering and the potential to help people and society through engineering work. The integration of control activities has had more limited success leading to the following recommendations for future project work.

III. FUTURE PROJECT WORK

Integrating a control engineering activity into a broadly themed engineering workshop has been seen to have some limitations. Those ideas related to communal goals and the overall theme for a workshop were generally better understood by students due to their continuity throughout the workshop. Post-surveys indicated that students generally grasped and retained the overarching concept introduced throughout the workshop, but often lost the "smaller details" such as the specialist language of control engineering and the direct connections with control systems that were embedded in the activities. Feedback from the classroom teachers who attended the workshops indicated that the language used could be more age-appropriate to enhance student understanding.

Due to these limitations, a revised approach to teaching control engineering to middle school students will be tested for the remaining duration of the project. This approach will involve creating a control themed collection of activities which rely on other fields such as the civil engineering, sound and optics control activities already described. By utilizing this approach, control principles will be explored with groups of students in a number of different applications areas. This will create greater opportunities for students to learn about control engineering and make connections to many engineering disciplines.

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Implementing a New Computer Science Curriculum for Middle School in Israel

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Abstract— as part of a national strategic plan recently established by the Ministry of Education in Israel to strengthen science and technology education, an innovative Computer Science (CS) curriculum for middle school was developed. One main goal of the new curriculum is to expose students at an early stage of education to the fundamentals of CS and computational thinking, and to encourage students to study CS in the future. We present the curriculum and its initial implementation, focusing on issues of teachers' professional development.

Keywords- *algorithmic thinking, computational thinking, computer science, curriculum, middle school, education, teachers' professional development*

I. INTRODUCTION

Aiming to increase the number of high-school students who choose to major in science and technology, the Israeli Ministry of Education launched the *Science and Technology Excellence program* (STEP) in 2011 to increase the number of high-school students who choose to major in science and technology. This unique program is part of the overall strategic plan to strengthen science and technology K-12

education in Israel¹. Currently, less than ten percent of Israeli high-school graduates major in both science and technology. Raising this low percentage may improve the readiness and preparation of potential candidates for academic studies in science and engineering, and eventually influence their becoming part of the high-tech industry.

The main goals of the STEP are therefore to expose middle-school students to the fundamentals of science and technology in order to encourage them to choose a major in these areas in high school, and to develop a sense of leadership in science and technology during their high-school studies. The new middle school STEP curriculum, which precedes the existing high-school curriculum in science and technology, creates a continual and comprehensive six-year science and technology curriculum for highly capable students. It includes extra hours of Mathematics, Natural Sciences (Chemistry, Biology, and Physics) and Computer Science (CS) combined with Robotics.

The Israeli CS curriculum for high school is well known internationally [7]; however, until recently, in typical Israeli middle schools the students studied computer literacy, except for a few short-term educational initiatives practiced on a local

¹<http://cms.education.gov.il/EducationCMS/Units/MadaTech/>

basis for learning CS. The need to rethink computing education on a national level complies with the current national effort to adapt the education system to the twenty-first century.

The education authority's decision to include CS in the middle-school's new STEP was based on the premise that learning CS in middle school would promote early acquisition of computational thinking, which in turn, would enhance students' scientific thinking and technological literacy. The guiding principle for the new CS curriculum has therefore been to focus on developing thinking skills rather than programming skills, and to expose students to various development environments using an inquiry-based approach, and utilizing learning-through-enjoyment pedagogical methods that can increase young students' motivation.

The curriculum consists of both mandatory and elective modules: *a. Introduction to CS*, which provides the basis for the entire program, and emphasizes the fundamentals of algorithmic thinking; *b. the spreadsheet*, with an emphasis on its usage for scientific inquiry; its inclusion in the CS curriculum bridges the gap between the CS middle school curriculum and other parts of the six-year STEP; *c. Selection between Introduction to Robotics*, which exposes students to engineering concepts and problems, and *Basic Internet Programming*; *d. The last module is devoted to developing a small programming project from scratch.*

The above modular program has been designed by a professional committee established by the Israeli Ministry of Education. The authors of this paper are all members of that committee. From 2011 to the present, the first two modules have been implemented in 183 pilot schools, concomitantly with the initiation of professional development activities under the supervision of the first author.

The next sections of this paper elaborate on the principles and constraints that guided the committee in designing the curriculum. The first section presents the rationale for teaching computing at the K-12 level, and lists the programs currently taught in Israel. Thereafter, the new CS curriculum for middle school is described, and finally, implementation issues are discussed, focusing on teachers' professional development.

II. K-12 COMPUTING PROGRAM IN ISRAEL

A. Rational and Motivation

Computer science provides the knowledge and skills foundation for contemporary technological advances: "Maintaining our ability to meet present and future challenges requires us to acknowledge CS as a core element of all STEM (science, technology, engineering, and mathematics) initiatives" ([11], pp. 15). Learning CS enhances computational thinking and may contribute to a better understanding of other subjects as well [12]. Strengthening the status of CS as a full-fledged and self-contained subject in the educational system is most important [11]. However, the increasing complexity of the field led to an unfavorable external image [3] and posed new challenges in motivating students to pursue CS as a career choice or a course of study in

which to major [11]. "Despite many years of our trying to broaden our image, computing is still widely perceived as a programmer's field... Many outsiders wonder whether CS departments will eventually disappear as the technology evolves and other fields take over as the main contributors of new computing technology" [3, pp. 336].

To address this problem on a national as well as a global level, Cohen and Haberman (2007) suggested that CS be presented as a **language of technology**, which describes structures, processes, relationships, and communications. Computer science serves as a platform for problem solving, knowledge representation, and formalization of processes, as well as for understanding technology and for performing technology-related processes [1]. CS should be taught to youngsters as one of five basic languages: a mother-tongue, an elective international foreign language, a language of science (mathematics), a language of art and body, and a language of technology (computer science), each of which is used to express themes and ideas or feelings associated with specific domains and contexts. "Long-term study of these five languages, along with intelligent practice while elaborating on utilizing communication skills, is highly useful for successful functioning on personal, national, and global levels" [2, pp. 54].

B. K-12 Computing Curricula in Israel

During the last few decades, various computing curricula have been taught in Israeli schools as an elective subject, ranging from computer literacy, up to computing fluency, usually learned at elementary and middle school as part of other subjects. This includes CS for high school in the academic track [7] and software engineering for high school in the high-technological track [9]. The curricula evolved over the years according to changes and development of the field. Pre-service and in-service teacher training courses were created to provide teachers with technical and pedagogical knowledge [7,10]. Many research papers were published regarding the implementation of these curricula using various pedagogical approaches and students' conceptualization of CS concepts and their problem-solving performance (for example, see a review in [11], pp. 29-51).

The CS curriculum for high school introduces CS concepts and problem-solving methods independently of specific computers and programming languages, along with their practical implementation in actual programming languages [7]. The program consists of five modules (90 hours each): (a) *Fundamentals of CS 1 and 2*, which introduce algorithmic problem-solving (two modules, 180 hours in total); (b) *Software Design*, which focuses on abstract data types and object-oriented programming; (c) *A Second Paradigm* - alternatives to this module are logic programming, functional programming, computer organization and assembly language, computer graphics, information systems, and stateless programming; and (d) *CS Theory*: Computational models.

The programming languages chosen for teaching fundamentals and software design have changed over the years and currently are Object Oriented (JAVA or C#).

The Software Engineering program: During the last two decades, a Software Engineering (SE) program especially designed for high-school level has been in operation in Israel [8]. The program consists of (a) an elective topic in natural sciences/introduction to technology sciences, (b) Computer Science, and (c) an elective and advanced topic in CS.

The program has scientific foundations and can be viewed as an extension of the CS program. The main goals of the program are (1) to introduce students to knowledge representation, system-level perspective and formalization of processes, and (2) to promote students' creativity, and enable them to construct an integrative knowledge of CS topics. The specialized topics that schools can choose from are as follows: Operating Systems, XML Web Services, Computer Graphics, Expert Systems, and Design & Programming of Information Management Systems. The students' final assignment is to develop a comprehensive software project related to the elected specialized topic.

III. THE NEW CS CURRICULUM FOR MIDDLE SCHOOL

The new CS program for middle school is part of the STEP, based on an overall strategic plan to strengthen science and technology K-12 education in Israel [13]. The program (180 hours: 60 hours a year, two hours a week) is intended for students from the seventh to the ninth grades. With regard to the high-school curriculum, a six-year sequence of the curriculum is created. The main goal is to impart knowledge and skills required for a person in the twenty-first century. It is not aimed at training students to be programmers or computer scientists, but rather to introduce students to logical and algorithmic thinking and to expose them to different development environments at an early stage. A somewhat similar approach has been recently suggested by the American Computer Science Teacher Association (CSTA) in their Level I model curriculum for K-12 Computer Science, in the parts that discuss K5-K8 [5].

Lowering CS contents from high school to middle school will enable excellent students from the academic track to complete the high-school curriculum a year earlier, during the eleventh grade. That will allow such a student to be exposed (if interested) during the twelfth grade to one of the specialized areas in the SE program taught in the technological track, and to develop a software project.

The first module constitutes the core of the whole program. Its main goal is to expose the students to the fundamentals of computational thinking and programming. The subjects include serial execution, variables, conditions, loops, counters, accumulators, messaging, and event handling. Since this is the first year the students study CS at school, it was important to choose a suitable programming environment that will:

- Expose the students to algorithmic problems and their solutions and enhance algorithmic thinking.
- Enable students to implement various control structures.
- Make programming enjoyable, interactive, easy to use, and graphically appealing.

- Be translated to different natural languages.
- Be free of charge (if possible).

Scratch (<http://scratch.mit.edu>) was the chosen environment. Other alternatives that exist worldwide include Logo-based environments, Alice (<http://www.alice.org/>), Greenfoot (<http://www.greenfoot.org/book/>), and more recently Bootstrap, "a standards-based curriculum for middle and high-school students, which teaches them to program their own videogames using purely algebraic and geometric concepts" (<http://www.bootstrapworld.org>).

The second year begins with introducing the students to using a spreadsheet for scientific research (**second module**). Teaching a spreadsheet is required for the mathematics and physics curricula. Hence, its inclusion in the CS curriculum helps to create a bridge between the curriculum in middle school and the general six-year STEP. The tools to be taught include representation of graphs, using mathematical and statistical functions, and wise use of conditionals.

The third module is elective and its guidelines are as follows:

- It is based on the knowledge taught during the first year.
- No new control structures are introduced
- Students are exposed to new kinds of algorithmic problems and new technologies.

It was decided that in the second year the main subject will be *Introduction to Robotics*, focusing on algorithmic problem solving and not (just) on the mechanical and electrical aspects. Students receive a ready-to-program robot and can add to it various sensors and download their software. The goals of adding robotics to CS curricula are to (1) combine logical thinking with engineering thinking, (2) expose students to other technological areas, and (3) stimulate the students to be independent learners. The module contains the following topics: controllers, actuators, sensors, electrical energy and mechanical energy, energy transformations, motors, an open-loop control, and a closed-loop control. Students in the program can compete in FLL competitions (<http://www.firstlegoleague.org/>).

Since the *Introduction to Robotics* module is budget dependent (which might be a problem) and because those teachers without an engineering or electrical engineering background were reluctant to teach this program, the authors decided to suggest an alternative module that is less engineering oriented and free of charge. In order to create more continuity between the middle-school and the high-school curricula, it was decided to suggest teaching *Basic Internet Programming* by focusing on client-side programming as an introduction to stateless programming (taught in an elective module in high school). The module focuses on HTML5 and JavaScript; the students practice conditionals and loops.

The fourth module, which is taught during the third year of study, is devoted to developing a programming project including writing a project proposal, modeling a problem,

designing a solution, and implementing it. The teachers can choose the development environment for their students. The programming project helps students internalize the use of algorithms for solving problems and prepares them for further studies in high school.

IV. IMPLEMENTING THE NEW PROGRAM

The program has been implemented in stages for the past two years. At the first stage 30 schools were selected to participate in a pilot program, most of which are located in the periphery of the country in order to promote a segment of the population that is less accessible to educational resources. Twenty-seven of them (709 students) continued to the next stage the following year.

At the second stage 183 middle-schools (5696 students) participated in the program. In each school, the students that were chosen for the program excelled in their age group. At the third stage about 100 additional schools are planned to join the program the following year (2013). The total number of teachers who teach the CS program this year is 172.

Teachers constitute the cornerstone of any curriculum [4,8,11]. Successful implementation of a new curriculum greatly depends on the pedagogical and content knowledge of the teachers as well as their satisfaction from the ongoing training and the support offered by the curriculum's initiators. Prior to the development of the curriculum presented here, no formal CS program was available for middle schools in Israel. Accordingly, recruiting and retraining teachers for the new program has been challenging but rewarding.

A. Preliminary criteria for approving teachers to teach the CS program

Initially, the Ministry of Education in Israel decided that the new STE curricula will only be taught by experienced and professional teachers. The rationale behind this decision is that qualified teachers should exhibit the following general qualities: (a) possess at least a Bachelor's degree in CS or engineering and a teaching certificate, and (b) have experience (of at least 3 years) in teaching the CS program at the highest level and in successfully preparing students for the high-school matriculation exam.

Since the criteria plan was restrictive, its implementation produced a shortage of qualified teachers. Academic retraining courses for prospective teachers with professional hi-tech experience were established to alleviate teacher shortages. Teachers having a background as high-tech professionals were assumed to have an additional advantage of encouraging students to study sciences, especially computer science.

B. Difficulties in assigning teachers

Shortly before the school year began, it became clear that assigning qualified teachers is problematic for the following reasons: (a) Qualified CS teachers who previously taught high-school students felt uncomfortable and even refused to teach middle-school students since:

- The emotional needs of the younger students were unclear to them;

- Teaching skills at the middle-school level seemed foreign to these teachers;
- Different physical locations of the middle-school and the high school complicated their work day logistically;
- Middle-school computer labs have a limited number of computers compared with high-school labs.
- The teachers needed to prepare lesson plans and teaching materials for the new program.

(b) The Ministry of Education had to assign tenured teachers to the program, even though they were not qualified for it.

(c) In schools that had not established a computer-related program and thus had no qualified CS teachers, it was difficult to find qualified teachers in the surrounding area, or to find a suitable teacher who would agree to come on-site and teach only two hours a week.

These kinds of difficulties were also encountered with Math teachers, but mostly in CS and Physics, since it was the first time those subjects were taught at middle school.

C. Reducing the criteria for qualified teachers

Owing to the difficulties in finding qualified teachers who could teach the program, it was decided to relax the criteria for accepting teachers, and to develop training courses for them. Teachers who did not meet the original requirements were permitted to teach the program provided that they agreed to participate in a suitable course. Relaxing the professional criteria resulted in accepting to the program less qualified teachers, for example, CS teachers who had previously taught only the lower levels in high school, qualified and experienced science/electronics teachers who had some CS education but who had not taught CS so far, students who were in their last year of academic CSED studies, and Computer Literacy teachers.

In implementing the program, several difficulties were encountered:

- Experienced high-school teachers were able to cope with the challenge of teaching excellent students but were not accustomed to teaching younger students.
- New teachers faced typical difficulties of entering the education system.
- New teachers and teachers with no CS background often taught at the technical-applicative level and did not focus on the program's algorithmic requirements.

D. Training Courses

Teachers are obligated to participate in a training program that was designed to provide them with pedagogical tools for enhancing their students' algorithmic thinking. The training consists of several courses, each of which is related to a specific module of the program. Additional course in Java and C# extends teachers' knowledge in order to give them an idea of what direction the students are heading to in high school. Each course lasts approximately 3 months. The courses are taught both in a computer lab and in an online environment to

ease the teachers' burden. There are three or four lectures per course and coursework is assigned weekly via a website.

E. Teachers' Support System

Reducing criteria implied that teachers constitute a heterogeneous group, with different backgrounds and knowledge. In addition, the fact that the teachers are physically scattered throughout the country made it difficult to support teachers and to arrange face-to-face (F2F) meetings. Therefore, there was an urgent need to create a supporting system that could overcome these constraints. In the beginning, the Ministry of Education program coordinators communicated with the teachers mainly through emails and phone conversations; therefore, a forum designed for the teachers in the program was established. The forum is mostly used for interacting with the program's coordinators. In addition, a blog was established in order to manage the distribution of instructional materials, either those developed by professionals or materials developed by teachers in the training courses that were found appropriate for distribution to other teachers.

F. Preliminary Evaluation

The program will be evaluated at two levels. One is by administering a nationwide exam aimed at assessing the students' understanding of the material taught. The first exam was administered at the end of the first year of the program and a preliminary evaluation of it is described in [13]. The second evaluation is planned to take place at the end of this year. The other level concerns the teachers.

Teachers completed a Likert-type questionnaire assessing their perception of the program (1 (strongly disagree) - 5 (strongly agree)). The questions evaluated the extent of students' internalization of programming structures and algorithmic thinking in their teachers' eyes (Table 1), and teachers' sources of support, and their general satisfaction with the program (Table 2). Sixty teachers completed the questionnaire; fifty of them taught the program to 7th grade classes for the first time, whereas the other ten teachers taught the program for the second year, in both the 7th and 8th grades. In addition to the questionnaire, personal conversations with teachers were conducted.

TABLE I. TEACHERS' ATTITUDES REGARDING STUDENTS' LEARNING

| <i>The Statements:</i> | <i>1st year teachers (N=50)</i> | <i>2nd year teachers (N=10)</i> |
|---|--|--|
| <i>The program is interesting</i> | 4.5 | 4.6 |
| <i>The program promotes students' algorithmic thinking</i> | 4.2 | 4.1 |
| <i>Students master conditional statements</i> | 4.2 | 4.5 |
| <i>Students master loop statements</i> | 4.1 | 4.3 |
| <i>The Algorithmic module contributed to students' algorithmic thinking</i> | 4.3 | 4.2 |
| <i>The Robotics module contributed to students' algorithmic thinking</i> | | 3.8 |

TABLE II. TEACHERS' ATTITUDES REGARDING THE PROGRAM'S SUPPORTING TOOLS AND THE TRAINING COURSE

| <i>I was assisted by:</i> | <i>1st year teachers (N=50)</i> | <i>2nd year teachers (N=10)</i> |
|---|--|--|
| <i>Colleagues who teach the program</i> | 3.2 | 3.0 |
| <i>Other teachers</i> | 2.5 | 3.3 |
| <i>The program's blog</i> | 4.1 | 4.0 |
| <i>The teachers' forum</i> | 3.0 | 3.6 |
| <i>The program's supervisors</i> | 3.1 | 3.6 |
| <i>The materials developed for the program</i> | 4.1 | 4.2 |
| <i>Comments regarding the training:</i> | | |
| <i>F2F meetings may be given up</i> | 1.9 | 2.9 |
| <i>I've developed additional materials based on examples I've seen in the course.</i> | 3.7 | 3.1 |
| <i>I would recommend my colleagues to join the training course.</i> | 4.3 | 4.1 |

According to Table 1, the teachers were highly satisfied with their students' learning outcomes. According to Table 2, the blog and the program materials are the teachers' most appreciated support tools. Despite the differences between the original program design and the actual situation, providing virtual support tools in addition to F2F meetings, established during the pilot stages, show that teachers were satisfied with the course plan and that their ability to use remote supporting tools is increasing. Teachers need fewer F2F meetings, and are able to study through consulting and by using virtual support tools. Apparently collaboration tools contributed mainly to retrieving more instructional materials and less to maintaining ongoing communication among the teachers themselves.

Additional information gathered from personal conversations and documentation of the difficulties encountered indicated that there was a great diversity of teachers' content knowledge and pedagogical knowledge. In addition, teachers' perceptions of the goals of the program and its feasibility in teaching middle-school students differed. For example, teachers expressed significantly different perceptions regarding the need for an informal, game-like learning approach, compared with the desire to move CS contents from high school to middle school.

V. DISCUSSION AND CONCLUDING REMARKS

The *Science and Technology Excellence* program for middle school, which includes the new CS program described here, is an educational initiative that aims at motivating and encouraging highly capable young students to choose science and technology studies in high school and academia. It is based on the assumption that early exposure to science and technology is a critical factor in attracting youngsters to these fields and in adequately preparing them as well as sowing the seeds for the development of the next generation of scientists and engineers.

The program is based on expanding the scope of math and science studies, beyond what most middle and high-school students learn today, and to new areas of science and technology that young students are not usually exposed to in the traditional and existing curricula. Computer Science

integrated with Robotics was chosen as one of the main scientific-technological areas to be included in the program. Until recently, no official CS curriculum by the Israeli Ministry of Education has been tailored to the needs and capabilities of seventh to ninth graders, which also takes into consideration the background and expertise of most middle-school teachers.

Lowering CS content levels from high school to middle school will enable excellent students from the academic track to complete the high-school curriculum a year earlier and during the last year of study to get a taste of the SE curriculum in the technological track, and to develop a software project. The aspiration to recreate for outstanding students a sequence of six-year high-level studying of computer science necessitated the construction and operation of a formal curriculum for the lower grades. The new program emphasizes the gradually building of basic concepts and principles in computer science, the development of logical reasoning and computational-algorithmic thinking, coping with the cognitive challenges of problem solving, exposure to the processes of software project development and the development of students' creativity skills. Achieving these goals is fostered by familiarizing the young students with several learning environments where these concepts and principles can be identified and elaborated.

The cornerstone of implementing a new educational idea or a program lies in the teachers; therefore, at this stage of implementing the program, we focused on in-service training and on evaluating the process that the teachers underwent and their feelings and attitudes at the end of one or two years of experience.

It was realized that the original plan of setting high criteria standards for approving teachers to teach the program was unrealistic; this resulted in reducing the professional criteria of acceptance to the program and the training courses; still, the formation of an array of courses and support tools during the first two years of implementation evidently helped those teachers with different backgrounds.

The information gathered in the preliminary assessment indicated that teachers' content knowledge and pedagogical knowledge were very diverse, as were their perceptions of the goals of the program and its feasibility in teaching middle-school students. They reflected on their satisfaction with their students' achievements and the available supporting tools. Noteworthy are the improved attitudes of those teachers who taught the program the second time regarding the program's potential to teach problem solving and to develop algorithmic thinking among young students.

A main conclusion to be deduced from this preliminary study is that building a properly tailored training courses for a heterogeneous group of teachers, as well as diverse supporting tools and suitable guidance, mostly on the web, contributes to the professional development of teachers and enables bridging the pedagogical and content gap between the desired and the actual availability of qualified teachers.

Future work will further examine the relationship between teachers' backgrounds and how they deal with the program's instruction, and the effect of teaching the entire 3-year middle-school program on teachers' perceptions of the program and its implementation. In addition, students' achievements will be evaluated as well as the percentage of students who choose to study computer science in high school.

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Work in Progress: STEM Capacity Building and STEM Outreach in India: A report on a recent NSF sponsored GK-12 George Mason Trip to India

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Abstract: This session reports on the experiences of seven NSF GK-12 fellows, A PI and Co-PI and external evaluator who participated in a one month trip to India in December, 2011-January, 2012. The seven fellows are a part of a GK-12 STEM capacity building program sponsored by the National Science Foundation that pairs graduate fellows with K-12 teachers to bring hands on, cutting edge, inquiry based science to the classrooms in the Northern Virginia area.

Index Terms: STEM Outreach, International Travel, STEM Capacity Building, India, GK-12

1. INTRODUCTION

This session reports on the experiences of seven National Science Foundation GK-12 Fellows who are graduate students in bioinformatics and computational biology, environmental science, physics, and computational sciences at George Mason University, the PI and Co-PI and external evaluator who participated in a one month trip to India in December, 2011-January, 2012. The seven fellows are a part of a GK-12 STEM capacity building program at George Mason and sponsored by the National Science Foundation that pairs graduate fellows with K-12 teachers to bring hands on, cutting edge, inquiry based science to the classrooms in the Northern Virginia area. Fellows are paired with elementary and middle school teachers over a two year period. The fellows are required to spend ten hours a week in classrooms in elementary and middle schools in Northern Virginia and spend an additional 5 plus hours a week in creating hands on activities based on their research. The fellows also design and deliver annual summer science camp, and provide “just in time” professional science content development for teachers. The fellows serve as mentors and models for the school students providing a concrete demonstration of the value and excitement of a career in science and the promise of careers

in science for woman and minorities. The fellows have also strengthened communication and presentation skills, and have gained new understanding of the challenges and opportunities of STEM teaching in US K-12 schools.

The National Science Foundation GK-12 program encourages projects to include an international component to their activities and provides supplemental funding for approved projects. The GMU GK-12 project PI, Rajesh Ganesan, wrote a supplementary proposal to NSF for funding for a one month trip to India which was subsequently funded for December 2011- January 2012. The objectives of the trip to India for the seven Fellows were threefold: 1.) Fellows were to gain knowledge of the ways in which research is carried out in Indian Universities and to make face to face networking contacts with researchers working on similar research topics. 2.) Fellows were to gain an understanding of STEM teaching in K-12 schools in rural and urban areas. 3.) Fellows were to gain an increased cultural knowledge of India and the Indian people.

4. Evaluation Procedures

The evaluation of the trip activities was carried out by the project external evaluator who was also one of the participants in the trip. Both quantitative and qualitative methods were used to perform the evaluation. Pre-trip and post-trip interviews and surveys have been done with the Fellows. Copious evaluator notes were taken during pre-trip meetings and during the entire course of the trip as well. The participant-observation method is often used in social science research and is a particularly valuable tool for anthropological research. This method is less used in evaluation studies, particularly ones that have as their focus STEM outreach activities.. The considerable amount of data

that has been collected is now being analyzed. Preliminary data analysis indicates that the trip has had a significant impact on Fellows views of research in India and future collaborations as well as on their views of Indian K-12 STEM education. The data also indicates that Fellow views on Indian culture and the Indian people have changed significantly. Add to paper:

2. RESULTS

Results from the post-trip survey indicate that 100% of the seven participating fellows were either satisfied or very satisfied with the trip overall. The participants confirm this finding by reporting in all of their open-ended post trip interviews that the trip was very fulfilling and met or exceeded their expectations. The pre-trip planning sessions were viewed as very valuable by 29% and valuable by 71%. As reported in the post trip interviews, the pre-trip details may have been too specific for those with previous international travel experience. One of the goals of the trip was to gain a better understanding of Indian K-12 STEM education. In response to seminars held at Miranda House, at the University of Delhi, 29% of the participants said their knowledge of Indian K-12 education increased significantly and 29% gained a new and deeper understanding of Indian K-12 education as a result of the talks at the university. In contrast, as a result of visiting a number rural and urban schools, 79% of the participants said they experienced a new and deeper understanding with the rest saying their knowledge had increases significantly. The impact of site visits had a much stronger effect on the fellows than did the lectures at Miranda House on K-12 education. When asked to rate the research meetings at the University of Delhi, 43% said the meetings were valuable or very valuable, the remaining fellows saying the meetings were either not very valuable or not valuable. The difficulty of arranging these meetings from a distance with a country such as India is reflected in the variety of experiences that the fellows had at their research meetings as reported in the post-trip interviews and open-ended questions on the surveys.

3. IMPLICATIONS

The implications of the data from the pre-and post trip interviews and surveys will be covered in more detail in our WIP presentation. Evidence for trip outcomes will be drawn from the surveys and from narrative material from the interviews.

A somewhat similar trip to China was organized during the same time frame by another NSF funded GK-12 program by a group at the University of Colorado at Denver (1). A significant difference between the two trips was that the trip to China had a narrow focus at only two institutions whereas our Indian trip involved about ten institutions. The advantages of a breadth versus depth approach for planning international STEM outreach trips will also be discussed.

Some of the questions that are to be answered by a close examination of the quantitative and qualitative data are:

- What are the specific indicators of change in Fellow attitudes as result of the trip? -
- What has been learned concerning trip planning and implementation?
- What are some of the unanticipated findings that arose as a result of the trip?
- What are kinds of things have been learned by our hosts in India as a result of the trip?
- How did our hosts and their students perceive our group and our activities?
- What is the evidence for long term impact of the trip six months after the end of the trip?
- What are some of the benefits and limitations of using participant-observation as one tool to evaluate intercultural experiences for graduate STEM students?
- What are the overall benefits for STEM capacity building here and in India as a result of this trip?

This work in progress session will present answers to these questions and will provide an interactive forum for the discussion of international STEM capacity building trips as a means to foster international STEM collaboration and cultural understanding.

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Open Channel Flow Misconceptions and Ontological Categories

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Abstract - National calls have been made for the identification of preconceptions and misconceptions in science and engineering. Identifying misconceptions can provide a basis for improved research-based curriculum development and implementation. The recognition of false beliefs and flawed mental models of these concepts can also contribute to theories of conceptual change. The purpose of this research was to identify misconceptions related to open channel flow. During spring and fall of 2011, out of 91 students from two sections of 'Water Resources Engineering' course, 50 students were interviewed, and 41 students were given a pre/post test. The goal of these open-ended interviews and pre/post-tests was to obtain detailed data on students understanding of open channel flow concepts. Results suggest students have misconceptions relating to the hydraulic and energy grade line (HGL/EGL), flow transitions, and flow profiles. Many students have the correct terms of the HGL and EGL but lack understanding of where the terms re on an open channel flow profile. A large percentage of tested students revealed false beliefs relating to transitions. For example, more than 50 percent of tested students drew a decrease in water depth for a subcritical drop, rather than an increase in depth. Students also had difficult in labeling subcritical, critical, and supercritical places along flow profiles and how water flows over or under different weir structures. Repairing these fundamental misconceptions is essential for students to be able to apply these concepts in diverse situations and learn more advanced topics.

Keywords – *Misconceptions, Open Channel Flow, Conceptual Change*

I. INTRODUCTION

Every engineering student has some sort of life experience with moving water. Therefore, every student in a course involving open channel flow concepts has some sort of constructed understanding of water and how it flows. Research has shown that some of these understandings are incorrect, and cannot be easily corrected [1]. Research on conceptual change can inform why some of these notions are harder to change than others by providing a theoretical framework for understanding the integration of existing knowledge with things that are learned in class. The purpose of this study is to

provide insights on students' misconceptions related to open channel flow within the context of the idea of synthetic frameworks developed by conceptual change theorist Stella Vosniadou [2].

II. BACKGROUND

Although all students have some form of preconceived beliefs about how water could flow from one point to another, their individual beliefs are different from student to student [3]. The difficulty of changing these beliefs is related to how embedded they are in students views of the world. Arguably, the most difficult misconceptions to change are those tied to ontological beliefs [4, 5]. Ontological beliefs are fundamental categories made of the types of things that exist. In engineering education, students have been found to miscategorize heat and diffusion in the incorrect ontological categories, and these misconceptions addressed through ontology training [4, 6]. As a simple example, it would sound odd to discuss how strong red is, because the "red" is not a type of thing that can be strong or weak: we share an ontological belief that "red" is categorized as a "color," and that "strength" is not a regular property of colors. It would be very difficult for students to learn about the relative strengths of different colors until they had undergone an "ontological shift" [7] to recategorize "colors" as types of things that can be strong.

When students attempt to learn around incorrect ontological beliefs, they can develop what Vosniadou calls "synthetic models." For example, in her work investigating students' conceptions of the shape of the earth, students would say the shape of the earth is round, but then indicate that if they walked a long way in a certain direction they would reach the edge [8]. She suggests in this work that students rely on what they have seen and develop ontological commitments based on these observations. For example, students believe that "things are as they appear to be" [9]. In other words, students have developed models of a flat earth through observation but have heard that the earth is round, and integrate both pieces into a 'synthetic model'. The idea of a flat earth is particularly robust, though, because it is tied to their commitment that

things are as they appear to be; in order to truly learn about a round earth, they need to shift their ontological commitment to things (i.e. the Earth) being as they appear to be (i.e. flat).

This study identified common misconceptions in open channel flow concepts in a junior level water resources engineering class at a public university, and interpreted these misconceptions within the context of ontological categories and synthetic models. The broader study included hydraulic and energy grade lines (HGL/EGL); flow transitions; flow profiles; identification of supercritical/critical/subcritical flow along an open channel; and hydraulic jumps. However, this article focuses on the results from the broad crested weir questions.

III. METHODOLOGY

A. Course Structure

The course of interest focused on water resources at a public university and is composed of three different main sections in the following order: pressurized pipe flow, open channel flow, and hydrology. However, participants were only interviewed about open channel flow concepts. Also, to be enrolled in the course, all students had to have completed the fundamental prerequisite course, fluid mechanics. The prerequisite course briefly covers the fundamentals of open channel flow such as laminar and turbulent flow, but does not detail anything related to the tested concepts. Lastly, the course was based on a popular textbook that details the fundamentals of the three topics that compose the course.

B. Participants and Interviews

Students that participated in this study were selected in order to include students from the top, middle and bottom quartiles in terms of academic performance, and were interviewed in a random order. The class is primarily composed of junior level students with the exception of few senior standing students. Only civil engineering students were enrolled in the course and participated in the interviews. We asked each participant to not discuss or reveal any of the interview questions to other classmates so internal validity would remain strong. Finally, the participants were told that a key containing the correct answers and detailed responses to each question asked would be provided at the end of all the interviews.

During spring 2011, 50 undergraduate students were interviewed using an open-ended interview method over a period of two weeks. Interviews followed a typical protocol that was semi-structured and allowed for probing questions related to difficult topics of open channel flow. The instructors identified the difficult concepts that compose the interview questions before this study began and the concepts were based from their previous knowledge, experience, and course notes. Interview packets were composed of a six-page handout that contained five questions related to open channel flow and one question related to pressurized pipe flow, shown in figure 1.

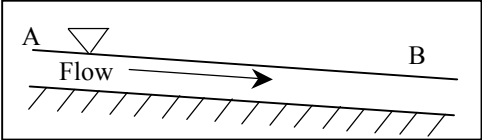
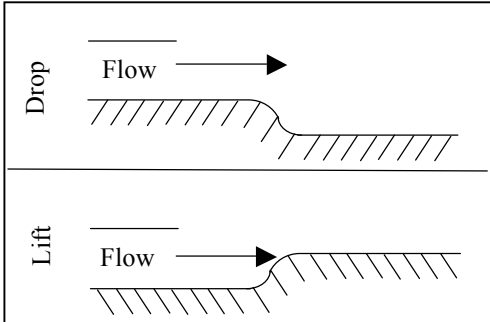
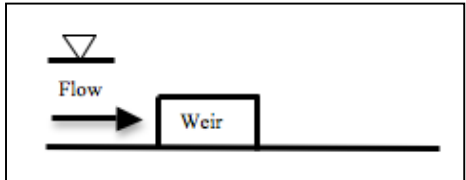
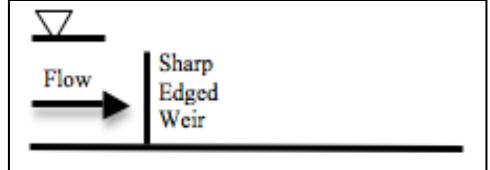
| Concept | Questions Asked |
|---|--|
| 1 Pressurized Pipe Flow | A) Draw the HGL and EGL between two points B) Write the energy equation between two points C) How would you figure out how much water flows between two points |
| 2 Open Channel Flow – HGL/EGL | A) Draw the HGL and EGL from points A to B. B) How would you figure out how much water flows from A to B? C) Write the Energy Equation between A and B.  |
| 3 Most Efficient Section | A) What is the most efficient section, A - D? B) How would you define the most efficient section? C) How many variables control most efficient section for figures A – D? (Choices were between a triangle, trapezoid, rectangle, and square channel geometry) |
| 4 Specific Energy | A) How does water flow downstream? B) How does the specific energy change between points one and two? (supercritical and subcritical drop and lift)  |
| 5 Flow Profiles | A) Draw the flow profiles for A – D. B) Label places of super/sub/critical flow  |
| 6 Hydraulic Jumps | A) Draw the flow profiles for A – D. B) Label places where a hydraulic jump occurs. C) What do you think a hydraulic jump is?  |

Figure 1. Interview protocol standard questions and order.

The pressurized pipe flow was question number one and held the purpose of an introductory question to allow students to become familiar and comfortable with the interviewing process. The remaining five questions covered the fundamental concepts of open channel flow in the following order: hydraulic and energy grade line; the most efficient section; transitions; flow profiles (broad crested weir results); and hydraulic jumps (sharp edged weir results).

C. Analysis Techniques

One graduate student coded all 50 interviews in a qualitative coding software program to prevent any inconsistencies within the data. The same graduate student transcribed three of the 50 open-ended interviews; a professional company transcribed the remaining 47 interviews.

Coding software was used to separate the collected data into common groups. A code is a piece of data that holds information of interest. In this specific case, when participants indicated preconceptions through using words such as 'built up' or 'previous experience', those statements were given a code. Once the data was coded for preconception evidence, data that held similar codes were grouped together to create a node. The process that was used is outlined below:

The first step in the analysis was simply to identify correct and incorrect responses to each interview question. The interviews were structured so that most questions had a clearly correct answer, such as the specific shape of the flow profile over a weir. Participant responses that were fundamentally correct, but lacked pertinent details (for example a flow profile in which the differences in water elevations were slightly too exaggerated, or where the area of critical flow was incorrectly identified) were still marked as "correct" for the purposes of this study.

The second step included differentiating the incorrect answers provided by the participants from step one. Although many students provided slightly different answers to a single question, the stated answers only differed by a small amount. Therefore, if similar answers were globally the same, they were grouped together.

Once the incorrect answers were grouped, specific words related to preconceptions were identified and coded. Many participants used common fundamental language such as 'subcritical flow' and 'uniform conditions'. When a participant stated they gave their answer based from previous experience or if they used words that were very primitive such as 'lift' or 'build up', the answer was coded, as those words were not taught during lecture.

Finally, once specific words and/or phrases were identified, more nodes were made to group common words together. For example, students that indicated their answer was based from previous experience were grouped together in relation to a specific answer. From the nodes, individual answers are analyzed in detail and specific quotes are pulled out to represent a common misconception and used in the results/discussion section.

The results detailed in the next section were a product from this process, and serve as an introduction to identifying what is difficult for students to understand.

IV. RESULTS

A. Content Review

A broad crested weir is essentially a three-dimensional rectangular block that crosses the full width of a channel and can vary in length. Participants were given the upstream water surface elevation and details shown in question 5 in Figure 1 above, and asked to draw and explain the flow profile. Figure 2 below shows the correct flow profile.

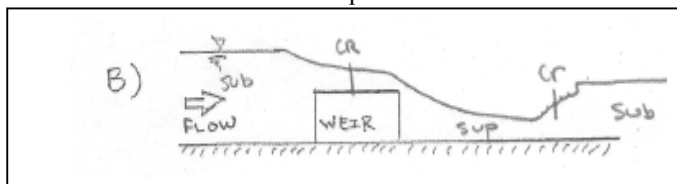


Figure 2. The correct flow profile for a broad weir.

The various changes in flow depth and velocity shown in Figure 2 can only be explained in terms of changes in the specific energy, and the complex interrelationships between specific energy, inertial forces and gravitational forces. Upstream water was in a subcritical condition, which would result in a transition to supercritical flow after the weir and critical flow at some point over the weir. Subcritical flow is located in the upper curve (1) of the specific energy curve as shown in Figure 3 below. As the fluid travels over the weir, it transitions energy from static (depth) to inertial (velocity) and transitions to point 2 on the specific energy curve (supercritical flow). Eventually, inertial forces would decrease due to friction on the channel bottom and sides, causing a shift from curve 2 to curve 1 in Figure 3. This appears as the hydraulic jump shown downstream of the weir in Figure 2.

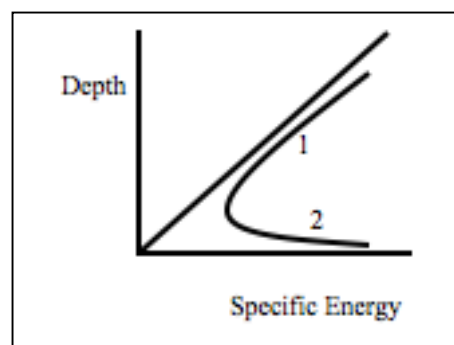


Figure 3. The specific energy curve. 1 is subcritical, 2 is supercritical flow.

B. Results and Discussion

Forty percent (20/50) of students drew the correct flow profile. Among the incorrect answers, the most common misconception was that the depth increases over the weir, then decreases after the weir. Figure 4 shown on the next page is a common misconception identified through the open-ended interviews. As you can see, the water level rises over the weir, and then decreases after the weir despite the fact that this

participant labeled subcritical flow before the weir. This participant indicated that critical flow would occur at the middle point of the weir, which is incorrect as the water level increased and did not transition to supercritical flow over the weir.

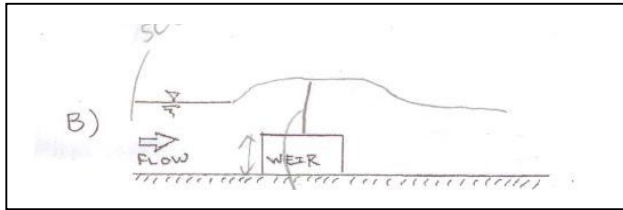


Figure 4. Common student drawing for this flow profile.

The following excerpt is typical of many students' explanations of this incorrect flow profile:

Student 1: *Oh, boy. So we're going to go over this weir. I think it kind of might hump up a little here. We have some, I don't remember what it's called, it's backflow...*

Interviewer: *Why do you think it humps up like that?*

Student 1: *Well, sometimes, there's that- I'm not remembering the term, it's basically gets- it can't go over this fast enough and so it kind of gets that buildup, it's that kind of- I can't remember the term but it kind of builds up on the back side there a little bit, builds up some energy. So then, anyway, over a weir, we'd probably kind of get the same, just depends on the speed and stuff.*

In terms of ontological categories and synthetic models, there are three significant components to this common incorrect answer: (1) the use of sequential language, (2) the emphasis on two linked variables, and (3) the image of a process with initiation.

1) Sequential Language

Some participants justified their flow profile as a logical chain of events in time with the latter events being caused by the former, or as a sequential process unfolding along the profile, with downstream events being caused by upstream conditions. For example, consider the following student quotes explaining their incorrect fluid profiles:

Quote 1: *"Okay. I know that it [the fluid] would hit the weir, and it would flow choke at least a little bit until it increased, and then as it goes over the weir, it would actually start going down."*

Quote 2: *"We have flow-choking occurring right here. Water is going to kick up against the weir, push back up from the subcritical and then force down to supercritical."*

Quote 3: *"So it's fallen in, it hits the weir; it wants to go over the weir."*

Quote 1 appears to explain the process as a temporal sequence: first the water hits the weir, then the "flow chokes," then it goes over the weir and finally "it would actually start going down." Quote 2 appears to be more spatially oriented and indicates locations along the profile where the water "kicks up" or is "forced down."

Characterizing flow over a weir as a sequential process is an ontological commitment: this phenomenon is the kind of thing that can best be explained by a list of events in which the order has causal significance. This misconception leads the students to create synthetic models to justify incorrect answers with concepts learned in class. Quote 2, in particular, correctly emphasizes the importance of subcritical and supercritical flow, but the ontological commitment to a sequential process leads to misidentifying then with different steps in the process, rather than fundamentally different physical processes.

2) A Two Variable System

Many students strove to find relationships between two (and only two) variables to explain their flow profiles. This misconception often, although not always, co-occurred with the two other misconceptions described here: for example quote 1 attempts to describe the flow profile as a relationship between the weir and flow depth. As exemplified in the following quotes, this relationship was the most common one, although velocity and energy were sometimes also invoked:

Quote 4: *"I'm not remembering the term, it's basically gets- it can't go over this fast enough and so it kind of gets that buildup."*

Quote 5: *"There'd be a jump initially at the weir, because it's going to push it up and afterwards it's going to go lower because the velocity will increase it, putting it lower."*

Quote 6: *"This weir slows down the energy right here so the pressure decreases and it drops in level."*

As a result of some students holding this framework knowledge, the system is composed of two things rather than a multitude of forces that contribute to how a fluid flows over a broad crested weir. These quotes also provide evidence that some students may not view an open channel system as a constrained system. Due to their ontological beliefs about the nature of open channel flow, these students are satisfied with their two-variable explanations – and indeed may be intentionally simplifying their answers in recognition of the value of parsimony. Ideally, the students' explanations would lead them to realize a flaw in their logic – quotes 4 through 6 do not explain the drop in water level predicted, for example. This is strong evidence for, and a product of, the students' synthetic models because there is a fundamental mismatch between the concepts applied, and the framework in which they are applied. Quote 6, for example, is technically correct in attempting to explain the profile in terms of energy, and is confounded by the synthetic model where energy can "slow down" at one location.

3) Process with initiation

Finally, many participants explained their profiles in terms of a process that had been initiated; some students indicated their answer was as a result of the fluid starting to flow after the weir was placed in the channel.

Quote 7: *"Okay. For this one you have flow coming into the channel, and into the weir. It's going to hit this and it will force super critical here. It will come down."*

Quote 8: *"I guess I would only put a weir into a system that's already in subcritical flow. I don't know why I think that,*

but that's just what I think, and so it would force the flow to go down to critical at some point."

Quote 9: "Because it needs to cross over the obstruction and the amount of flow decreases. It's all of a sudden obstructed."

Rather than looking at the instantaneous point in time, which would be ideal to draw the flow profile, these participants indicated that they are working with a dynamic model that began after placing the weir into the system. Quotes 7 and 9 show this clearly by indicating the system has flow "coming into the channel" which is "all of a sudden obstructed." Again, this approach often co-occurred with the ontological belief that flow over a weir is a sequential process: this is logical as a sequential process needs some kind of special initiation to being the causal chain. Students' preference for this type of reasoning is particularly interesting in light of the fact that all students were specifically instructed to consider the system in steady state. This mismatch between fundamental characteristics of the system (steady state, complex, conservative of mass and energy) and approaches to explanation is, again, evidence of the students' synthetic models.

C. Evidence of Misconceptions with Sharp-Crested Weirs

These misconceptions were reiterated in many cases in the context of sharp edged weirs. A sharp edged weir is essentially a thin broad crested weir. The correct profile of a sharp edged weir can be seen in Figure 5 below. As the water flows over the weir, it immediately drops (unless flood conditions are present) and transitions from subcritical to supercritical flow.

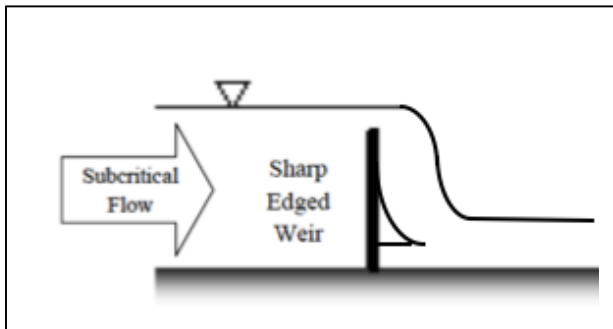


Figure 5. The correct profile for a sharp edged weir. Student two made very similar statements in relation to a sharp edged weir.

Student 2: For B there'd be a jump initially at the weir, because it's going to push it up and afterwards it's going to go lower because the velocity will increase it, putting it lower.

Interviewer: Why do you think the weir wants to push the water up?

Student 2: Because it has a constant flow initially. Has a constant flow and then it's you know hitting basically an object right there so it's got to go somewhere so it's going to go up first.

This exchange shows Student 2's characterization of the flow as a sequential process ("afterwards it's going to" and "then it's, you know, hitting basically an object") featuring two

primary variables (the weir and flow depth) to describe a process that has been initiated when the weir was introduced to the flow channel.

Student 2: For B [the sharp edged weir], because the weir's right there, the water underneath is going to have to jump up once it hits it, and so that's why there's a jump right there, and then after the initial jump, since there's nothing else the rest of the way, it's going to kind of even out.

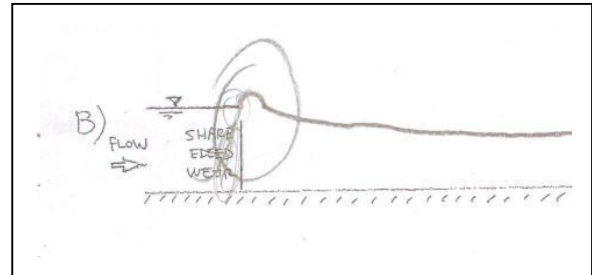


Figure 6. The incorrect flow profile drawn by student 2.

Again, this explanation relies heavily on working through the process sequentially with reference to two key variables (this time the weir and the "jump") and the initiation of the process ("have to jump up once it hits it").

V. DISCUSSION

There are interesting and potentially fruitful parallels between the misconceptions and synthetic models identified here and Chi's theory of direct versus emergent causal narratives [3]. Chi argues that one particular type of ontological belief is responsible for many misconceptions: the incorrect categorization of "emergent processes" as "direct processes." In her terminology, a direct process is one that is intentionally initiated by a causal agent and follows a logical pattern directed at achieving an end state. Research has shown that students incorrectly categorize diffusion as a direct process, where it is in fact an emergent process, and the result of random movement of molecules [4]. An everyday example of a direct process would be when a teacher instructs a group of students to line up, and then they do so. In contrast, an emergent process is one in which an observable phenomenon is actually caused by ongoing, non-directional and unobservable interactions that do not directly affect nor are they directly affected by the observable phenomena. An example of an emergent process would be if, in a roomful of students, every student wants to maximize the distance between him-or-herself and the whiteboard along one wall. After a while, the students would end up lined up along the opposite wall – not because they wished to form a line, but because each individual student would continue moving until they felt they could get no further from the whiteboard. Note that the students' desire to be away from the whiteboard does not have a necessary beginning, and does not change or end when the students form a line – it is simply a property or characteristic behavior of the students that, in some circumstances (a whiteboard along one wall of a room) results in students lining up.

In our findings, the flow profiles are equivalent to the students' line. The students' interviewed seem inclined to identify special causal agents (the weir, or the installation of

the weir) and sequences of events, which suggests they tend toward a direct causal explanation. The correct explanation of the flow profiles is more emergent, however, in that the fundamental processes do not have beginnings, or sequences, and are not intentionally causing the observable phenomena of interest.

VI. CONCLUSIONS

The identification of common misconceptions of open channel flow concepts is important and provides a way to qualitatively understand what the majority of students are having difficulty learning, and potentially why they are having these difficulties. Determination of these misconceptions is particularly compelling in light of the fact that these students' misconceptions have very likely been directly contradicted in their classrooms, homework and exams. Identifying other preconceptions can help further the validation of the argument presented here that students are operating incorrectly within a 'direct' process ontological category.

Some of the language that students' used to describe this process indicate that they may draw off of analogies with solid objects. For example, some students say the water 'steps up' the weir, as if it was a 'chunk' of water and not a viscous fluid. This is further evidence of direct and linear process thinking. Future research in other areas of fluid mechanics could investigate how and when students' use these analogies.

Additional research is needed to help build upon the current popular approach of addressing long lists of misconceptions, with varying results. Research utilizing theories of conceptual change and ontological categories could lead to approaches to instruction, such as ontological training, that address several misconceptions with one instructional approach. For example, students may not explicitly realize that they are utilizing direct process rules, where emergent ways of thinking could be more valuable. Future research could involve interview protocols that explicitly examine student's thinking about direct and emergent processes as they relate to open channel flow. This approach could be especially fruitful for examination of open channel flow because the use of emergent and direct rules depends on the scale of analysis (e.g. flow in a channel from one city to another vs. the development of eddies in open channels).

The identification of common misconceptions of open channel flow concepts is important and provides a way to qualitatively understand what the majority of students are having difficulty learning. Further, identifying any preconceptions can help professors teach more efficiently and effectively.

The results provide clear evidence that students are having difficulty understanding the fundamentals of open channel flow concepts. Whether this is due to lack of proper instruction, preconceptions and misconceptions are hindering the ability for these students to remotely understand open channel flow concepts. Although some concepts are easier and more intuitive than others, the global impact of the results is that students are having difficult understanding basic concepts as well as counter-intuitive concepts.

VII. ACKNOWLEDGEMENT

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Multi-Faceted Approach to Assessing the Quality of Courses Delivered Through Learning Management Systems: An Empirical Investigation of a Computer Literacy Course

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Abstract—There has been an increasing use of e-learning tools in higher education, which has resulted with a larger demand for assessment of their quality. This study proposes a statistical model to evaluate the e-learning system effectiveness from the users' perspective specifically within blended learning environments. The proposed statistical model uses six e-learning success factors extracted from relevant literature. These are, Information Quality, System Quality, and Service Quality Learners Attitudes, Supportive Issues, and Instructor Quality. A survey instrument based on proposed model was developed and applied to Middle East Technical University (METU), Ankara, first year students who are actively using Net-Class e-learning system as a supportive tool in their computer literacy course. The survey instrument was tested for reliability and validity using confirmatory factor analysis (CFA). Structural Equation Modeling (SEM) statistical analysis was used to validate the research model. The results show that, each dimensions of the proposed model had a significant effect on the learners' perceived overall satisfaction from an LMS. Findings of this research will be valuable for both academics and practitioners of e-learning systems.

Keywords: *E-learning; distance learning assessment; Structural Equation Model, Confirmatory Factor Analysis, Distance Learning: Methods, Technologies, and Assessment*

I. INTRODUCTION

Rapid developments in information technology (IT) have generated potential changes to teaching and learning [1]. Learning has been dramatically changed in the last decades. The development of network technology provides highly dynamic communications, multimedia tools make learning easier and convenient to use, databases offers several channels to create efficient platforms, information technologies serves better learning environment. Specifically, rapid advancements in internet technologies have resulted in significant impact on the learning industry. Consequently, the trend of using web-based or electronic learning as learning and/or teaching tool is now rapidly expanding into education [2]. Therefore, e-learning applications have become highly popular and applied

by several universities. A quote that belongs to Lockee, Moore, & Burton (2007) says that “*Only by evaluating the effectiveness of e-learning programs, we can justify their use and continue to develop their quality*” [3]. Hence, there is an important necessity for evaluation of every e-learning system [4-5]. The main contribution of this research is to bring previously build e-learning success criteria together and build statistical model based on those criteria. For this purpose, in this study, we have used previously used e-learning assessment metrics and survey created by Ozkan et.al. 2009.

In this paper, an *E-Learning System* or a *Learning Management System* (LMS) has been considered as a special type of an Information System (IS). An e-learning system or an LMS can be defined as “*the use of electronic devices for learning, including the delivery of content via electronic media such as Internet, audio or video, satellite broadcast, interactive TV, CD-ROM, and so on*” [6]. *Blended learning* or *hybrid learning* refers to “*learning events that combine aspects of online and face-to-face instruction*” [6]. Online learning can be defined as an option “*for students who wish to learn in their own environment using technology and/or the Internet*” [6]. The terms “*e-learning*”, “*online learning*”, “*computer-based learning*”, “*distance learning*” and “*web-based learning (WBL)*” are interchangeably used by researchers, and that approach will also be taken in this study.

The rest of the paper is organized as follows: Section II reports background information. Section III focuses on the research model and hypotheses. Research methodology is presented in Section IV. Section V deals with testing the hypotheses by statistical analyses and proposes new hybrid research model based on users' perceived effectiveness to use the e-learning system. The findings of this research help to develop more efficient LMSs with less effort and also provide insight into the best way to define e-learning success criteria for future research in this field.

II. RESEARCH MODEL AND HYPOTHESIS

A comprehensive e-learning assessment model has been developed to evaluate e-learning system success from users' perspective as depicted in Figure 1 [21]. The theoretical grounding for this research derives from existing information system success models such as DeLone & McLean's updated IS success models. Rather than using the existing DeLone and McLean's (D&M) model as it is, authors in [21] have extended it by integrating other dimensions related with e-learning. The final model has unique properties such as *course content*, *instructor*, *instruction quality*, and *learner attitudes*. If there were no extensions, the D&M IS Success model would be insufficient to assess an LMS effectively despite the fact that an e-learning system is a type of IS. Authors in [21] proposed HELAM (Hexagonal E-Learning Assessment Model) e-learning assessment model as a base, it has 6 dimensions:

- a) *System Quality*
- b) *Information (Content) Quality*
- c) *Service Quality*
- d) *Instructors Quality*
- e) *Learners Attitudes*
- f) *Supportive Issues*

System Quality: System Quality typically measures the performance of the system. One of the key dimensions of the DeLone & McLean's IS success model is "system quality". System Quality is an important indicator to measure an LMS's success. Moreover, nearly all of the researchers dealing with LMS success define system quality as a significant factor for user satisfaction [7] - [8] - [5] - [4] - [9] - [1] - [2] - [10] - [11] - [21].

Information (Content) Quality: Content Quality measures the appropriateness and effectiveness of the delivered information in LMS. This dimension is also one of the dimensions of the DeLone and McLean's IS Success Model, named as "Information Quality". Interactive instructional design is an essential factor for learning satisfaction and success [12] - [13] - [21]. Additionally, Shee and Wang [13] stated that learners place great value on content.

Service Quality: Pitt, Watson & Kavan stated that "commonly used measures of IS effectiveness that focus on the products rather than the services of the IS function [14]. Thus, there is a danger that IS researchers will mismeasure IS effectiveness if they do not include in their assessment package a measure of IS service quality" Also, DeLone and McLean reported that there is a significant relationship between an effectiveness of an IS system and service quality [15]. They define service quality as "up-to-date hardware and software", "responsive IS employees", "knowledgeable IS employees who do their job well". In addition, this study included other indicators for an effective e-learning service such as 'empathy'.

Instructors Quality: Several researches indicate the quality of an instructor as an important determinant for an

effective LMS [9] - [12] - [4] - [16] - [2]. Webster et. al. concluded that, it is not the technology but the instructional implementation of the technology that determines its effects on learning [1]. They also proposed that, instructors' attitudes toward a technology, teaching styles, and control over the technology will affect the learning outcomes [1]. Holsapple, et. al. proposed that instructors' attitudes toward technology-mediated distance learning systems be included in evaluations of these systems [8].

Learners Attitudes: Learners attitudes toward an LMS is considered as an important factor for creating an effective LMS by several researchers [5] - [1] - [9] - [7] - [2] - [10] - [8] - [4] - [11] - [21]. It is evident from these studies that to design effective e-learning environments, it is necessary to **understand target group**. Liaw, Huang and Chen have shown that the two learner characteristics, *perceived enjoyment* and *usefulness*, are positively related to intention to use an LMS [2].

Supportive Issues: The five dimensions, explained above, have been identified to be directly related to LMS success. However, there may be other factors affecting learners' attitudes which indirectly affect the success of an LMS, such as popularity of e-learning systems, general educational trends, technological developments, ethical and legal issues, environmental issues, i.e., geographically diversity, socio-economical level, diverse backgrounds. All these indirect factors have been included within the "Supportive Issues" dimension [21].

Levy in his "Assessing the Value of E-Learning System" book, divided e-learning components into seven categories. He stated that none of these components can create meaningful learning features without proper integration of all of them. He proved that these categories are all interrelated with each other [22]-[23]. Similarly, Khan underlines the correlations within the LMS factors [12]. In the light of all previous literature given above, this study emphasizes that examining these interrelations has become crucial to achieve an effective e-learning environment. Therefore, in this study, in addition to the six dimensions proposed, other interrelations among these six dimensions have also been tested. Any significant relationship found between any two dimensions has been added to proposed research model which is presented in Figure 1.

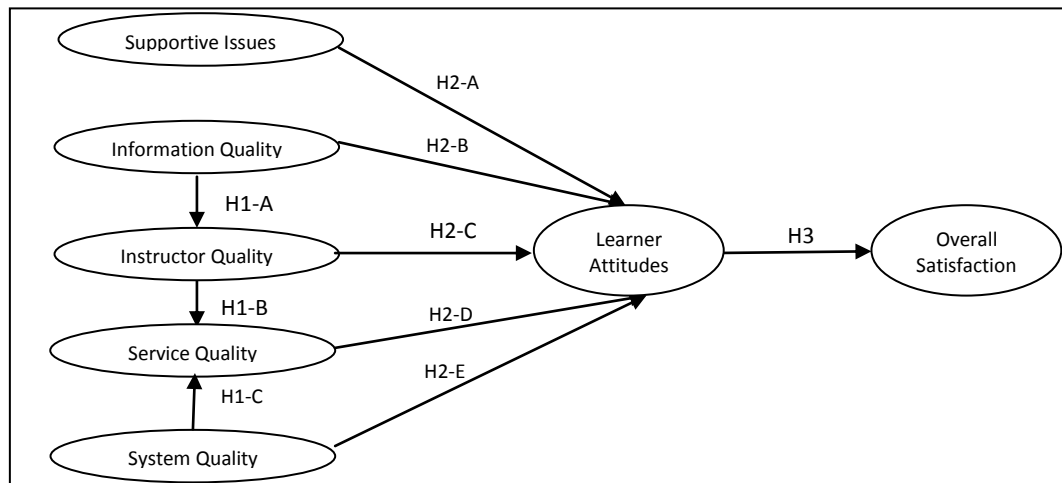


Figure 1: Proposed Research Model

The relations in the proposed research model have lead to the following set of hypotheses:

- H1-A: The quality of information is directly and positively related to instructor quality.
- H1-B: The quality of instructor is directly and positively related to service quality.
- H1-C: The quality of system is directly and positively related to service quality.
- H2-A: The quality of supportive issues is directly and positively related to learner's attitudes.
- H2-B: The quality of information is directly and positively related to learners' attitudes.
- H2-C: The quality of instructor is directly and positively related to learner's attitudes.
- H2-D: The quality of service is directly and positively related to learner's attitudes.
- H2-E: The quality of system is directly and positively related to learners' attitudes.
- H3: The quality of e-learning is positively related to learners' attitudes toward LMS.

III. METHOD

A. Measures – Survey Instrument

In this study, quantitative assessment methods have been used to build a statistical model for evaluating the effectiveness of an e-learning system. This research study uses a survey instrument developed by in [21]. This has been used to collect data from learners about their perceptions of the impact of the blended learning environment and LMS in regards to their benefits and satisfaction level. After developing the survey instrument based on critical e-learning success factors in the literature, the authors [21] were conducted a pilot study with the proposed survey with 30 Middle East Technical University students who were enrolled on the course entitled "IS100 Introduction to Information System Technologies and Applications". Additional to pilot

study, the survey developers applied the survey to students at both undergraduate and graduate levels who are users of a web-based learning management system, U-Link, at Brunel University. On their study, they applied several reliability and validity tests such as criterion-based predictive validity to assess the efficacy and effectiveness of the survey instrument's parameters in predicting learner's satisfaction, for that they used R square statistical methods. The R squared value of the survey is 0.963, which is very good indicator that the survey is likely to predict learners satisfaction.

The survey consists of two main parts. The first part aims to gather demographic data about the learners, and the second part, which is about learners' LMS experiences, is divided into six sections each of which corresponds to each proposed statistical model dimension. These are (1) *System Quality*, (2) *Information (Content) Quality*, (3) *Service Quality*, (4) *Instructors Quality*, (5) *Learners Attitudes*, (6) *Supportive Issues*. In this part, 5 point likert-type scale items have been used to collect data. Items are anchored from 1 to 5, where 1 indicates strong disagreement and 5 indicates strong agreement. All responses were guaranteed confidentiality.

B. Participants and Data Collection

The survey instrument was distributed online because the use of computer-assisted data collection can significantly improve the reliability of the data as it eliminates the human data entry step that includes some natural human errors.

Table 1 - DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS (BOTH ONLINE AND BLENDED LEARNING NETCLASS USERS)

| | Frequency | Percentage |
|--|------------|--------------|
| Gender | | |
| Male | 96 | % 44.23 |
| Female | 121 | % 55.76 |
| Age | | |
| Under 21 | 168 | % 77.4 |
| Over 21 | 49 | % 22.6 |
| Computer Usage Habits (per day) | | |
| <i>Spend time on using a computer/Internet (per day)</i> | | |
| Less than 1 hour | 31 | % 14.3 |
| Between 1-3 hour | 105 | % 48.4 |
| Between 3-5 hour | 58 | % 26.7 |
| Between 5-7 hour | 15 | % 6.9 |
| Between 7-9 hour | 3 | % 1.4 |
| More than 9 hour | 5 | % 2.3 |
| <i>Spend time on using a computer/Internet for educational purposes(per day)</i> | | |
| Less than 1 hour | 92 | % 42.4 |
| Between 1-3 hour | 100 | % 46.1 |
| Between 3-5 hour | 18 | % 8.3 |
| Between 5-7 hour | 4 | % 1.8 |
| More than 9 hour | 3 | % 1.4 |
| f Spend time on using U-Link (per day) | | |
| Less than 1 hour | 189 | % 87.1 |
| Between 1-3 hour | 17 | % 7.8 |
| Between 3-5 hour | 9 | % 4.1 |
| Between 5-7 hour | 2 | % 0.9 |
| Total | 217 | % 100 |

The survey was applied to students studying at Middle East Technical University (METU), Turkey. A total of 800 individuals participated in the survey. Out of those who participated in the study, usable data was obtained from 217 (~27% of the sample size) undergraduate Level 1 students who were enrolled on a computer literacy course entitled “IS100 - Introduction to Information System Technologies and Applications” at Middle East Technical University. IS100 course is a basic level computer literacy core course designed for all first-year students throughout the university. In this course both *blended learning*, and *online learning* style was used. As the learning environment, **NetClass** learning management system is used (<https://online.metu.edu.tr>). The same survey instrument was applied to both groups. 160 responses were obtained from blended users and 57 responses were obtained from online learners. Table 1 lists the respondents’ demographic characteristics, including gender, age and computer usage levels.

IV. RESULTS

The Structural Equation Model approach was used to validate the research model. This approach was chosen because SEM is a statistical technique for testing and estimating causal relationships using a combination of statistical data and qualitative causal assumptions [17]. Specifically, “SEM provides a great flexibility in estimating relationship among multiple predictors and criterion variables which allows modelling with unobservable latent variables; it estimates the model uncontaminated with measurement errors” [18]

A. Measures Reliability and Validity

Before running the Structural Equation Modeling model, each survey instrument was tested for reliability and validity using **confirmatory factor analysis (CFA)**. The model included 29 items categorized under proposed research model dimension. All the items’ factor loadings were greater than recommended level which is defined as 0.80 by [17], the greater factor loading indicates that similar items which measures the same hypothesis are producing similar scores. Factor loading is also a prerequisite requirement for SEM which was guaranteed by high item loadings.

According to Joreskog et.al., (1996), χ^2 (the ration between χ^2 and the degrees of freedom) provides direct statistical evidence for the test of model goodness of fit [17]. The observed normed χ^2 for measurement model was 2.24 ($\chi^2 = 4093.09$, $df = 1822$), which is smaller than 3 recommended by [19]. Other than chi-square various goodness-of-fit indexes were tested and summarized in the Table 2. All indexes shows good fit for the measurement model. Proposed model’s indexes are higher than recommended level, CFI is 0.91, which exceed the recommended cut-off level of 0.9 [17]. The root mean square error of approximation (RMSEA) is 0.076, which is below the cut-off level of 0.08 recommended by [20]. However, GIF index is slightly lower (0.78) than the recommended level which 0.8 [17].

TABLE 2 - GOODNESS-OF-FIT MEASURES

| Fit Indexes | χ^2 (Chi Square) | χ^2 / df | GFI (Goodness of Fit Index) | CFI (Comparative Fit Index) | RMSEA (Root Mean Square Error of Approximation) | P |
|--------------------|-----------------------|---------------|-----------------------------|-----------------------------|---|-------------|
| Recommended Values | - | ≤ 3 | ≥ 0.8 | ≥ 0.9 | $\leq 0.05 - 0.08$ | 0.00 |
| Model’s Values | 4093.09 | 2.24 | 0.78 | 0.91 | 0.076 | ≤ 0.05 |

B. Model of Interest (Structural Equation Model)

The results of structural model analysis are displayed in Figure 2. The structural model correlates the dimension with each other for instance information quality is linked to instructor quality. The statistical results showed that *system quality* positively affects *learners’ attitudes* toward used LMS. The result $R^2=0.69$ provides support for H2-E. Moreover, *information quality* significantly affects *instructor quality* ($R^2=0.67$) supporting H1-A. From H1-B and H1-C, *service quality* is positively affected from *instructor quality* ($R^2=0.40$) and *system quality* ($R^2=0.45$). Additionally, *service quality* ($R^2=0.30$), *instructor quality* ($R^2=0.66$), *information quality* ($R^2=0.40$) and *supportive issues* ($R^2=0.39$) has positive effect on *learners’ attitudes* which supports H2-C, H2-D, H2-A respectively. Lastly, *learners’ attitudes* toward an LMS is highly correlated with **overall user satisfaction** from used LMS ($R^2=0.70$) which supports H3.

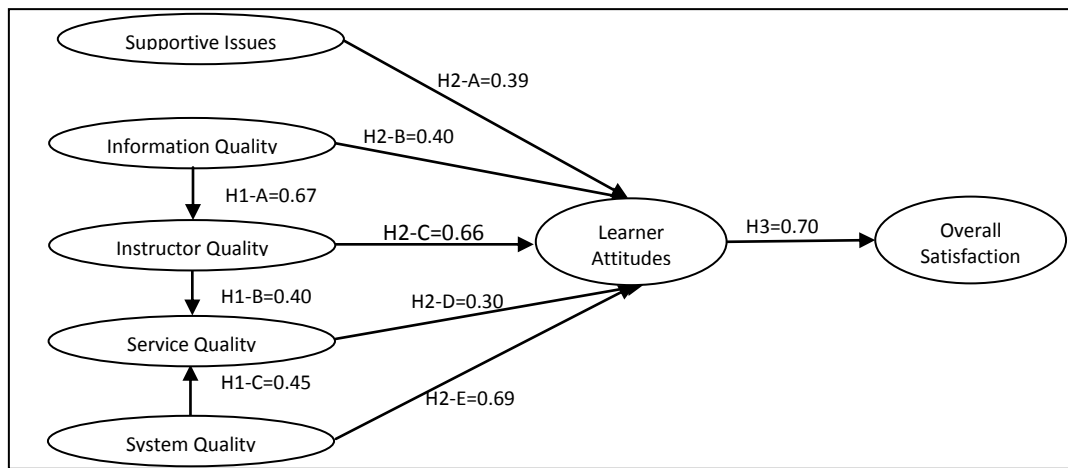


FIGURE 2. RESEARCH MODEL WITH STRUCTURAL EQUATION MODEL (SEM) RESULTS

V. CONCLUSION

This study attempted to propose a statistical model for evaluating e-learning within the higher education environment. The research in this paper sought to empirically test the constructs of this proposed conceptual model via a survey instrument and to demonstrate which were critical for e-learning systems effectiveness, particularly when implementing a computer literacy course. The instrument was validated and it has been proved that all six dimensions of the proposed e-learning evaluation model were important for the implementation of a computer literacy course via a learning management system. This study contributes to the e-learning literature with an instrument providing a roadmap for practitioners and researchers to better understand how e-learner's perceived satisfaction can be increased and how the use of learning management systems can be improved. In addition to this study, future studies may extend this model through adding other dimensions in parallel with changes in the e-learning field. Another future expansion would be to check the validity of the causal research model on different learning management systems.

VI. REFERENCES

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Work in Progress: A Semantic Annotation Scheme for Concept Maps

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Abstract – Concept Maps (CM) are custom-made graphical representations whose understanding (and therefore socialization and reuse) depends on adequate explanation by the author and so their main advantage is also their main constraint: the freedom to represent concepts and relationships between them in any way, mostly in idiosyncratic and not understandable ones. In this paper we show how information on meaning and application contexts of a Concept Map can be represented and how it would be added to a learning object database ordinarily accessed by teachers and students. We use a freely available CM editor and from the XML textual representation of a map, metadata are defined with additional information on its meaning as defined by the author and on the contexts in which it has been used. That representation of an annotated map is then incorporated into a functional learning objects database (a LO category that includes software developed for educational purposes). This scheme for semantic annotation has been analyzed through a case study with students from a Software Development Tech course, who reported their impressions when creating, socializing and reusing maps with FLOCOS database environment.

Index Terms – Concept Maps, Semantic Annotation, Learning Object, Metadata.

INTRODUCTION

Learning strategies and support materials are key issues for education in its various forms and has motivated a search for computer-based resources that might assist students and teachers to gather and organize information and share knowledge about any subject. In this context, Concept Maps (CM) are resources worth to exploit. CM are graphical tools able to communicate, represent and demonstrate knowledge about a particular topic, activity, text or any other object of analysis. This tool can be used both by teachers and by students and in areas like Science, Technology, Engineering and Mathematics (STEM) they can help to visualize abstract concepts and to grasp meaning in a stepwise way. CM can be used, for example, as a way to organize contents, to support evaluation, and to represent relationships and sub-relationships between concepts of a same area.

The goal of this work was to support CM reusability and facilitate their understanding through semantic annotation. With the adaptation of a Learning

Object (LO) repository to meet CM characteristics, we have presented a standard metadata fit to that task.

CONCEPT MAPS AND LEARNING OBJECTS

Through concept maps, domain-specific knowledge can be visually organized in different ways, one of which is a hierarchical structure with the focus concept at the top of the map. This focus concept leads into ‘child’ nodes defining their relationship to the main concept. CM, broadly conceived, are network diagrams in which concepts (nouns) are nodes and the relationships between concepts (verbs) are links.

CM allow their authors to choose different types of representations and use different vocabulary. However, such flexibility and freedom can produce semantic problems and ambiguities. The central difficulty in this challenge is the identification of an “adequate” or “relevant” map during a user search. CM are idiosyncratic, their custom graphical representation of author’s understanding of contents depend on an adequate explanation by those authors. Therefore, its main advantage is also its main limitation. The freedom to represent concepts and relationships becomes somehow a challenge to socialization and reuse. Consequently, there is a need for “commented” CM embodying information about context of use.

Learning Objects are structured and organized by metadata standards, making their search through current web tools more efficient. Since this is not the case with CM, we propose to structure them with standard LOs metadata and to add semantic annotation for their understanding and proper use. In the following paragraphs we describe how this is done.

METADATA

In order to add more information and flexibility to LO representation, we have adopted a novel standard for metadata, the Metadata for Functional Learning Objects (MFLO), implemented in [2]. As MFLO does not have enough resources to represent a using scenario by the object author – a relevant need for a proper CM description, we have adapted its structure using an ontology domain so that it would be able to add semantic annotations.

CASE STUDY

In order to evaluate suitability of metadata for structuring and organizing information from CMs, a case study was carried out with students of the 5th

period of a technology in software development (TSD) course at the Federal Education Institute of Amazonas (IFAM). These students had a good knowledge on software requirements analysis and were asked to: (i) learn about standard CM, (ii) develop specific CM, (iii) interpret and access other people CM and (iv) search CM attending to specific parameters.

As many students were familiar with metadata they were able to describe the metadata within their CM. However, doing the same thing with CM from other authors was described as “a very complex task”. The same situation happened when reading the CM’s key-concept, in other words, the starting reading point of the CM was difficult to find in CM that were created by other authors. Regarding the search for CM of other disciplines, many students stated that it was difficult to find CM even when searching for resources in other languages. Students said that even if a CM was found they often were not able to understand it. As a result of analysis on findings like these, several elements were removed and some were added to standard MFLO.

METADATA FOR CONCEPT MAPS

Data from the case study supported identify what of elements better added “semantic information” to a CM and how we structure them in a way that facilitate access and reuse.

The resulting metadata, called ‘MFLO-CM’ could then be used in a semantic annotation scheme showed in Figure 1.

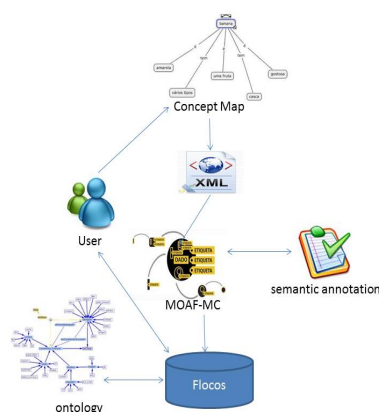


FIGURE 1
A SEMANTIC ANNOTATION SCHEME USING MFLO-CM

The scheme shown in Figure 1 has been implemented as a web-based software tool to support annotation of concept maps produced through a freely available CM tool called CMapTools¹. That editor has a plug-in tool that produces a XML equivalent for the original diagrammatic form of a CM. This linear representation of the CM was then transformed in a semantic-annotated learning object using MFLO-CM structures, described using a domain ontology and added to a freely available LO repository.

¹ <http://cmap.ihmc.us/>

ADDING CM TO A REPOSITORY OF LEARNING OBJECTS

The purpose of a repository is to facilitate the reuse of educational resources stored in learning management systems (LMS), learning content management system (LCMS), content portals (for an example, in search of digital library systems), or any application or software designed to access learning objects.

There are several public-available LO repositories, some maintained by research or higher education institutions, other by the Ministry of Education and other by private organizations. In order to test feasibility of the annotation scheme proposed here, we adapted FLOCOS (Functional Learning Object Collaborative System) – a LO repository developed by a research organization and used by teachers in real-world situations [1]. FLOCOS is a collaborative system to build FLOs described through the MFLO metadata. The users interact in the MFLO metadata generating new objects, or maintaining the existing ones. Through its update with the structure of MFLO-CM presented here, this repository can now manage and store all kinds of CM and provide them for their reuse.

A proof of concept, we have selected 24 concept maps produced by teachers and students from several science and technology courses carried on at IFAM, based on different contexts and purposes, and used the scheme shown on Figure 1 to make them available on FLOCOS.

CONCLUDING REMARKS

This paper describes a way for concept maps have incorporated information about their creation and intended used, and be integrated into repositories of functional Learning Objects. A case study was developed for requirements elicitation of metadata structure that was then used in a web-based software tool integrating a CM authoring tool and a learning object repository. Tests shown that this annotation scheme allowed CMs to be stored, accessed, organized and be available for reuse just like other LO. Structured authoring information also will allow CM to have their devising context make explicit.

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Work in Progress: Management of online assessments as a replacement for exams

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Abstract— Whilst online Learning Management Systems (LMS) environments are rapidly becoming commonplace and a justified means for supporting learning and teaching, courses are often unable to be entirely taught online due to the necessity for traditional paper-based examinations, usually of significant percentage weighting of the total course grade. In this paper, the author describes the preliminary development of procedures and workflows for managing online assessments as a replacement for these traditional examination conditions, seeking to reduce examination stress and increase assessment validity. An in-development software suite, based on a LMS log-file pre-filter mechanism and behavior identification heuristic engine, is introduced to assist with identifying online compliance and collusion.

Keywords— component; online assessment; examinations; examination stress; instruction compliance

I. INTRODUCTION

Engineering course assessments have typically consisted of set assignments concluded with a final written paper-based examination. Whilst this classical model is still valid, it is seeing re-invention particularly where courses are offered through online and mobile environments. The shift to online-compatible assessment-structures has obvious utility and technologically enables alternative assessment strategies. The aim of this paper is to demonstrate example methods in the management of one particular course where less traditional means are used, examined by the author. Within this course the assessment model transitioned away from classical assignment/exam approaches to incorporate an entirely online-exam. Although this transition afforded reinvestigation of assessment metric opportunities, it presented several challenges particularly ensuring academic integrity of the assessment responses. Whilst there is presently debate regarding the nature of online academic misconduct [1], experience shows that this is still of concern and worthy of consideration.

II. EXAMPLE COURSE

The presently ongoing course used in this case study is a 3rd year level electronic measurement course where students are required to demonstrate understanding of abstract concepts in their own-words pertaining to measurement science, and instrumentation principles through insightful interpretation of provided course materials as opposed to direct fact recall. This particular course requires a strong grasp of technical English. The student cohort studying this course is often diverse with students from Australia, Malaysia, Singapore and other Asia-Pacific nations. As a result, technical English comprehension

could not be assumed, as suitable ‘academic language’ may not yet have been sufficiently developed. It has been previously identified within this course that there was a significantly increased risk of examination stress caused by English interpretation and dissemination of technical concepts [2]. Additionally whilst assessment items were designed to be strictly individual submissions, some benefits were afforded through group discussion of the content. This presented a conflict within this course regarding the duality of specifically allowing student group discussion, participation and peer learning, whilst maintaining clear individual learning opportunities and metrics, and required monitoring and moderation. Because of these inequities, a solution was sought to ensure assessment compliance under these conditions.

A. Previous Assessment Structure

Prior to 2006, the final course assessment was based upon traditional metrics and a final written exam, worth a significant proportion of the total course marks (60%), was required to be sat at examination centers around Australia, and internationally. This examination required students to describe, in three hours, abstract conceptual interpretations of the course content, in English. The negative effects of examination-stress have been previously extensively reported, for example [3], showing in principle that this was a significant factor in poor student performance. A variety of techniques can consequently be applied to reduce stress and anxiety permitting closer examination of learning objectives [4]. These include: varying the assessment styles; relying less on memory for assessments; enabling greater expression of assessment experience; and relaxing time requirements for given assignment or examination test items.

B. Revised Assessment Structure

From 2006 onwards the previous examiner for this particular course transitioned all assessment to be entirely online based. The exception to this was physical construction assessments used to provide practical application of the theoretical concepts, for which there was no online equivalent. As a result of this online offering, the course assessment was modified to more closely incorporate improvements in reducing stress and language deficiencies. Consequently the following changes were made: preliminary formative quizzes used to train students in quiz answering techniques; increasing the time allowed for online assessment; providing memory support (open-book material); and replacing the traditional written exam with a significant open-book 24 hour timed

online quiz. These changes however necessitated the introduction of additional management to ensure academic compliance and integrity. From 2009 onwards the course assessment was updated to further consider stress and language issues, and improved course assessment management was introduced incorporating additional workflows, and improved assessment compliance monitoring.

III. ASSESSMENT MANAGEMENT REQUIREMENTS

A. Allowing plenty of time for answers

In moving to an all-online timed examination, the main aim was to reduce the effects of traditional examination stress. One fundamental issue with this approach, using the traditional LMS, was an inability to satisfactorily verify that individual effort was being assessed, and that real-time plagiarism was not occurring. Clearly face-to-face examinations permit verification of identity and enforcement of strict conditions. Whilst there are existing products for enforcing online examination conditions, for example [5], these were considered costly and outside the scope of achievability within this course. During the initial transition to online assessment, simple identity checking was performed through manual monitoring of the logfile data and comparing student response styles with acquired stylistic writing data from student's previous submissions. This was however a laborious and time consuming task, even when supported by phrase-matching and anti-plagiarism software available within the LMS [6].

To overcome this issue, the final online examination-assessment was re-configured with 20 different, but objectively similar, 'versions' of the final online assessment having being appropriately moderated to ensure equal academic opportunity across all variants offered. Each assessment was split into two parts; one involving numerical calculations able to be computer marked and graded automatically; and a second descriptive writing part allowing students to demonstrate a detailed understanding of the course concepts which was graded manually. These examinations were run over a 5 day period, configured to start in batches from both 9am and 7pm, available to students from the start time till 24 hours afterwards before closing. Flexibility in scheduling was offered, where students were able to pre-select which time slot offering they would attempt, affording them flexibility to optimize their own study or work schedule and account for when they best performed academically (for instance, day or night). Prior observations within the course between participants allowed assessment versions to be allocated to time-slots where the risks associated with potential plagiarism could be reduced. In order to provide increased confidence in these observations, custom software was created to automate modeling of student interactions, potentially permitting automation and allowing for significantly larger class sizes.

B. Behaviour Heuristics – 'PlagRemover'

This software was developed to offline-process the existing logfile data available within the LMS. These individual log entries captured the metadata for each web resource requested and identified; the user; the resource being accessed; the specific resource action; and the time/date stamp of access. *PlagRemover* then permitted complex filtering and reformatting of this data to enable more flexible and specific

queries to be answered. For the analysis used within the example course, this software was configured to identify co-located students sharing common Internet connections, or working within collaborative study groups (having similar internet protocol address ranges). Critically, the aim was not to victimize students for prior group behavior, but to instigate positive examination conditions that encouraged professional responses from students. As the custom software required prior data-sets to determine these relationships before the final assessment, prior online assignments of a smaller nature were utilized and analyzed. From the output of the software, co-located students at risk of plagiarizing were allocated individual or differing assessment batches to facilitate exam condition compliance.

IV. DISCUSSION AND CONCLUSION

An aspect for further development is investigating additional compliance options where students are checked against a list of actions required of them, including dates or deadlines for each action. This has direct utility in large classes, where automation could immediately identify disengaged students, who are not completing tasks or using the LMS appropriately, and target these students for assistance. At present, despite being an offline process, potential is seen in facilitating this functionality as a built in module within the LMS permitting real-time analysis of these logs. This has potential to yield more advanced and meaningful heuristics and immediate awareness of online student behavior. This immediacy has further benefit to the management of automated online examinations where student actions, either spatially or temporally, can be analyzed in real-time permitting automated corrective actions, or halting of the examination conditions, thus replicating in software some of the manual or visual checks that occur in other online examination integrity systems. Also of importance is the investigation of student awareness of these compliance systems and its effect on student performance during these assessments.

In conclusion, this work-in-progress presents the ongoing investigation of processes to maintain academic integrity for substantial online exams within the online teaching environment. Preliminary results conclude that LMS interaction analysis in conjunction with positive online examination conditions can assist in ensuring assessment validity and compliance.

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Exploring Student Understanding of Parallelism Using Concept Maps

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Abstract— This work explores the conceptual understanding attained by students in the area of parallel computing. Parallelism is continuing to grow as an important topic area in computer engineering and computer science. Even as it increases in popularity, only a limited amount of research has been done to determine how well students construct their knowledge of the field. This work aims to begin exploring the structure of parallel computing as understood by undergraduate computer engineering students. A small group of students was selected to create concept maps that illustrate their understanding. These maps have been used in many different areas of science and engineering. The maps were then analyzed and compared to a reference concept map developed by a group of computer engineering faculty. The results of this analysis revealed that students in this sample demonstrated a limited knowledge of parallelism and concurrency through the organization of their concept maps. The analysis of the concept maps also provides evidence that there is a moderate level of understanding of the challenges to implementing and controlling concurrency. However, the linkages created in the maps reveal students' misinterpretation of the goals of exploiting parallelism.

Keywords—Parallel computing, parallelism, concurrency, concept maps, conceptual understanding

I. INTRODUCTION

Parallel computing continues to gain interest as processor manufacturers have begun including more cores on their products. Increased demand for heterogeneous computing solutions has also created a need for engineers who understand the principles of parallelism. These trends have led to renewed discussion about how and when to introduce parallelism in an undergraduate computing curriculum. At the same time, it is necessary to evaluate the effectiveness of methods for teaching parallelism. This work aims to discover the knowledge structure that students in a traditional curriculum develop.

It is not sufficient to simply examine the understanding that students have of individual concepts related to parallelism. Rather, the links between concepts must also be studied. This study uses concept maps for this purpose. It is the first component in a multi-part study that also uses a concept inventory. The end goal of this study is to produce recommendations for integrating parallelism into an undergraduate curriculum. This part of the study, however, is focused only on examining what knowledge structure students

generate when educated in a curriculum that introduces parallelism and concurrency in the operating systems and architecture courses. The study was conducted at Purdue University, West Lafayette, Indiana with approximately twenty self-selected participants.

II. EXAMINING A PARALLEL CURRICULUM

Though parallelism is enjoying somewhat of a resurgence in computing curricula, concerns over its inclusion began decades ago [1]. In this recommendation, ACM detailed the importance of parallelism within a systems programming course and a computer architecture course. At this point, these were seen as the two avenues for introducing parallelism and concurrency to students.

The computer science education community continued to follow this model for some time. Bell noted in 1982 that “The subject of parallelism (or concurrency) has seen little light outside books and courses on operating systems” [2]. This was reflected to some extent even in 1994, when a major survey was completed that examined different universities’ approaches to courses on the topic [3]. This is still the way that the computer engineering department in this study views parallel computing in its curriculum.

Other universities have attempted novel ways to introduce parallelism into their curricula. One of these models is to introduce parallel thinking into the first year computer programming course [4]. This prevents any misconceptions that may arise from learning serial programming in depth before proceeding to parallel programming, but it can be difficult to create programming exercises of appropriate difficulty. However, introducing parallelism so early allows for integration of parallel topics throughout the entire curriculum.

Natural avenues for including parallelism are programming and algorithms courses. A course in data structures can be very naturally enhances to discuss thread-safe queues, for example. More advanced concepts such as GPU programming can also be included, as in [5]. Full integration throughout the curriculum beginning at the first year offers the greatest coverage of parallelism but raises concerns over what is pushed out to make room.

Another approach to including parallelism in an undergraduate curriculum is by offering a course devoted to it.

Many efforts have been made in this area (e.g. [6], [7]). Typically, this course is introduced late in a student's academic career and provides the opportunity to complete a large-scale software or hardware design project. Such a model misses out on opportunities for preventing sequentially-dominated thinking. However, whether this is a major concern is an open question. To help answer it, the computer science and engineering education communities need to better understand how students in these scenarios develop their understanding of parallelism.

III. CONCEPT MAPS

A limited amount of work has been done on examining student understanding of parallelism. Eccles completed a study on novice understanding of parallelism using schema theory and the card-sorting experiment [8]. This study has similar goals but uses concept maps to explore student understanding instead.

Concept maps were first introduced by Novak and Gowins in the early 1980's [9]. The goal of these graphic organizers is to represent a subject's understanding in a graphical, easy to understand format. A myriad of uses for these maps have been developed, including for teaching and assessment. Concept maps help to reveal the structural nature of one's understanding, which can provide valuable insight into how best to organize material in a curriculum. A typical concept map includes propositions as well as links between these propositions.

Two features of concept maps include their semi-hierarchical structure and labeling of links [10]. The term semi-hierarchical conveys the notion that links in a concept map often represent a hierarchy, but may also appear between propositions at the same depth or across very different depths. The labeling of links means that the graphical representation of some sort of relationship includes a label that describes the relationship. The validity of these links and their labels is an important factor in determining the 'quality' of a given concept map.

Novak and Gowins initially were hesitant to position concept maps as a tool for assessment, but recognizing the potential, they provided one method for evaluating student-generated maps. Based on Ausubel's learning theory, this scoring method is detailed in Table I. From this table, it is relatively apparent that a key determinant in the score of a concept map is the inclusion of cross links. Significant cross links show an ability to synthesize relationships within a content domain, an important indicator of learning.

Another method for scoring concept maps has been developed that relies on comparison to an expert-developed criterion map [11]. This method analyzes three metrics: proposition validity describes the number of relationships that are valid, regardless of relevance to the selected domain. Saliency is defined as the proportion of valid propositions to the total number of propositions, and congruence is the proportion of valid propositions to the total number of possible valid propositions from an expert concept map [11]. This scoring system incorporates part of Novak's method in the proposition validity score, but the other two scores assess different dimensions than Novak's component-based system.

A third method allows for more judgment in evaluating concept maps by providing a holistic rubric for assessment [12]. This approach examines three factors that are a combination of those used in the previous two methods. A correctness dimension is very similar to the congruence score that is part of the previous methodology. A score for organization is likely to correlate with the hierarchy dimension of the component scoring method (at least for subject domains that are, in fact, hierarchical), and the comprehensiveness score combines the congruence and saliency scores of the criterion-comparison method.

The engineering education community has begun to embrace concept maps as a learning tool [13]. Even more research has been done in the sciences. This tool has also seen some use within computer engineering [14]. Applying what has already been learned in these arenas can help create a more organized parallel curriculum.

For a more thorough review of the literature pertaining to concept maps, see [15].

TABLE I – Component Scoring for Concept Maps [9]

| Category | Scoring |
|--------------|--|
| Propositions | 1 point per valid relationship |
| Hierarchy | 5 points per valid level of hierarchy |
| Cross-links | 10 points per valid and significant cross link 2 points per valid cross link |
| Examples | 1 point per valid example |

IV. EXPERIMENT METHODOLOGY

1) Selection of Participants

In order to best answer research question (1), participants needed to be chosen who had completed courses in Operating Systems and Computer Architecture.

TABLE II– Procedure for Administering Instruments

| Activity | Description | Time Allotted |
|--|---|---------------|
| Introduction | Subjects were informed of their rights as participants | 5 minutes |
| Word association | Presented with the word 'Computer', participants were asked to create a list of as many related words as possible | 5 minutes |
| Introduction to Concept Maps | A brief lecture was given on the idea of a concept map and how to create one | 10 minutes |
| Word association | To help students generate their list of terms, the word association exercise was repeated with the term 'Parallel Computing' | 5 minutes |
| Concept map construction | Students were asked to generate a concept map for parallel computing using the terms developed in the previous exercise. Pencil and paper were used to construct the maps to eliminate training time for a computerized mapping program | 35 minutes |
| Concurrency Concept Inventory administration | Subjects completed the multiple-choice Concurrency Concept Inventory using pencil and paper. | 1 hour |

For convenience, these students were selected from the computer engineering program at Purdue University. Students were recruited using in-class visits and e-mail. The students first targeted were those in the capstone design course, as these students were the most likely to have already completed the OS and architecture courses. These students were told that they would be participating in an experiment to help aid researchers in their understanding of the students' views on parallelism. They were not told of the nature of the instruments they would be completing. These students were offered monetary compensation for their participation in the study.

2) Administration of Instruments

Students volunteered for a two-hour block of time in which to complete concept map generation and concept inventory administration. In order to provide the students with enough information to complete a concept map, part of this time period was set aside for training. A modified version of the procedure utilized by Ruiz-Primo was used to prepare students for the concept mapping process [11]. This process is outlined in Table II.

Because the goal of this work is to analyze the nature of student understanding of parallelism and not necessarily to fully evaluate the teaching program, students were asked to generate their own concept lists. This exercise provided an additional artifact for examination as well; for students who did not have a strong understanding of parallelism, the list of terms could be examined to determine which foundational knowledge may have been lacking.

3) Scoring of Instruments

The student-generated concept maps were scored by a set of reviewers following the scoring methods described in section III. The concept map developed for the Concurrency Concept Inventory was used as the criterion map for scoring methods that needed such a device. Reviewers' scores were compared and subjected to inter-rater reliability metrics to determine the validity of the scoring procedures. Qualitative observations were annotated and compared to numeric scores to arrive at conclusions regarding student understanding.

V. RESULTS AND CONCLUSIONS

Sixteen students participated in the experiment. All but one were male. Relevant information on the coursework of the population is provided in Table III.

TABLE III – Coursework Experience

| Courses Taken | Number of Students |
|--------------------------|--------------------|
| Both OS and Architecture | 5 |
| OS only | 1 |
| Architecture only | 5 |
| Neither | 5 |

The intraclass correlation coefficients for average measures are given in Table IV. The average of the three reviewers' scores is used throughout the remainder of this paper.

TABLE IV – Intraclass Correlation Coefficients

| Scoring Method | Intraclass Correlation |
|----------------|------------------------|
| Component | .795 |
| Criterion Map | .889 |
| Holistic | .791 |

Raters were largely in agreement for the criterion-map based scoring, while opinions deviated more noticeably for the other two methods. Looking into the component based method, different reviewers had divergent opinions on what levels of a hierarchy were to be considered valid.

Figure I and Table V show the relative scores for three different populations for each scoring method. From this chart, it is apparent that, as one would expect, scores for students who had never before seen parallelism covered in their coursework scored very low. These were Electrical Engineering students completing a microcontroller-based capstone design course. Their exposure to Computer Engineering concepts came during first-year programming and an upper-level microcontroller course.

Interestingly, students who had not completed the Operating Systems course (but had taken Computer Architecture) achieved higher scores on average. The small size of each sample is largely culpable for this; two of the students in the Architecture-only group had outside experience working with projects that made practical use of parallel design or programming. Figure I also shows that criterion-based scoring and holistic scoring agree more closely regarding the relative performance of each group.

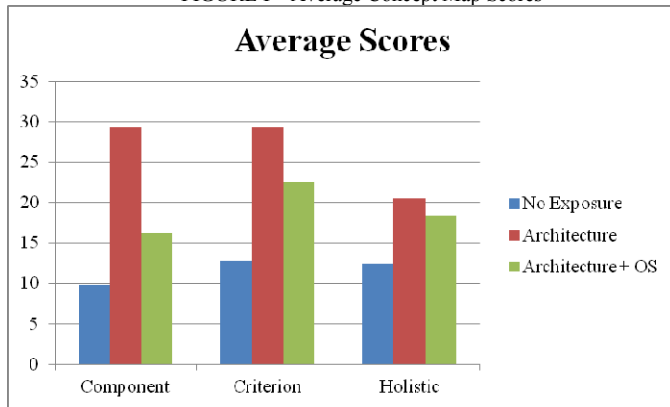
As a gauge of students' metacognitive abilities regarding parallelism, Figure II charts each student's self-reported confidence in their understanding of parallelism with the three concept map scores obtained. A linear regression identifies the trend in evaluating how well students rated their own abilities. The low R^2 values indicate a poor relationship between concept map score and student-provided confidence level. This indicates that students are not able to accurately judge their ability to apply principle of parallelism. Alternatively, they may be poor concept mappers or concept mapping does not accurately reflect their understanding in this instance.

TABLE V – Concept Map Scores

| Score | Average | Std. Dev. |
|-------------------------------|---------|-----------|
| Component – No exposure | 9.73 | 9.03 |
| Component – Architecture only | 29.40 | 12.64 |
| Component – Both courses | 16.20 | 2.85 |
| Criterion – No exposure | 12.73 | 8.66 |
| Criterion – Architecture only | 29.40 | 9.70 |
| Criterion – Both courses | 22.60 | 5.91 |
| Holistic – No exposure | 12.40 | 2.61 |
| Holistic – Architecture only | 20.60 | 2.70 |
| Holistic – Both courses | 18.40 | 2.19 |

One conclusion of this work is that students show a wide variation in their abilities to represent parallelism concepts in a concept map. This may change when the experiment is repeated with the change that students begin the concept mapping process with a list of terms instead of generating their own lists.

FIGURE I – Average Concept Map Scores



It is difficult to draw any conclusions on actual understanding of parallelism based on the scores obtained from the mapping process. The small sample size and high standard deviation of scores prevent any significant statistical observations.

While the scores do not necessarily paint a full picture of the level of understanding attained by students, some themes did emerge from the analysis of the map. Students with exposure to operating systems concepts typically included methods for concurrent processing, such as locks and synchronization, in their concept maps. This is to be expected, since the OS course emphasizes these constructs.

Student maps indicated a difficulty in understanding the difference between parallelism and concurrency. One map, for example, linked the two concepts together with a double-headed arrow, indicating an equivalence relationship. While often used interchangeably, concurrency focuses more on nondeterministic events being processed simultaneously. This is in contrast to parallelism, which aims at extracting as much performance as possible from a program by decomposing it into multiple components that can execute simultaneously. None of the concept maps generated showed an understanding of this distinction.

Figure III gives the distribution of concept mentions over the sixteen maps. Several observations can be made here. First, students acknowledge the shared memory and threading models for concurrency much more readily than distributed memory. Even the students who mentioned distributed memory models showed a deeper understanding of the other two models by including additional propositions and hierarchical levels related to shared memory and multithreading.

Students did not organize their parallelism concept maps by type of parallelism. In fact, no maps mentioned the differences between instruction-level, task-level, and data parallelism. Maps were more typically organized by identifying the challenges involved in implementing concurrency control and grouping subconcepts under each type of challenge. The benefits of parallelism, such as higher performance and reduced power usage, were explored at a more shallow level than the challenges.

It is also important to note that many more students mentioned the terms ‘hardware’ than ‘software’. Indeed, the focus of many maps was on hardware implementations that exploit parallelism. This is likely attributable to the large number of students in the sample who had completed the architecture course.

The observations made regarding the organization of maps reflects the limited knowledge of parallelism and concurrency of graduating students. By focusing solely on hardware and shared memory models, students misinterpret the goals of exploiting parallelism. A shift to a performance-oriented approach may yield benefits in expanding the breadth of student knowledge. While students seem to grasp many of the challenges in implementing and controlling concurrency, a renewed focus on algorithm performance, types of parallelism, and the relationship between hardware and software should be implemented to prevent the misconceptions discussed to this point.

FIGURE II – Score by Confidence Level

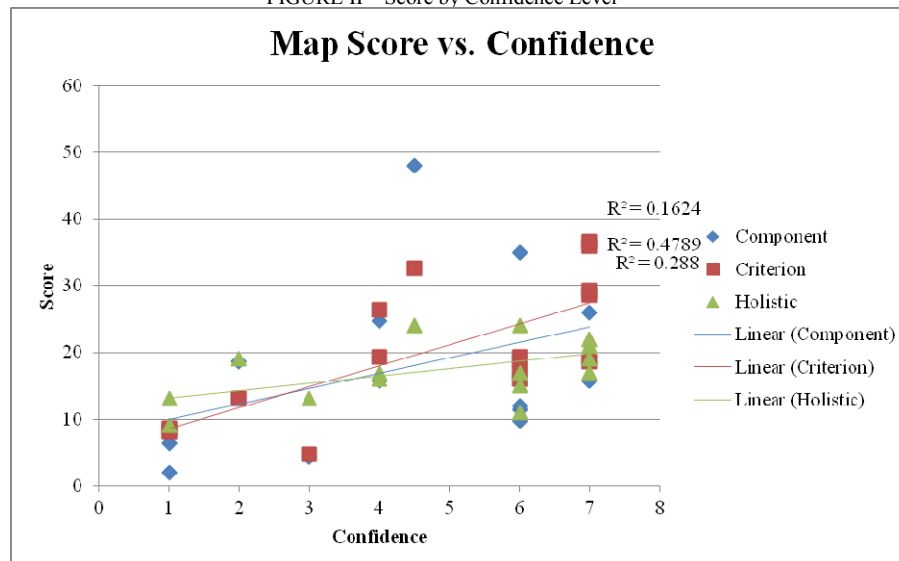
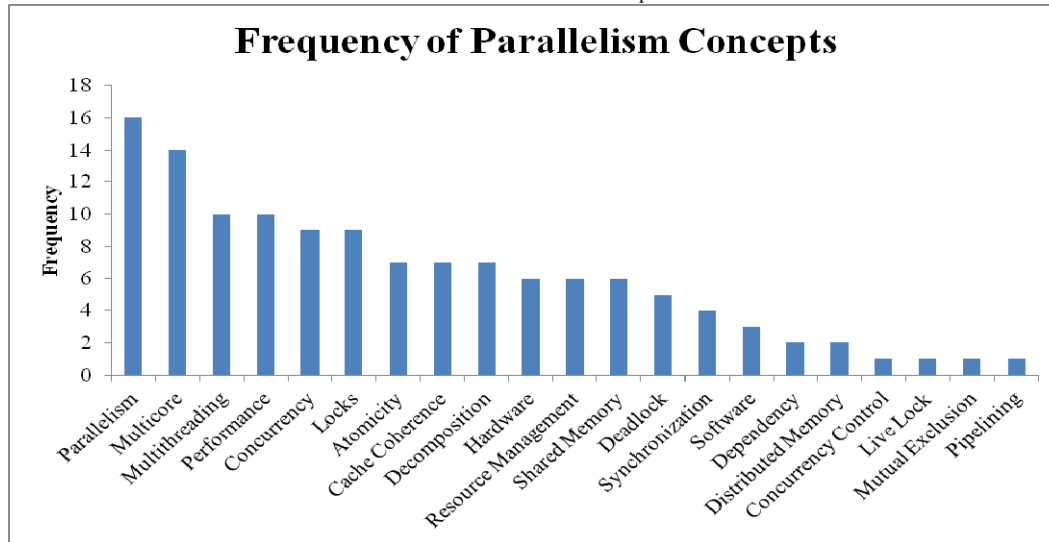


FIGURE III – Distribution of Concept Mentions



VI. FUTURE WORK

The students who completed this experiment also completed a concept inventory developed to analyze understanding of parallelism and concurrency [16]. The scores achieved on this inventory will be compared to the concept map scores. The sets of scores will also be compared to scores achieved by students who attempt the mapping process with a list of terms in hand. Lastly, the results of these studies will be used to make recommendations on when and how to integrate parallel computing into a traditional undergraduate computer engineering curriculum.

ACKNOWLEDGMENT

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A Mastery-Based Learning Approach for Undergraduate Engineering Programs

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We report the results of an action research study in which a modified mastery-based learning approach was implemented in three undergraduate engineering courses: engineering statistics, LabVIEW programming, and environmental engineering. In this paper, we describe both the action research and the modified mastery-based learning approach that was implemented. Findings from the analysis of data on student performance, and student and faculty perceptions of the approach are presented. In addition, we discuss our recommendations for modifications to the approach that could be used in future implementations.

Keywords: *action research, mastery-based learning, assessment, undergraduate engineering*

I. BACKGROUND AND INTRODUCTION

It is well documented that students' relative academic placement within their peer group is fairly constant, even across many years [1]. The same phenomenon is observable at the university level, where students who do well in their freshman year are often the students who continue to do well throughout the degree program. Moreover, in most class settings, a student who is a *fast* learner may be perceived as a student with high aptitude for the course material. A student who is *slow* learner, though perhaps perceived as having a low aptitude for the subject matter, may only need more time to learn the material.

Mastery-based learning is a pedagogical approach designed to help address these issues. Mastery-based learning was developed by Bloom and is based on two key ideas. First, it incorporates John Carroll's theory that student aptitude reflects a rate at which topics can be learned rather than an ability to learn topics. In addition, it incorporates the understanding that the idealized learning environment takes place when a single tutor is paired with a single student [2]. It has been shown to be effective in reducing the variability in student learning within a class, particularly improving the performance of students who require additional time to learn some of the topics.

When compared to traditionally taught courses, students in courses taught with a mastery approach attain higher levels of achievement and had more confidence in the material [3], [4]. One survey of mastery-based learning programs demonstrated that, on average, implementing mastery-based learning increased final examination scores by about 0.5 standard deviations in colleges [4]. Students who needed more time to master the course content experienced greater gains from the

mastery-based approach. The average improvement in scores of high aptitude students is 0.40 standard deviations; the improvement of low aptitude students is 0.61 standard deviations [4].

In the most traditional form of mastery learning, course content is delivered in units of instruction, which correspond to student learning competencies. Students are provided with attempts (as many as are necessary, theoretically) to demonstrate mastery of each learning competency and are then presented with feedback. If mastery is not demonstrated, the feedback provides guidance on learning progress and provides specific corrective activities to target the conceptual gaps the student needs to bridge. Enrichment activities that provide opportunities for students to tackle more advanced topics can be given to those who quickly master course topics.

Though this method has been widely applied at the K-12 level [3], [4], fewer studies have tested the approach at the college level [5]. In the university setting, the learning environment is more tightly constrained by limited instructional time. Additionally, larger class sizes make the traditional mastery-based learning style difficult to implement. This paper presents a modified-mastery based learning approach that deviates from the traditional implementation in that the cycle of formative assessments and feedback to master the material is finite. In three courses, content was divided into course-specific competencies. The implementation of this approach in two sections of a sophomore engineering statistics course, a one-credit LabVIEW course and a senior-level environmental engineering elective is presented below.

II. DESCRIPTION OF ACTION RESEARCH PROCESS

In the engineering department where this research occurred, faculty are encouraged to engage in scholarly teaching. Inspired by Ernest Boyer's [6] concept of the scholarship of teaching, this "involves a broad set of practices that engage teachers in looking closely and critically at student learning for the purpose of improving their own courses and programs"[7]. Action research is a methodological framework that is well suited for this type of inquiry. In its simplest form, action research is a systematic, self-reflective study undertaken by an individual to understand and improve his/her practices [8]. The study described in this paper was conducted using a specific type of action research: collaborative action research. The three co-authors: Jennifer, Caitlyn and Odesma; all from the same department at the time of the research, partnered as co-

researchers to explore common solutions for improving the learning experiences of students in their respective courses.

A. Starting Point

Following the steps outlined by Capobianco, Horowitz, Canuel-Browne, and Timarchi [8] and shown in Figure 1, the researchers began their collaborative inquiry by first identifying a shared starting point. Jennifer, who teaches a sophomore level statistics course, identified her concern with students' ability to deal with stochastic results outside of the statistics class. Her prior observations made her question whether her current instructional approach helped students learn some topics deeply enough to transfer to another setting, or facilitated the learning of the mechanisms, but not necessarily the application of the concepts. Caitlyn, who taught courses in the civil and environmental engineering focus area and would be teaching a senior-level environmental engineering elective for the first time, was concerned about the difficulties students in environmental engineering have contextualizing the non-technical elements of their work. Odesma, who taught courses in the electrical focus area and would be teaching a 1-credit LabVIEW course to sophomore-level students for the first time, was interested in understanding how to individualize instruction for different learners in a large class. This was of particular concern to Odesma given her prior experience observing the discrepancies among engineering students' prior programming knowledge and confidence.

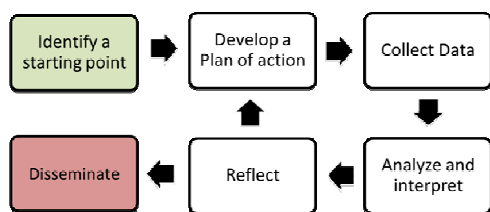


Figure 1: Steps Involved in Action Research [7]

The results of the starting point brainstorming activity, previously described, steered the team towards pedagogical and assessment solutions. Based on their prior familiarity and experience with mastery-based learning, this approach emerged as a potential candidate to address each researcher's concern. For Jennifer, the modularized curricular structure could allow for specific competencies to be included that address selection of appropriate statistical concepts and the application of the concepts in real problems. The affiliated assessments of mastery could then allow her to monitor students' performance in these competency areas (as well as all others), and provide corrective feedback to students who don't attain the competency. The feedback could potentially allow students to continue to improve and eventually demonstrate mastery at a later point in the semester. For Caitlyn, adding competencies related to the non-technical aspects of the course, which were weighted equally to the technical aspects of the course, could help students value the non-technical in the same way they value the technical components. As competencies, she would be able to monitor students' performance on both aspects (i.e., technical and non-technical), and provide corrective feedback when mastery is not attained. For Odesma, the multiple demonstrations of

mastery and individualized feedback, specifically related to the student's performance on the competency, could allow for a more personalized learning experience. In addition, the enrichment assignments could allow students who progress faster to continue to enhance their knowledge without needing to advance the entire class, or stifling their growth.

There are a significant number of research studies and how-to texts on mastery-based learning [9]. However, most of the examples are based on a K-12 context. There are few documented instances of the use of mastery-learning in college-level classrooms, and no instances related to the teaching of engineering subject matter. Given the differences between K-12 and tertiary-level learning environments, the typical individualized mastery-based learning approach did not seem practical for the researchers. A structured, feedback cycle was needed to make the approach fit in a 14-week course with a manageable amount of additional effort and preparation on the part of faculty, also managing research and service agendas. It was critical to preserve the distinguishable features, such as iterative, customized, formative assessment, to lead to improved student achievement, particularly in the problem areas identified by each researcher. From this shared challenge the starting point of the action research study emerged.

Starting point: We would like to institute a modified version of mastery-based learning in our respective engineering courses that: 1) preserves its distinguishing features (i.e., modularized according to competencies, multiple chances to demonstrate mastery, corrective feedback, and enrichment activities) and 2) will be implemented with a manageable amount of additional effort and preparation. We also hypothesize that the implemented approach will lead to high student achievement.

B. Plan of Action

Following the identification of a starting point, the next step in the action research cycle is the development of a plan of action to be piloted. This plan also includes the identification of a strategy for collecting data on the outcome of the action. The co-researchers worked together to define a mastery-based learning model that they could each use in their respective courses. The model differed from the traditional mastery-based approach in two ways that we considered necessary for effectively implementing a mastery-based approach in a higher education-based setting:

- 1) There were a fixed number of chances available to students to re-demonstrate mastery of a competency. Only two chances were given to demonstrate each competency, and a condition was placed on receiving the second chance.
- 2) Evidence assignments were introduced to provide an opportunity to practice competencies and receive formative assessment, similar to a typical use of homework assignments.

A full description of the mastery-based learning model that was piloted follows and is also shown in Figure 2.

Competencies: As part of this approach, the technical content and skills students were expected to learn in each course were divided into instructional units, called competencies. Competencies were aligned with previously established course learning objectives and departmental learning outcomes. The number of competency areas defined for each course is shown in Table 1. For each course, the students' final grade was determined by the number of competencies mastered by the end of the semester.

TABLE I: SUMMARY OF COURSES

| COURSE TOPIC (CREDIT HOURS) | STUDENT LEVEL | NUMBER OF STUDENTS | NUMBER OF COMPETENCIES |
|----------------------------------|------------------|--------------------------|---------------------------|
| ENGINEERING STATISTICS (3) | SOPHOMORE | 69 | 21 |
| LABVIEW PROGRAMMING (1) | SOPHOMORE | 44 | 4 |
| ENVIRONMENTAL ENGINEERING (3) | SENIOR | 15 | 33 |

Evidence Assignments: To help students prepare for competency assignments, in-class instruction was supplemented with additional learning activities that provided students with multiple opportunities to apply their understanding of the topics associated with the competency area(s) and get feedback on their performance. These assignments took the form of question(s) on a homework assignment or an in-class activity. The term, "Evidence Assignments," was used since these assignments provided evidence of the students' attempt to learn the topics, and their success or lack thereof with using the prescribed instructional approach. Completing evidence assignments on time ensured that students received timely feedback on their performance and suggestions for remediation when needed. Their performance on evidence assignments was not counted towards the final course grade.

Competency Assignments: Mastery of a competency is demonstrated through students' performance on competency assignments. These assignments can take the form of question(s) on a quiz or exam, an in-class activity or project. Each student received at least one opportunity to complete each competency assignment. Mastery was achieved when competency criteria are met. For example, one competency in Environmental Engineering was "Student can write balanced chemical reactions". The competency is mastered when the student correctly balances a chemical reaction. A passing score on a competency assignment translates to a prescribed number of competency points. If a student does not attain a passing score on his/her first attempt, he/she may get a second opportunity to re-demonstrate the competency at a later time. Second opportunities were only given to students who attempted all evidence assignments associated with the competency. Before a student re-demonstrates mastery, he /she will get feedback on his/her performance on the first competency assignment taken and suggestions for remediation, i.e., other approaches for learning the concepts.

Enrichment Assignments: Once a student demonstrates mastery of a competency, he/she may have the opportunity to

complete an optional associated enrichment assignment. These assignments present a challenge above and beyond the course material, and are designed to challenge and help extend students' understanding of the related topics. For example, in the statistics course, a course competency required students to be able to determine the probability of a random variable taking on a particular value from a normal distribution with given parameters. The associated enrichment activity supplied students with two data sets of unknown distribution, asked them to identify which of the two was normally distributed, determine the parameters of the distribution, and then estimate the probability of a random variable from that distribution taking on a particular value. Enrichment assignments were also assessed on a pass/fail basis. A passing score on an enrichment assignment translated to a percentage of a competency point. To attain an A+ in any of the courses, students had to complete some enrichment assignments successfully, in addition to achieving almost all other course competencies.

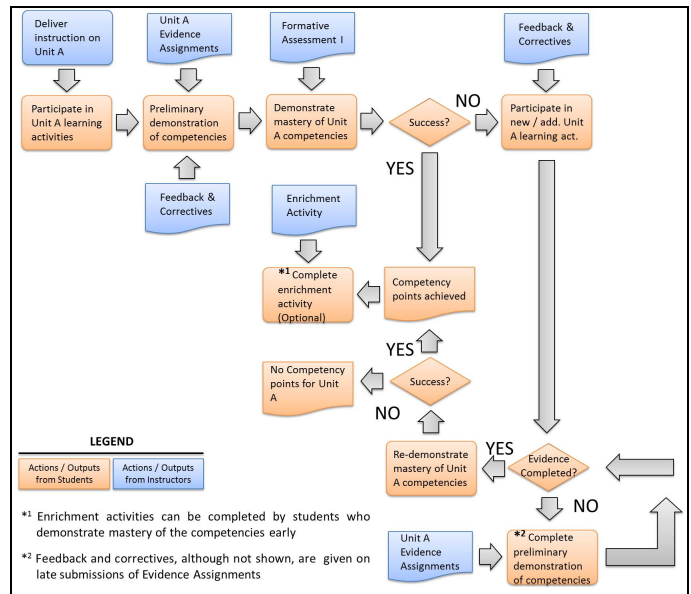


Figure 2: A Course Unit in a Typical Mastery-Based Learning Format

B. Reflection in the Action Research Process

An additional important part of the action research process is the ongoing and frequent reflection undertaken by the researchers, both individually and collaboratively. The action research process is iterative, and reflection facilitates the development of a critical awareness and deeper understanding of the action taken [8]. With each iteration, the action can be tweaked and improved. The researchers used journals to capture their weekly reflections based on observations made related to the course. They also met every two weeks to discuss and share interpretations of their experiences, and to strategize improvements to their actions.

III. DATA COLLECTION

To evaluate the described approach, several sources of data were collected, including student and faculty perceptions of the approach and student achievement data. The study was

approved by the Institutional Review Board at Arizona State University.

A. Student Perception Data

In each of the three classes, student surveys were administered multiple times to gather data about the students' perceptions of the approach. Surveys were administered in the two 3-credit hour classes four times (after 0%, 25%, 50%, and 100% of course competency assignments had been given) and in the one-credit hour class three times (after 0%, 50%, and 100% of course competencies assignments had been given to the students). The survey consisted of seven questions intended to measure student perceptions of both their understanding of effectiveness of the approach. Response options were arrayed on a five point Likert-scale ranging from strongly disagree to strongly agree (midpoint = neither agree nor disagree). The questions of this type are given below:

- Question 1: I understand the system by which I am being assessed in this course
- Question 2: I like the system by which I am being assessed in this course
- Question 3: I am aware of my current status (as related to course progress) in this course
- Question 4: The feedback I receive on Evidence Assignments is useful.
- Question 5: The frequency of feedback I receive on submitted assignments is sufficient for me to continue making progress toward demonstrating course competencies.
- Question 6: This class allows students with my learning style to succeed.
- Question 7: I am confident that after this course is over, I will be able to appropriately apply the skills that I am learning in this course to another situation.

Additional survey questions solicited open ended responses from students regarding the corrective feedback they were receiving, their learning style, and general suggestions about the approach.

B. Faculty Perception Data

Perceptions of the three participating faculty members were captured through weekly journaling.

C. Student Achievement Data

Student achievement data was based on the competency achievement of students in each class during the semester. Specifically, data was recorded by class on the percentage of competencies ultimately achieved, the percentage of competencies achieved on the second try, and the number of bonus assignments completed. The total number of competencies achieved gives a high level view of student performance, the number of competencies achieved on the second try gives an indication of how the feedback and extra time contributed to student success, and the bonus assignments provide data on whether students were able to demonstrate a higher level of learning for particular competencies.

IV. ANALYSIS AND INTERPRETATION

A. Student Performance Data

An objective of the mastery-based approach is to improve the number of students who master the majority of competencies within a course. While we do not have baseline data to compare to, Table II provides the summary data of the percentage of students who demonstrated mastery of at least 75% and at least 90% of course competencies in each of the three courses. As Table II illustrates, at least 70% of students in each of the classes demonstrated mastery of at least 75% of the course competencies, which is an encouraging result. Of note is that the percentage of competencies demonstrated does not necessarily map to course grade (different competencies can be worth different amount of points toward the course grade).

TABLE II: COMPETENCY ACHIEVEMENT BY CLASS

| COURSE | STUDENTS EARNING AT LEAST 75% OF COURSE COMPETENCIES | STUDENTS EARNING AT LEAST 90% OF COURSE COMPETENCIES |
|-----------|--|--|
| EGR STATS | 75.36% | 43.48% |
| LABVIEW | 79.55% | 61.36% |
| ENV EGR | 73.33% | 60.00% |

A particularly important result is the number of competencies that were earned on the second administration of a particular competency assignment. These second opportunities represent chances for students to have acted on the provided corrective feedback, and/or for the students who learned a particular competency at a slower pace, to demonstrate mastery. Table III shows the average percentage (and standard deviation) of competencies demonstrated on the second attempt for students in each of the classes. The data in Table III shows that students would have earned between 18% and 21% fewer competencies if the second chance (and associated corrective feedback) had not been provided. In a traditional assessment approach, this would likely have resulted in a significantly lower summative assessment for the course.

TABLE III SECOND CHANCE COMPETENCY ACHIEVEMENT

| COURSE | AVERAGE % OF COMPETENCIES EARNED ON SECOND TRY (STANDARD DEVIATION) | MAXIMUM % OF COMPETENCIES EARNED ON SECOND TRY |
|-----------|---|--|
| EGR STATS | 18.71% (9.22%) | 42.90% |
| LABVIEW | 21.21% (20.4%) | 66.67% |
| ENV EGR | 18.02% (9.00%) | 29.73% |

The final presented measure of student achievement is the number of enrichment assignments successfully completed by students in each of the courses. The statistics, LabVIEW and environmental engineering courses each had a total of 4, 2 and 4 enrichment assignments respectively. In all courses, the average number of completed enrichment assignments per student is less than one. A much larger number of students

submitted enrichment assignments. The assignments, however, were designed to require a higher level of learning of a particular topic; as such, many students did not earn credit for bonus assignments submitted.

B. Perception Data

In addition to student achievement, we also aimed to develop an approach that was well-received by both participating faculty and students. In the following sections, the analysis of the data from the student perception survey, and from the faculty journals, are presented. The numerical and qualitative data from the student perception data are presented separately

1) Student Perceptions

a) Numerical Data

The numerical data from the student perceptions survey is presented by question (question numbers correspond to those presented in Section III A) in Table IV, which gives survey results based on responses from students in all classes. A response of “1” indicates a response of “Strongly Disagree” while a response of “5” indicates a response of “Strongly Agree”. Of special interest to us is the change in responses across the multiple administrations of the survey. The implemented mastery-learning approach is a fairly different assessment approach from what they had experienced in other classes, and it is more complicated. As a result, we expected student perception of the approach to improve as the semester progressed and their understanding of the system got better. Table IV shows that for all questions, there was a positive change in the average student response. Also of note is that changes in the average responses between administrations of the survey become smaller with subsequent administrations. By the final administration of the survey, the average response was at least 4.10 to all questions, indicating that the students were satisfied with their understanding of the approach, their knowledge of their course performance, the feedback with which they were provided, and the knowledge they were learning in the course.

TABLE IV: NUMERICAL SURVEY RESULTS – ALL STUDENTS INCLUDED. RESULTS INCLUDE THE AVERAGE (AND STANDARD DEVIATION) FOR EACH OF THE SEVEN QUESTIONS. THE NUMBER OF RESPONDENTS IS SHOWN WITH THE PARANTHETICAL N VALUE.

| | 1 (N=74) | 2 (N=60) | 3 (N=30) | 4 (N=68) |
|----|-------------|-------------|-------------|-------------|
| Q1 | 4.04 (0.97) | 4.48 (0.72) | 4.73 (0.45) | 4.69 (0.53) |
| Q2 | 3.86 (1.12) | 4.03 (0.95) | 4.11 (0.98) | 4.11 (1.06) |
| Q3 | 3.77 (1.25) | 4.42 (0.96) | 4.53 (0.73) | 4.53 (0.66) |
| Q4 | 4.00 (1.35) | 4.19 (0.98) | 4.30 (0.95) | 4.56 (0.70) |
| Q5 | 3.90 (1.40) | 4.35 (0.95) | 4.23 (0.97) | 4.49 (0.73) |
| Q6 | 3.71 (1.36) | 4.13 (1.04) | 4.23 (0.86) | 4.20 (1.00) |
| Q7 | 3.81 (1.17) | 3.97 (1.11) | 4.17 (0.87) | 4.10 (0.90) |

b) Open Response Data

An informal analysis of responses to open ended questions yielded several trends in student opinion. These trends, along

with representative comments are presented here. The majority of student responses indicated that they were happy with the approach and the efforts made by the instructors in implementing the approach. Comments such as the representatives below support the positive numerical survey results:

- “I love it! It feels like I am succeeding and actually completing something whereas the ‘usual’ grading system feels like you start out with an A+ and slowly lose your grade instead of starting at 0 and progressing to an A+”
- “[I] Enjoy this learning style. I feel as though I have been given ample opportunities to succeed, and if I don’t, I am given the feedback to correct my thinking”

In addition to an overall satisfaction with the approach, four primary themes of student concerns emerged from the informal analysis of the open-ended survey responses: confusion about the assessment process itself, a desire for improved relationship between evidence assignments and competency assignments, frustration and acknowledgement with the importance of organization in implementing the system, and a dissatisfaction with the “pass/fail” notion of demonstrating competencies.

As mentioned previously, the comments about confusion on the process by which they were being assessed were not surprising to us. And, as was mirrored by the numerical survey results, the comments were less frequent in later administrations of the survey. Comments such as those below, however, do highlight the importance of spending time explaining the approach regularly during multiple class periods at the beginning of the semester.

- “It was really confusing in the beginning – I got behind because I did not understand this teaching approach”
- I think, initially the make-up method was confusing for most students. [Clarification] on this process would benefit future classes”

The concerns brought up by students about the relationship between evidence assignments and competency assignments are also important. Clearly, both types of assignments should tie back to the competency definitions themselves, and faculty implementing this approach in the future should pay special attention to ensuring that to be the case. Additionally, some of the student concern may have stemmed from a misunderstanding of the competency definitions themselves. Reminding students regularly to read the competency definitions may be helpful in allowing them to understand in advance the specific topics on which they will be assessed. Some representative comments from students follow.

- “The evidence assignments do not really prepare you for the competency assignments. We had to self-teach ourselves in order to get through the competencies.”
- “Competency tests should [not] introduce unfamiliar units or situations. Because there is only a single evidence assignment, the test should not be tricky in any way”

The third common concern raised by students was with regard to their observations that faculty organization of the course is more critical in this system than in a more traditional system. The students are exactly correct that faculty organization and timing in this type of mastery-based approach is critical. With a large number of competencies, the timeline for giving evidence assignments followed by ample time to apply corrective feedback before giving a competency assignment (and then giving at least one more competency assignment later in the semester) does not allow a lot of flexibility. In each of the classes, there were points at which this created some difficulties, evidenced by student comments such as:

- “Organization makes or breaks the system”
- “Evidence assignment due dates seem meaningless”

Finally, a number of students reacted fairly strongly to the fact that each competency is either “demonstrated” or “not demonstrated” for a particular assignment, giving the feel of a pass/fail type grading system. Ultimately, the competency based system actually gives students the chance to “fail” without incurring a negative impact on their summative course grade, but some students did not like the fact that they didn’t gain any partial credit toward their final course grade for efforts they had put into competency assignments. Some representative comments to this effect follow:

- “The one thing I would change is that if a student gets most of the questions right, they get the competency”
- “Right now it’s all or nothing...I think that’s very wrong”
- “Give some credit for all the assignments. Otherwise, it becomes too much of a pass/fail type system”

Each faculty member made the determination of what was required to “demonstrate mastery” of a competency on a particular assignment, and this was tied to the definition of the competencies themselves. In some cases, multiple concepts were tied up in a particular competency (e.g. interpret significance of a regression model and evaluate the validity of model assumptions), causing students who successfully demonstrated mastery of part of the competency but not the other, to not get “credit” for mastery. In future offerings of the course, these two-part competencies should be split to award student accomplishment of each individual learning objective.

2) Faculty Perceptions

During the action research project, faculty perceptions of the process were recorded in weekly journal entries. Each of the participating faculty members observed and noted specific successes and areas for improvement about the process from her specific class. However, of greatest interest were the several themes present across all classes, which are highlighted next. Journal entries were shared in our biweekly meeting and common themes were identified as a group, as is common practice in an action-based research project.

- The modified mastery learning approach provided a good structure for the course. For example, in-class

activities that counted as evidence assignments resulted in a higher engagement in these activities than in previous course offerings (in which the activities were not directly tied to course grades).

- Students who took advantage of the system succeeded. Moreover, the students who were the most engaged benefitted the most from the mastery based approach.
- Providing the individualized corrective feedback dramatically increased the typical workload for a faculty delivering a course.

V. SUMMARY AND CONCLUSIONS

This paper presented an action research project that resulted in the creation and implementation of a modified mastery-based learning approach in three undergraduate engineering courses. The collected data demonstrated that the approach resulted in high student achievement and also general satisfaction about the approach from participating students and faculty. Data on student and faculty perception did suggest some areas for improvement, including developing a more efficient way for faculty to deliver feedback and more careful coordination between competency definition, evidence assignments, and bonus assignments.

Future work on the approach will include a formal investigation of the effectiveness of various feedback mechanisms, a focused effort on developing approaches for making the feedback cycle more efficient for faculty, while still being useful and meaningful to students, and more rigorous evaluation of the impact of the approach on student achievement.

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How does Academic Preparation Influence How Engineering Students Solve Problems?

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Abstract—In first year engineering courses, students possess a wide range of academic preparation such as their exposure to various mathematics courses and pre-engineering programs. Additionally, students bring perceptions about their abilities, and have already begun practicing preferred methods of analysis and documentation. Understanding how students with different backgrounds develop problem solving skills in first year engineering programs is of critical importance in order to close achievement gaps between diverse populations.

This study examines how students solve engineering problems and identifies variations based on student factors of gender, ethnicity, mathematics preparation and achievement, and prior engineering experience. Solutions for three problems from 27 students were analyzed ($n = 68$ solutions). Students worked out problems using custom-designed software that digitally records ink strokes and allows researchers to associate codes to the problem solution at any point, even in portions of the problem solution that would not have been available without the use of this technology, such as in erased work.

Differences in how students solve problems were assessed based on the prevalence (or absence) of elements and errors in the problem solving process, which were evaluated using task analysis. Results indicated that pre-engineering experience did not have a significant impact on successfully solving problems; however, having completed a calculus course was significantly related to successful problem solving. Future research will expand the study population to a larger sample of first year engineering students across multiple semesters, identifying key strategies that are absent for students with low mathematics preparation, and to investigate relationships between prior academic preparation and indicators of metacognition.

Keywords— *problem solving; first year engineering; academic preparation*

I. INTRODUCTION

Engineering students must apply basic mathematical skills and reasoning to solve problems, ranging from arithmetic manipulations to analysis of variables. However, the level of mathematic and engineering preparation they bring to their first-year courses vary widely. Often instructors find that students do not have the prerequisite knowledge needed or

have strong enough analytical skills to learn new concepts successfully. The instructor may even feel it is necessary to review prerequisite material to the entire class before continuing to new concepts, which can restrict the amount of material that can be covered in a course.

In view of the one-way migration pattern from engineering majors [1], it is important to identify factors that cause students to withdraw from or fail to succeed in engineering courses. Here we examine problem solving proficiency as a potential factor. Engineering students from underrepresented groups such as females and minorities have been shown to have distinctly different engineering education experiences [2]. Research indicates that males seem to exhibit more advanced problem solving performances than females [3] and that females doubt their problem solving abilities more than males [4]. Research on the mathematical problem solving of minority students has shown that they suffer a larger dropout rate from engineering than all other students [5] and exhibit a lower success rate solving non-routine problems, even though their solutions indicate proportional skills levels [6]. Malloy defined non-routine problems as those “that could be solved with multiple strategies, could be solved with holistic or analytical strategies, and required inferential, deductive, or inductive reasoning [6]. This definition of non-routing problems describes contextual “story” problems in a typical first year engineering course. If this trend is evident in first year engineering problem solving, it could shed light on a potential factor attributing to the higher than average withdrawal rate for under-represented minorities. Understanding how students with different backgrounds develop problem-solving skills in first year engineering programs is of critical importance in order to close achievement gaps between diverse populations.

When students work through problems, they construct an interpretation of the concepts being taught using pre-existing knowledge [7]. For meaningful learning to occur, a learner must make sense out of the information presented and have relevant conceptual knowledge to anchor new ideas [8]. A learner’s framework of relevant concepts allows him or her to solve problems efficiently and successfully. When this prior knowledge is lacking or inappropriate, the learner has difficulty solving the problem in the intended manner [9].

This study investigates the relationship between how students solve problems and their prior academic experiences,

specifically prior mathematics courses and any pre-engineering experience such as involvement in FIRST or Project Lead the Way. FIRST is a program that encourages students ages 6-18 to build science, engineering, and technology skills through designing, building, and programming robots [10]. Research suggests that students who participated in FIRST Lego League showed increases in confidence and overall technological problem solving performance [11]. Project Lead the Way is a Science, Technology, Engineering, and Mathematics (STEM) education curricular program geared toward middle and high school students. Its goal is to develop critical-reasoning and problem-solving skills [12]. Research suggests that students who participate in Project Lead the Way have higher achievement in reading, mathematics, and science [13].

II. METHODS

A. Engineering Problems

This study examines problem solving solutions from students enrolled in a first-year undergraduate engineering course. Solutions were captured for three different problems typical of those given in a first year engineering course. Three problems covered topics of 1) efficiency, 2) circuits, and 3) pressure. All problems had 1) a constrained context, including pre-defined elements (problem inputs), 2) allowed multiple predictable procedures or algorithms, and 3) had a single correct answer [14]. All three problems were story problems, in which the student is presented with a narrative that embeds the values needed to obtain a final answer [15].

The first problem involved a multi-stage solar energy conversion system and required calculation of the efficiency of one stage given input and output values for the other stages [16]. The second problem required students to solve for values of components in a given electrical circuit. This problem, developed by the project team, also contained a Rule-Using/Rule Induction portion (a problem having one correct solution but multiple rules governing the process [15]), where students were asked to determine an equivalent circuit based on a set of given constraints. The third problem involved total pressure calculations and required students to solve for values within the system, and convert between different unit systems [16]. None of the problems required the use of calculus to solve. Example solutions for each problem are shown in Figures 1-3. Sixty-eight solutions were analyzed.

B. Participants

There were 27 participants, 6 females and 21 males. Twenty-three of the participants were Caucasian. Seven of the students had prior engineering experience through extracurricular activities. In terms of mathematics preparation, 4 of the students' highest mathematics course was Pre-Calculus, 3 had taken AP Statistics but no Calculus, 11 had taken AB Calculus, and 9 had taken BC Calculus.

Handwritten solution for Solar Efficiency Problem:

$$\eta = \frac{P_{out}}{P_{in}}$$

Stage 1: $P_{in1} = 2000W$, $\eta_1 = 41\%$, $P_{out1} = P_{in1} \cdot \eta_1 = 2000W(41) = 820W = P_{in2}$

Stage 2: $\eta_2 = ?$, $P_{out2} = \frac{P_{in2}}{\eta_2} = \frac{820W}{.45} = 1822W$

Stage 3: $\eta_3 = 37\%$, $P_{out3} = \frac{P_{in3}}{\eta_3} = \frac{1822W}{.37} = 4924W = P_{out2}$

Final answer: $\eta_2 = 45\%$

Figure 1: Solution for Solar Efficiency Problem

Handwritten solution for Equivalent Circuits Problem:

Circuit diagram: A 12V source connected to three resistors in series: R_{eq1} , R_{eq2} , and R_6 .

Calculations:

$$R_{eq1} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{1}{\frac{1}{20} + \frac{1}{30}} = 12\Omega$$

$$R_{eq2} = \frac{1}{\frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}} = \frac{1}{\frac{1}{40} + \frac{1}{50} + \frac{1}{60}} = 15\Omega$$

Final equivalent circuit: $R_{eq} = R_{eq1} + R_{eq2} + R_6 = 12\Omega + 15\Omega + 20\Omega = 47\Omega$

Current: $I = \frac{V}{R} = \frac{12V}{47\Omega} = 0.255A$

Figure 2: Solution for Equivalent Circuits Problem

Handwritten solution for Pressure Problem:

Diagram: A rectangular block of height $h = 25'$ and width $W = 20'$.

Calculations:

$$P_T = P_{hydro} + P_{atm} = \rho g h + P_{atm}$$

$$\rho = \frac{P_T - P_{atm}}{g h}$$

$$\rho = \frac{405300 Pa - 202650 Pa}{9.8 \frac{m}{s^2} (7.6 m)} = 2720.86 \frac{kg}{m^3}$$

Figure 3: Solution for Total Pressure Problem

C. Technology used to Capture Problem Solving Processes

Problem solving data was obtained via students' completed in-class exercises using a program called MuseInk, developed at Clemson University [17, 18]. This software was used in conjunction with tablet computers that were made available to all students during the class period. Students worked out problems in the MuseInk application, which digitally records ink strokes and allows researchers to associate codes to the problem solution at any point, even in portions of the problem solution that would not have been available without the use of this technology, such as in erased work. Solutions were coded using the coding scheme developed by Grigg and Benson to describe cognitive and metacognitive processes, errors, and strategies revealed in student work [19].

D. Statistical Analysis Methods

To investigate differences in how students solve problems, statistical analyses were conducted to assess differences in 1) the presence of problem solving elements, and 2) the frequency of use of problem solving elements. Evaluations assessed student factors including gender, ethnicity, and prior academic experiences such as pre-engineering experience and highest level of mathematic course taken.

Repeated measures ANOVAs were conducted to determine if significant differences existed in the presence of task elements, errors, strategies, or answer state that are attributable to student factors of gender, ethnicity, pre-engineering experience, or mathematics preparation. Repeated measures ANOVAs were also conducted to evaluate differences in the frequency of task usage among problem solutions to further explore how problem solving solutions vary between populations. Only significant effects of student factors are reported. P values of 0.05 were utilized as the significance level.

III. RESULTS

Analysis was conducted on 54 codes of process elements, errors, strategies, and solution accuracy. For codes related to process elements, the basic structure set forth in the coding scheme by Wong, Lawson, and Keesee was used within the categories of knowledge access, knowledge generation, self-management [20]. For codes relating to errors, a structure derived from error detection literature in accounting, was used to classify errors as conceptual and mechanical errors [21, 22] with an added classification of management errors to capture errors in metacognitive processes. Strategy codes were obtained from a subset of strategies that appeared most applicable to story problems from the compilation described in "Thinking and Problem Solving" [23].

A. Assessment of students' use of problem solving features

Results were evaluated for all codes of process elements, errors, strategies, and solution accuracy for the collective sum

of problem solutions, hence repeated measures ANOVAs were utilized to account for variations attributed to the problem. If the code was associated to a problem solution at least once, that code was determined as present, even if the work was later modified to eliminate its presence in the final solution.

The level of academic preparation of female students was quite different from that of male students. Of the female students in the study, only 33% had calculus experience compared to 86% of male students. Additionally, none of the female students had pre-engineering experience compared to 33% of male students. Therefore, it should be noted that differences found in terms of gender may be due (at least in part) to differences in level of academic preparation. This will be explored in future data analysis that includes a larger sample population of students.

Findings revealed significant differences that are attributed to gender. Females were more likely than males to explicitly write out equations and then plug in values in separate steps ($p = 0.035$), and had a higher occurrence of incorrectly deriving unit ($p=0.002$). Additionally, females' solutions were more likely to indicate the use of lower level strategies such as a "guess and check strategy" ($p = 0.030$) or a "plug and chug strategy" ($p=0.53$) while males' solutions were more likely to indicate the usage of advanced approached such as a "chunking strategy" ($p = 0.048$). Males exhibited a higher level of mastery, as they were also more likely to obtain a correct solution. Full results are shown in Table 1.

TABLE 1: SIGNIFICANT EFFECTS OF GENDER BASED ON REPEATED MEASURES ANOVAS

| Process Analysis Measure | F ratio | p value | Mean (Female) | Mean (Male) |
|----------------------------|---------|---------|---------------|-------------|
| Plugged values in equation | 4.62 | 0.035 | 1.00 | 0.77 |
| Incorrect unit derivation | 10.75 | 0.002 | 0.20 | 0.04 |
| Plug and chug | 5.23 | 0.026 | 0.53 | 0.23 |
| Guess and check | 4.95 | 0.030 | 0.33 | 0.11 |
| Chunking | 4.08 | 0.048 | 0.07 | 0.30 |
| Correct Answer | 13.23 | 0.001 | 0.13 | 0.64 |

The level of academic preparation of minority students was roughly equivalent to that of the remainder of the students. Of the minority students in the study, 75% had calculus experience compared to 78% of non-minority students. Additionally, 25% of minority students had pre-engineering experience compared to 26% of non-minority students. Therefore, it is reasonable to assume that differences found based on ethnicity are not attributable to prior academic experiences of completing a calculus class or participating in a pre-engineering program.

Very few significant results were found based on ethnicity. The only significant findings were that minority students had a larger number of solutions that did not utilize units throughout the problem solving solutions ($p<0.001$) and with correct answers but with incorrect units ($p=0.003$). Full results are shown in Table 2.

TABLE 2: SIGNIFICANT EFFECTS OF ETHNICITY
BASED ON REPEATED MEASURES ANOVAS

| Process Analysis Measure | F ratio | p value | Mean (Caucasians) | Mean (Minorities) |
|-----------------------------|---------|---------|-------------------|-------------------|
| Missing Units Throughout | 15.87 | 0.000 | 0.00 | 0.20 |
| Correct but Incorrect Units | 9.28 | 0.003 | 0.05 | 0.20 |

In terms of prior academic preparation, there were only a few significant findings that supported claims in the literature that pre-engineering programs enhance problem solving performance. There were no significant differences found for success in the classroom overall, or for correct problem solving solutions. Significant differences revealed that differences were mainly based on format of solving problems; students that had pre-engineering experience had a larger number of solutions where they identified prior knowledge ($p=0.018$), documented algebraic steps ($p=0.018$) and explicitly identified their final answers either by boxing in their answer or writing out the conclusion in sentence form ($p=0.030$). Full results are shown in Table 3.

TABLE 3: SIGNIFICANT EFFECTS OF PRE-ENGINEERING EXPERIENCE
BASED ON REPEATED MEASURES ANOVAS

| Process Analysis Measure | F ratio | p value | Mean (With pre-engineering Experience) | Mean (Without pre-engineering Experience) |
|--------------------------|---------|---------|--|---|
| Identify prior knowledge | 5.89 | 0.018 | 0.12 | 0.02 |
| Document math | 5.91 | 0.018 | 0.94 | 0.65 |
| Identify final answer | 4.93 | 0.030 | 0.88 | 0.61 |

A more extensive set of differences were revealed between students based on mathematics preparation as distinguished between students with and without calculus experience. It was revealed that students who had not yet taken a calculus class beyond pre-calculus committed more errors and had more rework than students with calculus experience. Solutions from students without calculus experience were more likely to utilize labeling or renaming ($p = 0.012$), have incorrect unit

TABLE 4: SIGNIFICANT EFFECTS OF CALCULUS EXPERIENCE
BASED ON REPEATED MEASURES ANOVAS

| Process Analysis Measure | F ratio | p value | Mean (With Experience) | Mean (Without Experience) |
|---|---------|---------|------------------------|---------------------------|
| Labeling / Renaming | 6.75 | 0.012 | 0.38 | 0.75 |
| Incorrect unit derivation | 5.94 | 0.018 | 0.04 | 0.19 |
| Incorrect unit assignment | 4.34 | 0.041 | 0.04 | 0.19 |
| Using incorrectly generated information | 4.69 | 0.034 | 0.17 | 0.44 |
| Missing units throughout | 6.74 | 0.011 | 0.00 | 0.13 |
| Correct Answer | 7.61 | 0.008 | 0.62 | 0.25 |
| Correct but Incorrect Units | 6.45 | 0.014 | 0.04 | 0.18 |

derivations ($p = 0.018$), have incorrect unit assignment ($p = 0.041$), use incorrectly generated equations ($p = 0.034$), have missing units throughout the entire attempt ($p = 0.011$), and have answers that were correct but in incorrect units ($p = 0.014$). Similarly, students with calculus experience were more likely to obtain correct answers. Full results are shown in Table 4.

B. Assessment of frequency of use of problem solving features

As a means of validating the results found based on the presence of codes, the same evaluation was conducted based on differences in the frequency of codes. When assessed by frequency of codes, fourteen of the eighteen significant differences remained with eight additional significant effects.

Most differences were found for effects based on gender, with one discrepancy and four additional effects. Based on frequency of use, there was not a significant difference in the number of times males or females plugged values into equations. This may be explained by males iterating through more instances of plugging in values within the same problem than females (eg. trying more combinations of possible solutions.) Additional effects found that females solved for intermediate values more frequently than males ($p = 0.035$), identified more known values, ($p = 0.029$), and identified more errors ($p = 0.006$) though this may be due to committing more error such as more frequently using incorrectly generated information ($p = 0.034$). These additional effects support the results indicating that females showed a tendency of using lower level strategies. Full results are shown in Table 5.

TABLE 5: SIGNIFICANT EFFECTS OF GENDER
FOR FREQUENCY OF USE OF PROBLEM FEATURES

| Process Analysis Measure | F ratio | p value | Mean (Female) | Mean (Male) |
|---|---------|---------|---------------|-------------|
| Solve intermediate values | 4.65 | 0.035 | 3.27 | 2.17 |
| Identify known value | 5.00 | 0.029 | 2.80 | 1.42 |
| Identify errors | 8.17 | 0.006 | 6.20 | 3.87 |
| Incorrect unit derivation | 10.75 | 0.002 | 0.20 | 0.04 |
| Using incorrectly generated information | 4.70 | 0.034 | 0.80 | 0.32 |
| Plug and chug | 5.23 | 0.026 | 0.53 | 0.23 |
| Guess and check | 4.95 | 0.030 | 0.33 | 0.11 |
| Chunking | 4.09 | 0.048 | 0.07 | 0.30 |
| Correct Answer | 4.51 | 0.038 | 0.33 | 0.85 |

Only one additional significant effect was revealed based on ethnicity with no discrepancies; minority students more frequently assigned units incorrectly ($p=0.030$). This finding also supports the original analysis by revealing another significant effect related to the use of units. Full results are shown in Table 6.

TABLE 6: SIGNIFICANT EFFECTS OF ETHNICITY
FOR FREQUENCY OF USE OF PROBLEM FEATURES

| Process Analysis Measure | F ratio | p value | Mean (Caucasians) | Mean (Minorities) |
|-----------------------------|---------|---------|-------------------|-------------------|
| Incorrect unit assignment | 4.93 | 0.030 | 0.07 | 0.30 |
| Missing units throughout | 15.87 | 0.000 | 0.00 | 0.20 |
| Correct but incorrect units | 9.27 | 0.003 | 0.05 | 0.20 |

For students with pre engineering experience, there was one discrepancy and one additional effect uncovered. While the relationship to documenting math was not evident when assessed based on frequency, it was revealed that students with pre-engineering experience more frequently ignored problem constraints ($p=0.004$). While this finding is surprising, it reiterates that pre-engineering experience does not ensure that students' solutions will be procedurally or conceptually correct. Full results are shown in Table 7.

TABLE 7: SIGNIFICANT EFFECTS OF PRE-ENGINEERING EXPERIENCE
FOR FREQUENCY OF USE OF PROBLEM FEATURES

| Process Analysis Measure | F ratio | p value | Mean (With Experience) | Mean (Without Experience) |
|-----------------------------|---------|---------|------------------------|---------------------------|
| Identify prior knowledge | 5.90 | 0.018 | 0.18 | 0.02 |
| Identify final answer | 6.54 | 0.013 | 1.29 | 0.76 |
| Ignored problem constraints | 8.77 | 0.004 | 0.47 | 0.10 |

For students with calculus experiences, significant effects for labeling / renaming and incorrect unit assignment disappeared when assessed by frequency; however, two additional significant effects of calculus experience emerged. Students without calculus experience both erased work ($p = 0.024$) and identified errors ($p = 0.003$) more often than students with calculus experience, though this may be due to the higher frequency of specific errors. Therefore, these results also support the original analysis. Full results are shown in Table 8.

TABLE 8: SIGNIFICANT EFFECTS OF CALCULUS EXPERIENCE
FOR FREQUENCY OF USE OF PROBLEM FEATURES

| Process Analysis Measure | F ratio | p value | Mean (With Experience) | Mean (Without Experience) |
|---|---------|---------|------------------------|---------------------------|
| Erasing work | 5.33 | 0.024 | 1.33 | 2.53 |
| Identify errors | 9.67 | 0.003 | 3.71 | 6.41 |
| Incorrect unit derivation | 6.46 | 0.014 | 0.03 | 0.18 |
| Using incorrectly generated information | 5.26 | 0.025 | 0.27 | 0.88 |
| Missing units throughout | 5.74 | 0.020 | 0.00 | 0.12 |
| Correct Answer | 6.16 | 0.016 | 0.86 | 0.35 |
| Correct but Incorrect Units | 5.69 | 0.020 | 0.04 | 0.18 |

IV. DISCUSSION

This analysis revealed several significant differences in how students solve problems and revealed that differences of male gender and calculus experience were related to a higher probability of successful problem solving attempts, though none of the populations tested showed significant difference in terms of overall course grade.

While course grades did not indicate a difference in achievement between male and female students, females seemed to struggle with problem solving more than males. Solutions completed by females were more likely to contain instances of incorrectly derived units and lower level strategies to approach the problems and solutions completed by males were more likely to result in a correct final answer. Units seemed to present more problems for students who did not have calculus experience (with more instances of incorrect unit assignment, missing units throughout, and having answers with incorrect units) and minority students (with more instances of missing units, and answers with incorrect units). However, it seems that females and students without calculus experience are at least aware of their performance deficiencies, as both had a higher frequency of identifying errors.

Therefore, this analysis revealed some targeted needs of specific student populations within this particular first year engineering course. While these results do have similarities to those found in the literature, these results are not necessarily generalizable to the entire population of first year engineering students. However, other instructors could utilize the methodology described in this paper as a means of identifying areas of instructional needs of students in their own classes.

V. CONCLUSIONS

This study supports current literature that shows significant differences based on gender in terms of how students approach problem solving, and supports the literature that shows a lack of significant differences in how students from different ethnic backgrounds solve problems (with the exception that students in this particular group struggled with consistent use of units). While research conducted on middle school students showed that minority students struggle with non-routine problems, this was not evident in this study. It is possible that engineering students (or at least the engineering students that participated in this study) have strengthened their problem-solving skills through advanced mathematics courses. Future research will investigate the interconnectivity of predictor factors using regression models to control for certain effects (such as gender and ethnicity) while exploring the impact of academic preparation.

The results of this study suggest that while academic preparation in the form of pre-engineering experience significantly influences how students solve problems, it did not indicate a significant impact of the probability of success in this course overall or in successfully solving problems. However, academic preparation in the form of previously completing a calculus class (but not necessarily grade) was associated with successful problem solving. This brings into question whether

there is something about going through a calculus class that has bearing on problem solving success, such as a familiarity with conducting more complicated sets of procedures, or whether it is the students' natural mathematical abilities that have enabled them to get into a calculus class at an earlier age that has the greatest impact. Future analyses will compare results of a mathematics placement test that is given to all incoming freshmen at our institution in order to test whether mathematical skill level is a better predictor of success than the highest level of mathematics course completed.

Future research will also expand the study population to a larger sample of first year engineering students across multiple semesters, identifying key strategies that are absent for students with low mathematics preparation, and to investigate relationships between prior academic preparation and indicators of metacognition.

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Understanding Industry Experiences: From Problem Solving to Engineering Students' Learning Gains

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Abstract— This paper reports the findings from surveying a diverse group of undergraduate engineering students (N~100) who participated in summer industry experiences. The goal was to capture and understand (a) the nature of industry experiences and (b) students' learning outcome gains (cognitive and affective) during these industry experiences. Ultimately, we aim to understand how students learn in real-world problem solving contexts in order to transfer such learning and such experiences into the engineering classroom. In undergraduate curriculum, well-structured problems with known solutions acquired through preferred solution methods are encountered more frequently than ill-structured problems. The linear process of problem solving teaches students a procedure to be memorized, practiced, and habituated, a process that emphasizes getting answers over making meaning. Real-world problem solving, though, commonly encountered in industry experiences suffused with complex and ill-structured problems, foster cognitive development of essential, problem-based, and globally competitive problem solving skills. Although industry experiences offer many benefits and enable engineering students to begin the practice of solving real-world complex problems, there is limited research on students' learning outcomes and skill gains as a result of participating in such experiences. Further, there is a lack of understanding of characteristics of the problems or projects that students work on. Our research serves to address these limitations.

Keywords- Industry Experience; Complexity; Structuredness; Complex problem solving

I. INTRODUCTION

Industry experiences, which are highly promoted and supported by Corporations and other agencies, offer many benefits for our students and present a great opportunity for them to learn essential and globally competitive skills. Benefits include: (a) gaining real-world experience in professional engineering environments; (b) having the opportunity to apply skills and knowledge learned in the classroom to real-world problems; (c) working with state-of-the-art processes, equipment, and tools; (d) learning how to work in teams in a professional atmosphere and improving communication skills; (e) developing self-confidence and a positive attitude about future career options; and (f) improving their opportunities for post-graduation jobs. Employers can also benefit from the arrangement by hiring high-performance individuals. Industry experiences not only provide meaningful practice for engineering students, but also deepen a student's understanding of the profession and the workplace. Our overarching research

goal is to understand *what students learn* during industry experiences as a means of also understanding *how students learn* and *how they use and transfer complex problem solving skills* in new settings. Our goal is to capture and understand both (a) the nature of industry experiences in regards to problem solving and (b) the students' learning outcome gains (cognitive and affective) during these industry experiences. Industry experiences can vary widely depending on the work a student is assigned, however, analysis of the typical project stages and overall project difficulty (in terms of complexity and structuredness of the project) allow aggregate data to be collected and comparison of different industry experiences. Complexity gives us insight into the cognitive load imposed on the problem solver and takes into account the required domain knowledge to solve the problem, the intricacy of the solution path, and the depth of integration of varying domains [1]. Structuredness pertains to how well a problem is defined or identified as well as how well the problem solving process is structured in terms of the methods and analysis used [1]. The research questions guiding this effort were:

(1) *What is the nature of (industry experiences) in regards to complexity and structuredness?*

(2) *What are engineering students' learning outcomes during industry experiences?*

In addressing these questions, we hope to not only contribute to our understanding of industry experiences, but also measure what students are learning during an industry experience. Having developed a pre and post industry experiences survey, comprised of both qualitative and quantitative items, we collected data to better understand the layers of problem solving of industry experiences, the structuredness and complexity of such experiences, as well as students' learning outcome gains. By understanding these real-world and authentic experiences, we hope to gain insight into translating the cognitive and affective learning gains offered by industry experience into pedagogical practice at the undergraduate level [2,3].

Empirical and anecdotal evidence supports that industry experiences benefit students in a concrete manner [4], however instruments and knowledge of the outcomes acquired, and to what degree, is still understudied. Researchers at Kettering University developed an instrument that includes questions assessing the extent to which a cooperative education experience aligns with the Engineering Criteria (EC2000)

outcomes as well as questions about the company, and the supervisor [4]. The results support the multi-faceted benefits of cooperative education with 7 of the 11 outcomes having a response over 80% [4]. In a similar vein, researchers at Virginia Tech developed and implemented National Engineering Students' Learning Outcomes Survey (NESLOS), also derived from ABET a-k criteria, to understand how cooperative experiences help to make better engineers. [5]. The survey categorized outcomes by technical, professional, and personal, and revealed that the industry experience resulted in student growth in all three areas. Although some studies have looked into the overall positive impact (such as earnings and grade point average) of industry experiences [6-8], the bodies of knowledge and learning outcomes from being involved in industry settings have been insufficient. Our research serves to address this limitation.

II. METHOD

A. Theoretical Framework

A systematic and integrated analysis of industry experience problems was undertaken through application of the theoretical conceptualization of problem difficulty by [1]. The hierarchical structure of problem difficulty is comprised of two subcategories: 1) problem structuredness and 2) problem complexity. Structuredness encompasses the interdisciplinarity, dynamicity, heterogeneity of interpretations, number of unknowns (intransparency), and number of viable solution paths for the problem (competing alternatives) [1]. Structuredness is a dimension that measures how well a problem is defined or identified and how well the problem solving process is structured in terms of the methods and analysis used. Complexity encompasses the breadth of knowledge, attainment level of domain knowledge, relationally complex thinking (relational complexity) and intricacy of the path taken to arrive at a solution [1,9,10]. Complexity is a dimension that looks into the required domain knowledge to solve the problem, the intricacy of the solution path, and the depth of integration of varying domains. In a sense, complexity lets us gain insight into the cognitive load imposed on the problem solver, whereas structuredness relates to the depth of the problem itself that the problem-solver must understand.

B. Item Development and Data Collection

The theoretical framework outlined above guided the development of the survey items to capture and understand (a) the nature of industry experiences and (b) students' learning outcome gains (cognitive and affective) during these industry experiences. The items were developed by members of an interdisciplinary research team comprised of experts in engineering, engineering education, psychology, and measurement. Two of these research team members also had engineering industry experience.

Items on the survey were designed to address problem difficulty parameters and student learning outcomes. A total of 11 items were developed and administered to understand the complexity and structuredness of industry experiences. **Table I** presents the type of survey items used to measure each problem difficulty parameter. Seven questions assessed complexity and

four questions assessed structuredness. The survey included a mix of both Likert scale and open-ended items, allowing for qualitative (QUAL) and quantitative (QUAN) data, and thus offsetting the limitations inherent in both. In this paper we only present quantitative data. The NESLOS survey [4] was used to capture students' self-evaluation of their learning during an industry experience. Overall, the survey emphasizes assessing perceived knowledge and skills of: (1) problem-solving, (2) writing and communication, (3) teamwork, (4) organization and project management, (5) science, technology, engineering and math, and (6) interest and engagement in the project. Additionally, the NESLOS data are mapped to the ABET a-k criteria to demonstrate how the industry experience met accreditation objectives. The resulting survey instrument went through several iterations before administration. A concurrent nested strategy commonly used in mixed-methods research [11] was employed in this study. This strategy allowed for interpreting both types of data simultaneously in a single research study.

TABLE I. MAPPING PROBLEM DIFFICULTY PARAMETERS TO ITEM TYPE

| Problem Difficulty Parameters | | Item Type |
|-------------------------------|---|------------|
| Complexity | Breadth of Knowledge | QUAL |
| | Attainment of Domain Knowledge | QUAN |
| | Intricacy and Relational Complexity | QUAN |
| Structuredness | Dynamicity, Heterogeneity, Intransparency, Competing Alternatives | QUAN, QUAL |
| | Interdisciplinarity | QUAL |

Students who participated in a 2011 summer internship took the online survey shortly after completing their internship. The results from the quantitative post-internship survey items pertaining to problem characteristics (difficulty and complexity) and perceived cognitive and affective gains, are presented in the current study. Participant identifier information could not be collected to ensure participant anonymity.

C. Student Participants

Of the 107 students who participated in a summer 2011 internship industry experience, the following backgrounds were represented: engineering (N = 97), technology (N = 6), science (N = 8), other (N = 1) (Note that students could select more than one discipline). The majority of students were rising seniors (N = 70). The remaining students were rising juniors (N = 19), rising sophomores (N = 5), and first year graduate students (N = 9). There was also one third year graduate student, one Ph.D. student, and one international student.

Out of 77 participants who provided their gender, 50 (65%) were male and 27 (35%) were female. Out of 77 students who provided their ethnicity information, 71 (92%) were Caucasian, 4 (5%) were Asian-American, 2 (3%) were African-American, and 1 (1%) was Native-American. Out of 77 students who self-reported their GPA, 15 (19%) had an A (4.0) average; 29 (38%) had an A- (3.7) average, 22 (29%) had a B+ (3.3) average, 8 (10%) had a B (3.0) average and 3 (4%) had a B- (2.7) average.

III. RESULTS AND DISCUSSION

In this section, our focus is on understanding the nature of industry experiences and what students learn during industry experiences. More specifically, we aim to better understand these experiences through the lens of problem structuredness and problem complexity. Data analysis of the quantitative items was aggregated and descriptive statistics were tabulated and graphed to facilitate interpretation.

A. Complexity and Structuredness of Industry Experiences

We begin examining the complexity of industry experiences by addressing the breadth of knowledge required to work on and solve such problems. The next set of survey items were designed to give us insights into the intricacy and relational complexity of industry experiences. More specifically, we wanted to decompose the typical project completion process to gain insight into the intricacy of the solution path length and the relational complexity of the process. The following seven major stages of an industry experience project defined by the research team are:

- Identifying and understanding the project
- Establishing project goals, requirements, and constraints
- Coordinating resources to complete project tasks
- Gathering information or collecting data to complete project tasks
- Analyzing results and making conclusions or recommendations
- Managing the project (planning, timelines, budgets)
- Documenting (technical reports and presentations)

Utilizing these seven stages, Likert scale items were included in the survey and were focused on measuring the perceived percentage of time that students spent on each of the project stages, the degree to which these stages were defined for the students, as well as the inherent difficulty of conducting each project stage. The results from the items related to percentage of time that students spent on each of the project stages are summarized in **Fig. 1**. It is evident that the students spent half of their time on three stages: collecting data, analyzing results and making conclusions, and identifying the project. These numbers align with expectations of interns who are treated as trusted members of a team. Tasks that students spent less time on were likely those they received help with. The project stage that students seemed to spend the least amount of time on was project management.

In regards to students' ratings of difficulty of conducting the seven project stages, based on a scale of 1 to 10 (1 – very easy to 10 – extremely difficult), we observed from **Fig. 2** that students' overall mean ratings varied from 3.78 to 5.47 (sd ranged from 2.06 to 2.41). The three project stages with the highest difficulty ratings, all above 5, were collecting data, analyzing data and making conclusions, and coordinating resources. The data in **Fig. 2** correlates to reported time spent in each project stage. Stages perceived as less difficult are

where students spent less time. Stages perceived as the most difficult are where students spent most of their time. The three stages in between, documenting, coordinating resources, and identifying the project, were likely not difficult on a conceptual level but required time to learn company procedures and policies, thus taking a moderate amount of time.

Another survey item that provided insight into the complexity of an industry experience asked students to rate on a scale of 1 to 10 (1 – not at all challenging to 10 – very challenging) how challenging the industry experience was overall. Student responses to this survey item are summarized in **Fig. 3**. Overall, the data revealed that the mean rating for all students was 6.81 (sd = 1.62), with about 73% of the students giving a rating of 6 or above (i.e., challenging range); these results suggested that industry experience was perceived as a rather challenging experience for students. Qualitative responses, not shown here for brevity, confirm that students perceive the industry experience to be challenging but also rewarding.

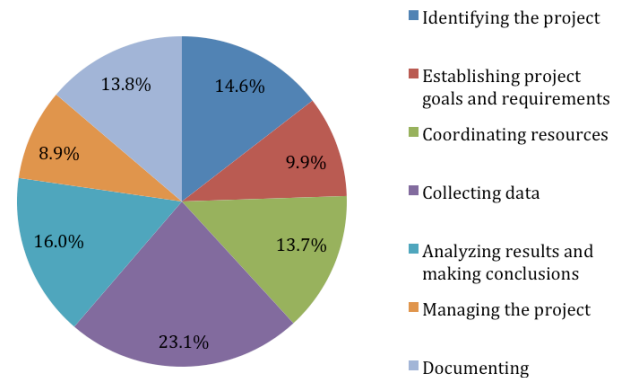


Figure 1. Percentage of time spent on each project stage ($N = 85$).

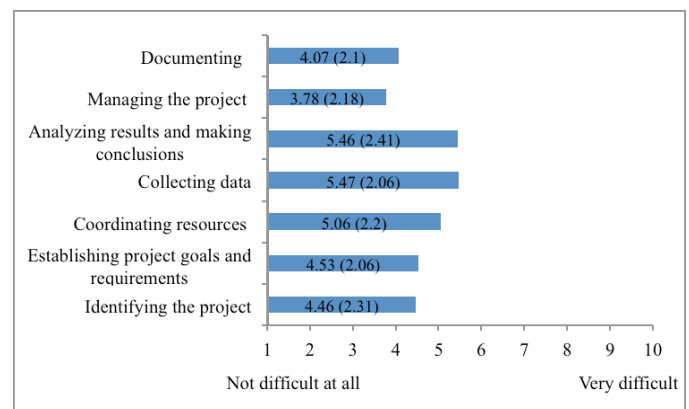


Figure 2. Bar chart of students' mean ratings (standard deviations) of how difficult each of the project stages were ($N = 81$).

The categories of structuredness are coupled in many ways, particularly dynamicity, intransparency, heterogeneity, and competing alternatives (as shown in **Table I**), therefore it was very difficult to operationalize these into survey items that capture each parameter individually. However, multiple survey items, Likert scale and open-ended, were developed to provide insights about the structuredness of industry

experiences. We begin examining the structuredness of industry experiences by examining how well the project stages are defined or identified.

Students were also asked to rate how well-defined each of the seven project stages was on a scale of 1 to 10 (1 – not well-defined at all and 10 – extremely well-defined). Descriptive statistics (mean values and standard deviation) are summarized in **Fig. 4**. Students’ mean ratings varied from 5.88 to 6.91 (sd range from 2.30 to 2.88). From the data we can estimate the percentage of students who gave a rating of 6 and above (i.e., well-defined range) in comparison to students who gave a rating of 5 and below (i.e., ill-defined range). From this estimation, we observe that the majority of students (73%) rated the project stages to be in this well-defined range (6 or above). These results suggest that not only were all seven project stages rated fairly consistently (i.e., one project stage did not appear to be more well-defined than another), but that overall these stages were fairly well-defined for the students. Internships, which are typically offered during the summer months and can range from 8-12 weeks in length, provide short-term projects for students to work on. As student participants are seen as interns, projects and tasks given are generally expected to be more structured or well-defined than ill-structured allowing for more time to be devoted to practical application of engineering concepts.

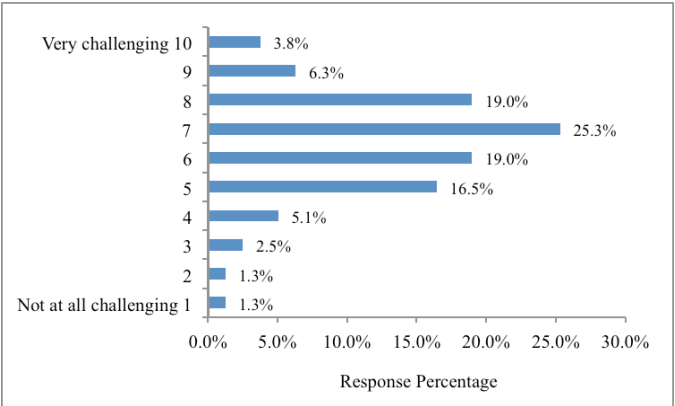


Figure 3. Response percentage for survey items pertinent to challenge of the Industry Experience (N = 79).

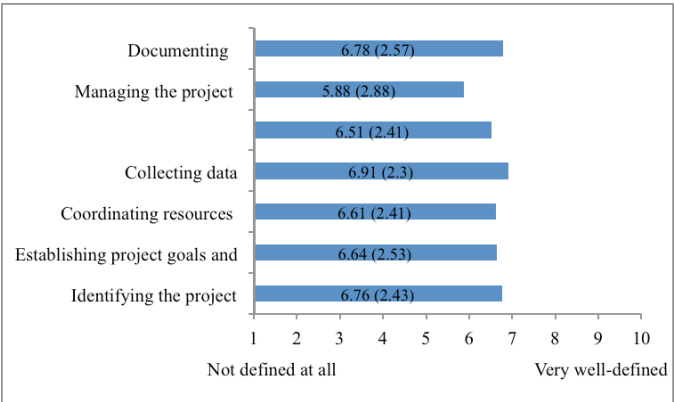


Figure 4. Bar chart of students’ mean ratings (standard deviations) of how defined each of the project stages were (N = 85).

Further, **Table II** shows the data from four survey items that gave us insight into the complexity and structuredness of the problem solving process during the industry experience. The first four items listed speak to the complexity of the problem solving process and the results suggest that about 83% of the students perceived the amount of knowledge and skills that needed to be gained to complete their projects was substantial, but the difficulty of this knowledge and skills was about average. There were also four items, designed to capture the dynamicity and intransparency of the solution path, pertaining to structuredness of the problem solving process. These results suggest that a good amount of the knowledge and skills that needed to be gained to complete the project was provided and also a good amount of instruction on the steps and path to complete the project were also provided to the students. Overall, these results suggest that although students perceived the problem solving process during industry experiences to require a substantial amount of knowledge and skill gains (i.e., requiring a substantial amount of cognitive load), students also perceived that there was a good amount of direction and instruction on these knowledge and skill gains. The problem solving process in industry projects seems to be quite complex, but also somewhat structured. For engineering interns or even entry-level engineers, this model seems to be appropriate.

B. Cognitive and Affective Learning Gains During Industry Experiences

In regards to learning outcome gains, NESLOS was used to assess over fifty learning outcomes relevant to problem solving. **Table III** shows the top ranked learning outcomes based on 70% of the students rating the learning outcome with a response of 4 (correlating to *More than adequate ability*) or a response of 5 (correlating to *High ability*). Responses of 4 and 5 are desirable as they further support the benefits of an industry experience. The results show that the highest learning outcomes for students pertained to: (1) oral and writing communication skills (ABET criteria g); (2) personal growth (confidence, intellectual growth, taking ownership of learning, leadership) (ABET criteria i, f); (3) applying computational, numerical, and experimental tools (ABET criteria k); (4) applying engineering design skills (ABET criteria c); (5) understanding the global and societal impact of engineering solutions (ABET criteria h); (6) collaborating with others and effectively working in a team (ABET criteria d); (7) solving engineering problems (ABET criteria e). Overall, it is evident from these results that students have substantial learning gains as a result of participating in industry experiences. It is interesting that the findings are representative of the skill set that Corporations are looking for in engineer hires.

Students were also asked to reflect on the STEM and other (i.e. affective) knowledge they had prior to the industry experience and the knowledge gained through participating in the experience. **Table IV** illustrates students’ responses to the questions asking them to evaluate the extent of knowledge in the STEM areas before and after the industry experience, as well as the difficulty of that knowledge. An additional

question asked students to evaluate the extent of other or additional skills knowledge before and after the industry experience. The knowledge category of other allows for the measurement of affective learning gains, which include personal and professional topics such as technical writing and presentation, project management, teamwork, learning, and decision making. A scale of 1 to 10 (1 – none and 10 – Extreme Amount) was used. The results suggest gains in knowledge across all measured areas. The highest of these is engineering knowledge. This aligns with expectations as students are working on new projects that require application

of prior knowledge as well as synthesis of field or new engineering knowledge. The second highest gain is other knowledge, which further reinforces that real-world problems, such as an industry experience, do lead to affective learning gains. In terms of knowledge difficulty, engineering knowledge appeared to be the most difficult and mathematics knowledge appeared to be the least difficult. These results suggest that industry experiences do indeed challenge students to not only apply knowledge they have gained during their undergraduate careers, but also to continue learning and gain new knowledge in multiple areas.

TABLE II. RESPONSE TO ITEMS CHARACTERIZING THE PROBLEM SOLVING COMPLEXITY AND STRUCTUREDNESS OF THE INDUSTRY EXPERIENCE

| Survey Items | N | Likert scale | Mean | % Response of 4 or 5 |
|--|----|--|------|----------------------|
| Items pertaining to project complexity (a higher rating implies more complexity) | | | | |
| How much knowledge and skills did you have to gain to complete the project tasks during your Industry Experience (IE)? | 79 | 1 – “None” to 5 – “A lot” | 4.13 | 83% |
| How difficult was this knowledge and skills that you had to gain to complete the project tasks during your IE? | 79 | 1 – “Very Easy” to 5 – “Very Difficult” | 3.10 | 23% |
| How many ways could the project tasks be completed during your IE? | 79 | 1- “Very Few” to 5 – “Many” | 3.11 | 45% |
| How difficult were the steps or path to complete the project tasks during your IE? | 79 | 1 – “Very Easy” to 5 – “Very Difficult” | 3.11 | 27% |
| Items pertaining to project structuredness (a higher rating implies more structure) | | | | |
| How much of the knowledge and skills needed to complete the project tasks were provided during your IE? | 79 | 1 – “None” to 5 – “A lot” | 4.16 | 67% |
| How defined or explicit were the knowledge and skills needed to complete the project tasks during your IE? | 79 | 1 – “Very Defined” to 5 – “Very Undefined” | 2.81 | 83% |
| How much instruction on the steps or path to complete the project task did you receive during your IE? | 79 | 1 – “None” to 5 – “A lot” | 3.58 | 46% |
| How defined were the steps or path to complete the project tasks during your IE? | 79 | 1 – “Very Defined” to 5 – “Very Undefined” | 2.87 | 84% |

TABLE III. DESCRIPTIVE STATISTICS FOR NESLOS BY A-K ABET CRITERIA (N = 78).

| NESLOS Learning Outcome | ABET a-k Criteria |
|--|-------------------|
| Convey ideas verbally and in formal presentations | g |
| Demonstrate strong leadership skills | i |
| Demonstrate confidence in oneself | i |
| Convey technical ideas in formal writing and other documentation | g |
| Apply computational and numerical tools (e.g., programming, modeling and simulation software) to solve engineering/scientific problems | k |
| Collaborate with others when working on engineering/scientific projects | d |
| Take new opportunities for intellectual growth or professional development | i |
| Recognize intrinsic interest in learning/intellectual curiosity | i |
| Generate multiple and alternative solutions/concepts | c |
| Understand the impact of engineering solutions in societal and global contexts | h |
| Demonstrate strong organizational skills | f |
| Formulate and justify the need and relevance of a problem or project | e |
| Apply experimental tools (e.g., machining, instrumentation) to solve engineering/scientific problems | k |
| Demonstrate originality and independent thinking | i |
| Set and pursue her/his own learning goals | i |
| Design a product, process, or system to meet desired needs | c |
| Recognize contemporary scientific, engineering, and technology issues | j |
| Recognize knowledge transfer between real-world engineering/scientific problems and coursework | h |
| Reach beyond oneself (challenge himself/herself to new limits) | i |
| Effectively manage conflicts that arise when working on teams | g |
| Recognize the need for lifelong learning | i |

TABLE IV. EXTENT TO WHICH PARTICIPANTS POSSESSED KNOWLEDGE IN THE STEM AREAS

| | Average Rating of Knowledge Possessed (St. Dev.) | | | Difficulty of Knowledge (St. Dev.) | N |
|--------------|--|----------------|--------|------------------------------------|----|
| | Before IE | After IE | % Diff | | |
| S | 6.26 (1.93) | 7.93 (2.00) | 27% | 5.22 (2.21) | 27 |
| T | 6.13 (2.01) | 7.87 (1.63) | 28% | 5.4 (2.35) | 45 |
| E | 5.81 (2.22) | 8.02 (1.41) | 38% | 6.16 (2.02) | 63 |
| M | 8.19 (1.97) | 8.52 (1.89) | 4% | 3.81 (2.14) | 48 |
| Other | 6.04 (2.40) | 8.24 (1.38) | 36% | 5.37 (2.64) | 49 |

IV. CONCLUSION

In this paper, industry experiences were investigated to gain insight into the nature of such experiences in regards to complexity and structuredness, as well as to gain insight into students' perceived learning gains. The hope is that this research can aid engineering educators in understanding real-world engineering practice from industry and translating such practice into the engineering classroom. Our findings indicate that industry experiences:

- engage students to continuously learn new knowledge and skills. The dynamically changing learning environment challenges students, but also enables them to learn important problem solving skills.
- are moderately structured with most of the project steps being well-defined, but most project stages are still considered to be challenging to very challenging.
- enable students to apply STEM knowledge, but also gain a substantial amount of new STEM knowledge. This is especially true for engineering knowledge.
- enable students to grow technically, cognitively and affectively through the practice of multiple cognitive operations in the context of a continuously changing and dynamic team environment.
- involving a significant amount of teamwork and mentorship were important factors in a successful project and experience.

Our motivation was to understand the nature of industry experiences as a means of translating and integrating real-world problem solving into the classroom. Problem based learning pedagogies can serve as the framework for this transferability. According to educational researchers [8], classroom problem-based learning experiences should be ill-structured with a moderate degree of structuredness, authentic by being contextualized to real-world workplace settings, complex enough to be challenging and engaging to students' interests, adapted to students' cognitive development and prior knowledge, and amenable to problem examination from multiple perspectives. Industry experiences do in fact meet these criteria for ideal classroom problem-based learning experiences.

Future work includes analysis of qualitative responses via thematic coding, triangulation of qualitative and quantitative data, and analysis of team and mentor data. Open-ended and Likert scale items related to teamwork and mentorship will be analyzed for correlations to project complexity and structuredness as well as student learning gains. We expect that classification of real-world industry-based problems will lead to an understanding and characterizing of complex problem solving domains and processes. Once further analysis is complete recommendations for transferring real-world complex problem solving (based on industry problems) in engineering undergraduate and high school courses as well as K-12 outreach settings will be made.

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Work in Progress: Outreach Assessment: Measuring Engagement

An Integrated Approach for Learning

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Abstract— The Learn By Doing Lab (LBDL) at Cal Poly, San Luis Obispo is an on-campus laboratory where 5th through 8th grade students are taught by undergraduates who may be planning a careers in teaching. The two populations - elementary students and undergraduates - are equally important in the process. Since 2008, the lab has seen over 4000 elementary and junior high students and over 100 undergrads have participated. In most outreach assessment the number of individuals participating is an important metric, but this last Spring we experimented with a more in depth measure of effectiveness. As in any learning experience engagement in the process is an essential ingredient. Although there are several methods of measuring engagement, we chose to observe the activity of the participants as a proxy for engagement. Two industrial engineering (IE) undergraduates who themselves have been exposed to the topics of work sampling and observation studies had an opportunity to improve professional skills through this application. This involvement of undergraduates is consistent with the LBDL and Cal Poly's motto of "learn by doing." These two students, who are also co-authors, spent multiple hours coding and randomly sampling the of the elementary and junior high students as well as the undergraduate teacher's activities. Not only did the IE students discover important insights for the LBDL they also learned how to apply work sampling in a research setting. This paper discusses the integrated learning environment and the next steps involved in these undertakings.

K12 outreach; observational studies; integrated leaning

I. INTRODUCTION

A quandary in K12 outreach activities is the effectiveness of the events. Whether it is a hands-on laboratory like we have at Cal Poly or informal science activities, the effectiveness is often measured by the number of individuals participating [1,2]. Sometimes there is a self-report survey given, but the reliability and validity of such instruments is hard to determine. We tried an observational method that has been used successfully in other educational settings [3].

Initially we wanted to explore the observational method to see if any insights could be gained regarding student learning or the design of the activities. We also thought this could be used in other educational settings. As we explored this method it seemed similar to "work sampling" [4], a method of determining time standards in the Industrial Engineering (IE) practice. Students in our IE program are exposed to this technique but the chance to practice this method is limited. Given this, we recruited two students (co-

authors on the paper) to help develop the assessment method as a work sampling task.

There are two groups of interest in the LBDL. The first is the K12 students (we refer to these as "K12 students") who visit the lab and the second group is the college students (we refer to this group as "TA's") who take the class to explore the possibility of a career in teaching. Both of these groups were observed.

As we progressed we saw that there were actually three goals of this study. As we initially desired, the first goal was to measure engagement in the outreach activity for both the K12 students and the TA's. The second was to practice this method of assessment so we could use it in other settings. The third goal was to provide an opportunity for IE undergraduates to hone their skills in a technique used in their field. This paper starts with a brief description of the LBDL activities and then discusses the three goals. We also will touch on the unique integrated nature of this study.

II. DESCRIPTION OF THE LBDL ACTIVITIES

The LBDL is an on-campus laboratory where 5th through 8th grade students are taught by undergraduates who may be planning careers in teaching. Since 2008, the lab has seen over 4000 elementary and junior high students and over 100 undergrads have participated. The activity in this specific study involves the building and testing of a wind turbine. TA's begin the one hours session with a short discussion about engineering practice. The TA's then work with small groups of K12 students to develop an efficient wind turbine. The turbines are tested using a fan to determine the blade configuration (i.e., size, shape, and pitch) that generates the maximum voltage. Students are encouraged to test and adjust. The activities are repeated twice a day with a different group of K12 students. A successful activity has students talking and testing in a fun active environment.

III. WORK SAMPLING AND OBSERVATION STUDIES

Work sampling is a technique used by IE professionals to determine work content. The study is designed using random samples and statistical analysis to determine the approximate rate of occurrence of the activities. The output from the technique is a statistically confident definition of proportion of occurrences. This is very similar to the engagement observation studies described in the literature.

A. Reflection by the IE Students

“Learning the concepts of work sampling within lecture was quite different from applying it to the Learn by Doing Lab. The objective and procedure to obtain results were given to us in our courses, but in the LBDL there weren’t predefined procedures for work sampling. As a team of two, we discussed the best ways to record data, observe the subjects, and analyze the information. This freedom worked positively in allowing us to fortify our previous knowledge of work sampling and statistical analysis. The research was truly a “Learn by doing” example as it allowed us to test our proposed research methods and learn what worked and what did not. Seeing the material in lecture is one thing, but being responsible for the research and observation was truly beneficial for me. Before, my knowledge was adequate, but now I feel much more comfortable in applying my skills to real world situations. I can see that work sampling cannot only be applied in factories, but really in any situation.”

B. Next steps

The transfer of knowledge from lecture to research activity, in this case the LBDL, was a valuable experience. We plan on having undergraduate students to participate in this type of research activity in the future. There are many areas of observations that are of interest and knowing how this helped the students more thoroughly understand work sampling technique encourages us to use it in the future.

IV. OBSERVATION TO MEASUREING ENGAGEMENT

To define the observational categories we spent time watching activities. This lead to five different categories for the TA’s: Working, listening, interacting, traveling and idle. For the K12 students three categories were used: Working, focused watching, and idle. We set up a schedule of random observations for a total of between 15 and 20 observations during the two hours of activities each week. There were between 12 and 16 TA’s each day and between 30 and 40 K12 students. It was important to take the observations in a random fashion to maximize statistical validity. The data was collected and analyzed for insight into the activities.

A. Reflection

Several insights came from the studies. First the process of observing is not straightforward. We had to make adjustments in the process after the first week. The categories were initially not defined with enough detail. In addition tracking all subjects was difficult. In hindsight having two observers scoring and tracking, would have helped the validity of the study. We considered video taping the labs for both a visual record and for validation of observational judgments.

B. Next steps

As we continue to develop these studies we will have two individuals observe and score the subjects. Although it might be ideal to videotape and watch the videos to develop scores, it would make this tedious activity even more so and we feel the interest level for the researcher would fall.

We are using these observational techniques for other studies on engagement, including a random study of classroom activities across campus and in studies that contrast innovative teaching to traditional lecture.

V. EFFECTIVENESS OF THE LBDL ACTIVITES

The observational studies themselves lead to several insights into the outreach activities. In order to statistically test the comparisons we ran Chi-Square goodness of fit tests. All reported differences had a $p=.001$ of lower, but we would feel more comfortable if we had had multiple observers to validate the observations.

A. Reflection

- The younger K12 students spent more time watching while the older students spent more time working
- The second group of K12 students each day had higher proportions of working. This may have been due to a kind warm-up or practice for both K12 students and TA’s.
- The lower ratio of K12 student to TA’s the higher the proportion of working time.
- When there were more females in a group the group spent more time working.
- The TA’s were noticeably more active in the activity when the children were younger probably because more explaining was necessary.

B. Next Steps

As we refine our ability to observe the insights gained will help to develop more effective outreach activities.

VI. CONCLUSIONS

The LBDL provided an exceptional place for us to practice aspects of integration. We integrated the IE student’s curriculum into an observational study on engagement in order to develop insights into activities that help engage K12 student interest in STEM activities. As we progress in our practice in these areas we believe we will be able to develop effective measure of engagement while encouraging technique development through educational research.

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Development of a Design Task to Assess Students' Understanding of Human-Centered Design

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Abstract— *In this paper, we describe our process for creating a design task to assess students' understanding of human-centered design. The development process involved conducting a series of pilot tests, with analyses of the data from each prior pilot motivating revisions made to the next versions of the assessment design task. This paper is a formative look at the seven iterations of the design task that have been administered. We will discuss the information we gained about the students' understanding and the design task itself and how it informed the revisions. We will also discuss student perceptions of the design task, features of the design task that helped or hindered eliciting, and capturing, the participants' design process and major breakthroughs in the task development process.*

Keywords—assessment; human-centered design; design task

I. INTRODUCTION

Developing a human-centered approach to design is vital to appropriately preparing graduates for the globally competitive workplace. The National Academy of Engineering's report on the Engineer of 2020 challenges engineering educators to consider both the demands currently being placed on our recent engineering graduates, and the world in which they will practice [1]. Human-centered design (HCD) has been shown to increase productivity, reduce errors, reduce training and support costs, improve people's acceptance of new products, enhance companies' reputations, increase user satisfaction and reduce development costs [2,3]. One of our concerns is the process of teaching HCD and the assessment of the student learning. An important facet of education is assessment; it allows instructors to provide feedback to students on their learning. To this end, we are creating a design task to assess students' knowledge about, skills in doing, and feelings toward HCD. This assessment tool could be used not only by instructors, but also by researchers to plot out the turning points in students' understanding of HCD over time as well as to investigate the impact of various pedagogical interventions. However, in order to create a valid assessment of students' understanding of HCD, it is important to begin with a theoretical understanding of the construct we want to assess [4]: in this case, HCD.

Our theoretical understanding of our construct, human-centered design (HCD), is based in what has been published on HCD and empirical research study. From the literature, HCD is a design process in which there is a purposeful focus on the end users, clients and stakeholders throughout the design process. Key principles of HCD are: the active involvement of users, a clear understanding of the user and task requirements, and

iteration of design solutions [3]. IDEO, a global design and consulting firm, believes the HCD process begins by, "examining the needs, dreams, and behaviors of the people we want to affect with our solutions" [5]. Therefore, in order to assess students' understanding of HCD, we must evaluate, and capture, the design process that students demonstrate to complete the design task. Another important phenomenon to elicit is how students are making their design decisions and what informs those decisions [6].

From the literature, we also can learn from other design researchers' efforts to assess students' understanding of design, [7-11], although previous assessment efforts have not explicitly focused on aspects related to a HCD process. To address this gap, a recent empirical study was undertaken to identify and describe dimensions of variation in students' understanding of HCD [12, 13]. From this study, [12, 13], we learned that there are seven qualitatively different ways in which students experience and understand HCD:

- 1) *As a technology-centereed process*
- 2) *As service*
- 3) *As a process of gathering user information that is inputed into a linear process*
- 4) *As a process of keeping users' needs in mind*
- 5) *As design in context*
- 6) *As commitment to users' and stakeholders' needs*
- 7) *As empathic design*

These categories (or ways of experiencing/understanding HCD) differ in terms of students' understanding of their users as well as the level of their design skills and ability to integrate the knowledge [13]. The third through seventh categories are nested hierarchically, where moving from the third category to the seventh represents a more comprehensive understanding of HCD or designing for others [13]. Two categories that were distinct and not included in the main nested hierarchy of categories: those whose experiences lacked design processes (service) and those who did not appreciate the knowledge, experiences and perspectives of the users or the value of involving the users in the design (technology-centered).

II. METHODS

To date, seven pilots have been administered to more than seventy undergraduate participants ranging from first-year students to seniors that included engineering and non-engineering majors. All of the pilots to date have been done

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with undergraduate EPICS (Engineering Projects In Community Service) students. Participants also ranged from students participating in EPICS for first time to students with several semesters completed in the EPICS course. The EPICS design course was targeted because it is a service-learning course that emphasizes an HCD process to achieve the wants and needs of the users and stakeholders. Additionally, the EPICS program is open to all undergraduate majors from first-year to senior undergraduates. Such diversity was sought out because one goal of the assessment task is that it be discipline neutral or able to be used across engineering, technology and computing majors. One of the aims of this project is to be able to categorize participants, as done in the previously mentioned empirical study in which participants' experiences were defined and placed into one of the seven distinct categories, where each category represented one way of experiencing HCD [13].

Participants were mainly recruited through course announcements. With the exception of one round of pilot testing, participants worked individually for approximately one hour on the design task packet. The "design task packet" consisted of a scenario assignment in which, "rather than solving the technical or design problem presented in the scenario, students are asked to describe how they would go about finding the solution to the problem" [14]. The types of activities participants were asked to complete evolved from critiquing and creating Gantt charts, to creating visual representations, filling out a detailed table, and completing reflection questions. The types of data that were collected, depending on the pilot, consisted of what participants wrote down to solve the design task, any drawings and sketches, critiqued and/or participant created Gantt charts, informal group discussions, and finally a table and reflection questions (to be discussed later). Participants only wrote or drew on the design task packet they were given and the packets were collected at the end of the one-hour time limit.

To analyze the artifacts, we examined the data for evidence of the HCD principles, as stated earlier: the active involvement of users, a clear understanding of user and task requirements, and iteration of design solutions [3]. Desired forms of iteration include involving users and stakeholders at multiple points or throughout the design process or gathering information from stakeholders and details about stakeholders' needs multiple times throughout the design process. Additionally, we looked for evidence that decisions were being based on stakeholder needs and stakeholder feedback. The analysis process also involved trying to place participant responses into one of the seven categories presented in [13]. Being unable to place a participant response in a distinct category meant that the design task either a) was not able to elicit data that would indicate their understanding of HCD or b) could not effectively capture the participants' design process. Thus, improvements were made in following pilots.

III. DESIGN TASK DEVELOPMENT

An overarching goal for the development of the design task was to not only assess students' understanding of HCD, but also to practice HCD ourselves. The "scenario" we attended to was to create a design task assessment that would be a

discipline neutral, in-class assessment to be used by any educator or researcher to assess students' understanding of HCD. Thus, some of our stakeholders include: engineering educators, researchers, and students. These stakeholders will continue to be included in our design process through conversations with expert engineering educators and students, and iterative rounds of collecting data from students. In all, we conducted seven rounds of pilot testing. Each round yielded unique insights into a) the question of how to measure and elicit design understanding and b) students' understanding of design and their perception of the design task itself.

In pilots one through four participants worked individually on the design task and they were asked to either 1) create a Gantt chart that would describe the steps they would take to complete the challenge presented in the scenario or 2) critique a Gantt chart and then produce their own Gantt Chart. The task of critiquing a Gantt chart was inspired by Bailey's investigation into design process knowledge [10]. We created two different scenarios, the "Natural Disaster" and the "Soap Box Derby." The Natural Disaster scenario had a broader scope and the Soap Box Derby scenario was situated in a design course project that other students had previously worked on. The process of developing the task has revealed interesting findings and provided insights into how students react with different instructions and design scenarios.

A. Pilot One (9 participants, all engineering majors)

In pilot one we used the Natural Disaster scenario. The intent was to provide a situation that was accessible and motivating to all disciplines. We also intended to put "humans" at the center of the design task in an attempt to elicit a human-centered (versus primarily technological) design response. The scenario read as follows:

"A natural disaster has occurred on the west coast of the United States. A vast majority of residents have lost their jobs and homes. You, and the design company you represent, are being considered to be placed in charge of the recovery effort to identify and develop solutions that will restore the livelihoods of the residents. Carla S. Helpful, a local resident, will be your guide and help you find the resources you need, whether it is materials or people. The economy of the town you will be responsible for is heavily dependent on tourism, seafood, and the natural landscape of the area. To be selected as prime project managers for this job you have to describe what your activities would be for the first month as well as providing concepts that your team would deliver to the community in the coming months. Use a Gantt chart to plan out the activities to be done for the first month."

We provided blank Gantt charts for participants to use. The artifacts collected included the design task packet: any notes participants made on blank areas of the paper, and the completed Gantt charts. We purposefully left "livelihood" undefined and didn't indicate what kind of natural disaster had happened. This was done in an effort to encourage participants to seek out stakeholders and to inquire as to what their needs would be. However, from the discussion after the task was done and examining the artifacts, it appeared that participants took the role of first responders such as FEMA (Federal

Emergency Management Agency) or the American Red Cross. Four of nine responses were focused on getting temporary housing, food, and clean up. This was most likely due to the wording of the scenario and the one month timeline given to plan for (in pilot four the Natural Disaster scenario was slightly adjusted). From discussions with participants, because of the scenario wording participants felt that they would be arriving to the affected area just after a natural disaster hit and thus it was an emergency and participants had to act quickly. These participants focused on managing the disaster and made design decisions based on their own understanding of the situation and not by gaining an understanding the stakeholders. Other participants, five of nine, focused more on rebuilding the economy. These participants exhibited more information gathering activities and had more breadth of considerations than the first responder group. However, all participants seemed to focus on project management instead of design. Regardless of which group the participants fell in, it was still impossible to place participant responses in of the seven distinct categories experiencing HCD [13]. This version of the design task did not elicit information which would facilitate our characterization of their understanding of HCD.

B. Pilot Two(8 participants- 4 engineering, 1 graphic design, 1 computer graphics technology, 1 computer science, 1 chemistry)

In pilot two participants were given the Soap Box Derby scenario. We choose this scenario because we wanted to see what effect of narrowing the scope of the project would have on eliciting a HCD response. The Soap Box Derby scenario is situated in a design course and was an actual EPICS project that we felt students could relate to. The timeline for completion in the scenario was a semester (five months) instead of one month as in the Natural Disaster scenario. The scenario was developed from a study designed to assess moral decision making [15]. In line with our goal of making a discipline neutral assessment, they created scenarios that were “general, universalizable ethical issues, broadly constructed” [15]. The scenario read as follows:

“You are the team leader of an EPICS team that will be delivering a finished project this semester. Your team has designed a new Soap Box Derby car that opens the race to children who have physical and cognitive disabilities by allowing an adult to ride in a backseat and maintain full control of the car. By allowing an adult to ride in a backseat and maintain full control of the car you have enabled children to participate in the Soap Box Derby racing event who previously could not have done so safely. Based on suggestions from the parents, you have added spring tension to the child’s steering wheel in front in order to simulate the feeling of driving and make the child’s experience more realistic and fun. The child will not have the ability to control the car, only the illusion of control. However, your team assumes that the children would like to have total control of the soap box. To help solve this dilemma, and create a consensus between all parties, you decide to interview the special needs caregivers, who are responsible for the children while the parents are at work. It is clear that in order to get this project completed and delivered this semester your team may have to redesign the soap box to

meet the needs of all the stakeholders involved, as well as manage the potential public relations issues surrounding any controversial design decisions. Unexpectedly, before you are able to do any interviews, your advisor informs you that he has to leave town and will not be back until the end of the semester. Your advisor informs you that: ‘Your task is to redesign the Soap Box Derby car this semester. Create a Gantt chart to describe, in detail, the activities to be completed during this semester leading up to delivery of a finished project. Include the specific design decisions you would make and the different roles your teammates would take.’ ”

We provided blank Gantt charts for participants to use. The artifacts collected included the design task packet: any notes participants made on blank areas of the paper, and the completed Gantt charts. In comparison to the first pilot, we were able to observe good indicators of HCD thinking such as participants including more iteration with stakeholders in their design processes. In seven of eight cases, evidence was present (but not conclusive evidence) that lead us to believe that design decisions were being governed by stakeholders’ needs and feedback. However, none of the participants saw a need to meet with the actual organizers of the event, which would show more a breadth of considerations. Also, we started to notice participants using umbrella terms such as “stakeholders” instead of specifying who they meant: parents, children, etc. Participants would also neglect to indicate what was meant by “feedback.” Feedback from whom, and about what? This would all be valuable information that would further aid in evaluating responses. Trying to have participants give more detailed responses became a reoccurring theme. Finding out how to elicit more detail from participants was discovered in later pilots. However, this scenario did seem to elicit a more HCD response than the Natural Disaster scenario. Participants took on the role of designer in this scenario more than did the participants who worked on the Natural Disaster task.

C. Pilot Three(8 participants-4 engineering, 1 general communication,1 physics, 1 computer information tech, 1 information systems)

In pilot three we used the same Soap Box Derby scenario but asked participants to first critique a given “completed” Gantt chart and then create their own. The additional instructions stated, “First, critique the design process given to you by a fellow teammate describing any improvements you would make or activities you would keep. You may also shade in areas of the process to lengthen time or to show concurrent actions. Then, create your own Gantt chart considering if you had unlimited resources and people.” Additionally, in reference to the Gantt chart given we asked, “what is good about this process and why?”, and “what would you do differently, and why?” This procedure is similar to the investigation into design process knowledge [10]. In similar fashion to the [10] study, we included design process strengths and weakness in the Gantt chart given to the participants. Some of the weaknesses were: no stakeholder involvement throughout the process, design decisions were based on team assumptions, and lack of breadth of context. The strengths of the design process were: iteration, testing, and brainstorming. However, the iteration was not done with the stakeholders. It was purely technical

iteration (something akin to troubleshooting): design, test, and redesign cycle. As in the other pilots, we provided blank Gantt charts for participants to use. The artifacts collected included the design task packet: any notes participants made on blank areas of the paper, the critiqued Gantt charts, answers to the questions, and the participant completed Gantt charts. From the artifacts collected we saw that half the participants did address at least one of the weaknesses. For five of eight responses, it was still hard to determine if design decisions were governed by consideration of all stakeholders. Also, when participants would make corrections to the Gantt chart given, some improvements would not always be copied over to the Gantt chart they created. This created a disconnect in participant performance and added difficulty in determining a participant's thinking. When compared to the first two pilots, where participants had to create Gantt Charts from scratch, there was also less detail or less explanation of the activities to be accomplished that were entered onto their Gantt charts. We attributed the reduced detail to participants mimicking the low level of detail in the Gantt chart we gave them. When comparing the effect of providing a Gantt chart to critique versus having participants solely creating a Gantt chart from scratch, participants would give more detailed responses which included discussing activities on the Gantt chart or giving overall explanations of their plans or their point of view of what needs to be accomplished. In this pilot, participants stuck to answering the questions in reference to critiquing the given Gantt chart from a fellow "team member."

D. Pilot Four (13 participants-10 engineering, 1 undecided, 1 film and video studies, 1 computer graphic technology)

In the fourth pilot we addressed some of the issues we saw with the initial Natural Disaster scenario. We stated that first responders had already been in the area for months and were preparing to leave and that the focus had shifted from immediate relief to stabilization. We also introduced a funding agency which participants had to present their strategy to, a strategy "that will lead to the generation of concepts that would be further developed in the following months." The modified Natural Disaster scenario also included a "completed" Gantt chart for participants to critique and then to create their own, with the same additional instructions as given in pilot three. However, the Gantt chart activities were different and situated in the Natural Disaster scenario. The strengths were meeting with residents to determine initial needs and brainstorming. The weaknesses of the Gantt chart given were iteration, testing, and minimum stakeholder involvement like never presenting ideas to residents. We provided blank Gantt charts for participants to use. The artifacts collected included the design task packet: any notes participants made on blank areas of the paper, the critiqued Gantt charts, answers to the questions, and the participant completed Gantt charts. After collecting and analyzing the data, not everyone picked up on the weaknesses of the given Gantt chart. Participants still seemed focused on project management. Four of thirteen only presented their results to the funding agency. Another four of thirteen participants were solely concerned that some activities could be done concurrently and/or earlier on the timeline. On the other hand, there were ten of thirteen responses that had a more breadth of consideration than the first pilot, exhibiting at least

one of the following: talking with FEMA and the American Red Cross organizations, presenting ideas and getting feedback from residents or considering infrastructure issues not mentioned in the scenario. The detail in the responses was also slightly better than the third pilot, which may have mirrored the more detailed description of the activities in the Gantt chart given. Still, the Soap Box Derby scenario elicits more data that would help indicate participant understanding of HCD than the Natural Disaster scenario. From this point on, we concentrated on refining and perfecting the Soap Box Derby scenario.

E. Pilot Five (12 participants-10 engineering, 1 computer science, 1 computer and information technology)

In pilot five we experimented with another format for capturing participants' design processes because we noticed weaknesses in solely using a Gantt chart. We decided to have participants demonstrate their design process on a calendar. A calendar was provided that showed each day during the entire semester. This change was also motivated by the informal discussions with participants from the previous pilots. During the discussions the participants talked about how they would plan their personal activities or schoolwork. Using a calendar was one method that surfaced often. Also, for this pilot we had participants work in groups of two to four. This was done in an effort to mimic true design practice where designers work in teams and not individually on projects. Participants were given the Soap Box Derby scenario, same as in pilot two, and were instructed to work in teams and report back using the semester calendar. Once the artifacts were examined, the level of detail and the richness of the responses were much less than any of the previous pilots. Moreover, because of working in groups, it was impossible to know who the design task was assessing. Did each member have an equal role? Or who contributed the most?

Analyzing the artifacts collected from pilots one thru five we learned that the Soap Box Derby scenario elicited a more HCD response than the Natural Disaster scenario. This was evidenced in being able to see more HCD principles manifested in the artifacts from the pilots where the Soap Box Derby scenario was used. Also, having participants create a Gantt chart from scratch provided a more detailed response from participants and a richer artifact to evaluate. We also noted some of the limitations of the Gantt chart. We could not tell how participants perceived the stakeholders and what types of information they were getting from stakeholders. Furthermore, it is often difficult to say for certain if we are witnessing iteration or concurrent actions from the Gantt chart. This would all help us further evaluate participant responses. Thus, we decided that we needed something to complement the Gantt chart or an alternative form for capturing the participants' design process.

F. Pilot Six (10 participants-all engineering)

For pilot six we wanted to address some of the limitations of the Gantt chart, such as being unable to tell: how participants perceived stakeholders, the type of information participants were getting from stakeholders, and if we were witnessing iteration of concurrent actions. Also, we wanted to combat the use of umbrella terms such as "testing", "stakeholders", and

“feedback” which were limiting the level of detail and prohibiting further understanding of participant responses. Therefore, we created Table 1 for participants to fill out that would supplement the weaknesses of the Gantt chart. The table is similar to the Gantt chart in that the individual activities to be accomplished are listed vertically in the left-most column. However, the addition of the three other columns allows us to uncover more of the participant thinking than a Gantt chart.

TABLE I. TABLE TO SUPPLEMENT GANTT CHART

| What tasks must be done? (List tasks individually) | What information will you need to be able to do this task? | What or who is the source of information? | Why is the task being done? What is the purpose of the task? |
|--|--|---|--|
|--|--|---|--|

The Soap Box Derby scenario was also adjusted so that it would not lead participants to indicate that they would interview stakeholders (when this is something they normally would not include in their design process) and statements explicitly stating that one of the objectives was to get a consensus between all stakeholders were eliminated. That is, statements such as, “To help solve this dilemma, and create a consensus between all parties, the team decides to interview the special needs caregivers” were eliminated. Also, participants were given the option of creating a flow chart or flow diagram instead of using the blank Gantt chart given. Giving participants the option of using the Gantt chart or creating a flow chart or flow diagram was motivated by discussions with colleagues at the Frontiers In Education (FIE) conference in 2011. They commented on the “confining nature of the Gantt chart.”

After analyzing the artifacts it became clear that implementing the table was a valuable step in the right direction. The information contained in the table supplemented the information collected in the Gantt chart. Not only did participants list their activities on it, but they also had to include explanations of why each activity was being done and with whom. Responses on the table were extremely easy to interpret and made explicit what participants planned on doing and why they were doing the various activities. The umbrella terms mentioned before were not as much of a concern as before because with the table, if one column was unclear the others would help to clarify an activity. However, based on the information from the Gantt chart and table, it was difficult to place participants in the higher categories of description of experiencing HCD, or the “more comprehensive ways of experiencing human-centered design” [13]. To place participants in categories such as “commitment to involving stakeholders to understand perspectives” and “empathic design” there needed to be more unpacking of a) how participants saw the importance of stakeholders and b) participants’ attitudes towards stakeholders.

G. Pilot Seven (13 participants-11 engineering, 2 computer science)

Pilot seven represents the culmination of all of the improvements and insights gained by conducting and analyzing pilots one through six and also reflects feedback from a special

session at FIE 2011. As stated before, after conducting pilot six the usefulness of the Gantt chart was called into question. Although the Gantt chart elicited some information that helped to characterize participants’ understanding of HCD, it lacked specific and motivational information. In addition, from discussions with expert design educators at the FIE conference, it was suggested that the form of the visual representation should be left open to the participant instead of presenting a Gantt chart. This was also evidenced from examining the artifacts from previous pilots, where some participants would make drawings or sketches on their own without instruction. Therefore, the Gantt chart was removed and replaced with blank space for participants to create any sort of visual representation. Also, as learned from pilot six, the table should be supplemented with questions that expose how participants view stakeholders and their attitudes toward them, along with how important participants felt the stakeholders’ needs were to be incorporated into the design. Consequently, we created reflection questions. The reflection questions were given after the design task was completed and collected. Reflection and self-monitoring can be forms of learning effective design practice [11]. Thus, completing the reflection questions along with the design task would possibly skew the results. Participants could presumably look through the task, see the reflection questions and that would affect how they would complete the table. The reflection questions are: 1) As a designer, what do you feel is important to consider when doing design? 2) What does it mean to do design well? How do you measure success? 3) Do stakeholders have a role in the design process? Describe why, or why not? And 4) What if you had unlimited access to children, parents, experts etc., what would you want from them? How would you include them in the design process? The version of the Soap box Derby scenario for pilot seven is as follows.

“It is the first day of the fall semester (or quarter). You are the team leader of a design team that will be delivering a finished project this semester. Your team has designed a new Soap Box Derby car that opens the event to children who have physical and cognitive disabilities by allowing a professional driver to ride in a backseat and maintain full control of the car. Soapbox derby cars are towed to the top of a small hill and they “race” by coasting down the hill on a straight track. While there are no turns in the course, the cars have steering to maintain control of the cars. In a traditional Soap Box Derby car, the child is by him or herself and steers the car. By allowing an adult to ride in a backseat and maintain full control of the car your team has enabled children to participate in the Soap Box Derby event who previously could not have done so safely.

“Your team has studied other designs for children with disabilities and these designs either have no steering for the child in the front seat or they have added spring tension to the child’s steering wheel in order to simulate the feeling of driving and make the child’s experience more realistic and fun. In either case the child can not actually control the car, the child only has the illusion of control. The question has been raised if the design should allow children who are capable of steering to do so with the driver being able to override the child. The information that you have at this point does not point in one direction or another. Your team’s advisor confesses that she/he

is not an expert in this area and has deferred to the team to determine the best design. Your advisor has stressed, however, that the new design has to be finished this semester. As the team leader, you are asked to develop a plan to get the design right and to make sure it is finished this semester (or quarter).

“Fill out the table given to describe, in detail, the activities to be completed during this semester (or quarter) leading up to delivery of a finished project. Include the specific design decisions you would make and the different roles your teammates would take. The blank space provided on the following pages is for you to use as you see fit. You can create a visual representation (flow chart, flow diagram, Gantt chart, or other picture) to show the sequencing and/or relationships of the activities or simply use to get your thoughts together.”

The pilot seven process of collecting artifacts consisted of presenting the participants with the Soap Box Derby scenario, and instructing them to create any form of visual representation, and then to fill out the table provided. Once participants finished the design task, in which they were allotted fifty minutes to complete, participants were then given the reflection questions to answer, all done individually. The entire process took usually less than one hour for participants to complete both the design task and the reflection questions; about the length of a typical class session. With this version of the HCD assessment, by analyzing the design task and reflection questions we are able to categorize participants' demonstrated understanding of HCD.

IV. CONCLUSION AND NEXT STEPS

The results from the pilots demonstrated that using a scenario that is situated in a design course, allowing participants to create their own form of visual representation along with the implementation of the table and reflection questions, is an effective way of eliciting a human-centered design response and capturing a detailed design process from students. With the Soap Box Derby scenario we are able to elicit a designer response and not a first responder or project manager response. With the table, we are able to elicit enough detail to categorize participants. The artifacts show that many times participants create flow diagrams that, sometimes, show the sequencing of events, something that may have been lost by not using Gantt charts. Even when participants do not create flow diagrams the visual representations can demonstrate HCD principles such as iteration with the stakeholders, although not always. The table effectively captures these features that are not shown in the diagrams. The reflection questions provide valuable insight and often elicit responses that are not captured by the table or the diagram related to participants' attitudes toward the role and importance of stakeholders.

Fittingly, the development of this assessment took a human-centered design approach. With the students or participants being one of the stakeholders, we first had to understand how they would interpret the design task and what scenario would elicit data that would indicate their understanding of HCD. With design educators and researchers also being stakeholders,

we sought them out to get their feedback as the task was being developed. The next phase is the development a rubric for consistently scoring participant responses. In the same fashion of human-centered design principles, educators' and researchers' needs are at the center of our process. The rubric must be easily understood and can be used by any educator or researcher. Developing the rubric will be done in conjunction with validating the design task by conducting follow-up interviews with participants. Follow-up interviews will follow a similar protocol as illustrated in [13].

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LILES System: An Educational Engineering Application in Linguistics and Cognitive Science

A Novel Interdisciplinary Paradigm

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Abstract— This study shows how employing cognitive visualization in a specific engineering application can foster learning. It provides recent experimental analysis of an innovative language-learning support system that is based on a new approach to the study of kanji, our "Learner's Visualization (LV) Approach". Our research examines how intermediate and advanced students use visualization to cognitively deconstruct (divide) kanji in different ways as they study. We analyze these differences with a new learning support system, our LILES system. The LILES (Learner's Introspective Latent Envisionment) System, guides learners to choose from a set of possible "kanji deconstruction layouts" (layouts showing different ways a given kanji can be divided). Throughout the learning experience, the system assists learners in updating their "kanji deconstruction level" (the average number of parts they visualize within kanji according to their current cognitive processing). The analysis proves that there are cognitive differences: advanced learners deconstruct kanji into more parts ("blocks") than intermediate learners do, and while both improve their kanji deconstruction levels with the LILES system, there is a more significant change in intermediate learners. For students of engineering, this study provides an excellent example of the practical implementation of systems design in an effective language-learning support system.

Keywords- educational engineering applications; learning support system; visual cognition; kanji deconstruction level; cognitive maps

I. ENGINEERING EDUCATION AND LEARNER INDIVIDUAL PREFERENCES

A. Learning styles in engineering education

Felder found that learning styles of most engineering students and teaching styles of most engineering professors are inconsistent in several dimensions. He observed that most engineering students are visual, sensing, inductive, and active, and some of the most creative students are global. On the other hand, most engineering education is auditory, abstract (intuitive), deductive, passive, and sequential. In this sense, there is a mismatch that leads to poor learning performance, teaching frustration, and a loss to society of many potentially exceptional engineers [1].

B. Learner individual preference and cognitive visualization

Furthermore, it has been suggested that individual differences between learners also play an important role. For example, Plass and Homer analyzed the role of individual differences on cognitive load in multimedia learning [2]. They found that the role of learners' preferences and abilities is significant in their learning process. The focus of the present study is to evaluate the role of *preferred visualization* in cognitive deconstruction to determine what features may promote learning. Increasing the techniques in an instructor's repertoire would lead to a teaching style that is both effective for students and comfortable for the professor. In this way, the above mentioned intrinsic mismatch will naturally decrease.

C. Intermediate and advanced learners

While in our previous study we examined the case of beginners [3], this paper examines and contrasts the case of intermediate and advanced learners in order to find further and comprehensive implications and suggestions for improving the design of future educational web-based programs based on cognitive science that could be used as experimental computational models in engineering courses.

II. STUDY OF A COGNITIVE MODEL BASED APPLICATION

A. Aim of the study

The aim of this study was to implement a learning support system that makes it possible to analyze the cognitive way in which kanji students visually divide or "deconstruct" kanji during the learning process. This system, the Learner's Introspective Latent Envisionment System (LILES system), is based on our novel approach to kanji-learning called the Learner's Visualization (LV) Approach. This research is original in that it analyzes the cognitive differences between intermediate and advanced learners as they study, with a focus on how many recognizable "blocks" or parts they visualize on average within unfamiliar kanji. Our findings have shown that *beginning* learners tend to progress from visualizing many small blocks within each kanji to visualizing just a few larger

blocks per kanji (although this does not necessarily lead to advanced students visualizing entire kanji as just one recognizable block) [4]. This study strives to determine the cognitive differences that may exist in the way intermediate and advanced learners visually deconstruct kanji, especially while learning new kanji using the LV Approach. In this paper, we discuss our experimental results and summarize the main contributions this study makes to the field of kanji-learning.

B. Further Motivation

We are further motivated by the crucial need to determine not only what specific factors account for better learning results, but also how this happens. Doing so, we could certainly establish how to enhance future learning systems with cutting-edge educational engineering applications in accord with the most recent findings.

III. KANJI BACKGROUND

A. Kanji writing system research

The Japanese writing system is comprised of a unique blend of scripts: kanji (which are derived from Chinese characters), two kana syllabaries (which are phonetic), Roman letters and Arabic numerals. This offers fascinating questions for research, and kanji has been the main topic in numerous studies. In one work related to the present study, Tollini remarked on the importance of understanding how Westerners “see” kanji, especially during the initial stage of the learning process [5]. He stated that Westerners recognize kanji based on visual recognition laws different than those employed by the Japanese [5]. According to the work of Takagi, the complexity of recognizing a kanji can be reduced if learners visually break down the kanji into smaller parts, and organize them [6].

B. Kanji learning approaches

Radical approach. This method uses “radicals” (in Japanese, 部首 bushu) as the key elements of any kanji, grouping kanji according to radicals present within the characters. Limitations of this approach lie in the heterogeneity of the different groupings and in the fact that there are variations on the radicals’ shapes.

Frequency-based learning approach. This approach is based on Monbusho’s Educational Kanji Chart (教育漢字の学年別漢字配当表). Its main drawback is the fact that some kanji are taught without taking into account their visual components. For example, “eat” (ta-beru, ku-rau/SHOKU) (食) is taught in the second grade, but its component, “good”(yo-i, RYOU) (良) is taught in the fourth grade. Teaching a kanji without previously teaching its elementary parts is common but may not be efficient for foreigners.

Component approach. This approach emphasizes learning the building blocks of kanji. All the parts of a kanji are identified as components. A component is a set of strokes which keeps the same visual shape. For example, 歌 is composed of the components: 可 and 欠; another example, 東: “木 and 日” or “田 and 木”. Components are associated with a pattern, which defines the relative position of them.

Learner’s visualization approach. This novel approach proposed by Inostroza involves three elements: 1. the learner’s visual cognition, 2. multiform “deconstruction” of kanji, and, 3. block analysis/synthesis [3]. The first element, the learner’s visual cognition, is the way in which a learner visually divides a kanji into parts or “blocks”. The second element is the set of all the possible options of how that kanji could be divided or “deconstructed” into blocks, from the highest number of small blocks down to just one block (which would be the entire kanji itself as a single block). The third element is the analysis/synthesis cognitive strategy embedded in the approach which allows the user to analyze the given kanji by selecting any block inside it for further study, or to synthesize that block with a bordering one inside the same kanji, suggesting a larger block to be considered that combines the two smaller ones.

IV. COGNITION BACKGROUND

A. Cognitive processing of kanji vs. kana

Neuropsychological research has shown that when one reads Japanese, the kana and kanji scripts are processed by different areas of the brain. Usui et al found that kana and kanji are both processed in the LBTA (the left basal temporal area, also called the left inferior posterior temporal lobe), but, the two scripts are processed in different areas of the LBTA [7]. Interestingly, kanji is processed in the same area of the LBTA that is responsible for recognizing and naming pictures and objects. This suggests that the visual shapes of a kanji play a key role in the reader’s cognitive processing, which is congruent with neuropsychological literature [8]. Nakamura et al found increased activity in this area of the LBTA during the acts of visually fixating on kanji, physically writing kanji, mentally writing kanji, and mentally recalling kanji words [9]. Ino et al concluded that the brain processes kana and kanji in different areas of the LBTA because of the quite different characteristics of the two scripts and the mental tasks required to read them [10].

B. Cognitive maps and kanji visualization layouts

Cognitive maps are a method our brain uses to accumulate and store knowledge (primarily spatial information) in the so-called “mind’s eye”. The brain links related visual concepts in a mental network (a “map”) to facilitate their accessibility. This reduces cognitive load, and thus enhances recall and learning.

V. RESEARCH QUESTION AND LILES SYSTEM

A. Research question

This study is primarily focused on identifying whether or not there is a cognitive difference in intermediate and advanced learners as to their “kanji deconstruction visualization”.

B. Existing kanji learning systems vs. the LILES system

To this day, there are no kanji learning systems currently in use that facilitate the analysis of how learners update their kanji deconstruction level, which is the purpose of this study. With the exception of the LV System that we have developed, no existing system is based on the Learner’s Visualization (LV)

Approach, which guides learners to explore and update the way they deconstruct (visually divide) kanji [3]. Therefore, to pursue our study we have adapted our previously implemented Learner's Visualization (LV) System in a way that would allow us to analyze learners' behavioral results, with the goal of eventually explaining how the LV Approach facilitates learning. We have named this system the LILES System, where LILES stands for Learner's Introspective Latent Envisionment System, to convey the concept that when learners visually deconstruct kanji into layouts of blocks (groups of strokes) and update their preferred deconstruction layout via this system, learners *envision* (see or picture in their mind) possible deconstruction layouts in an *introspective* way (given to examining one's own perceptual experience), bringing to fruition new ways to visualize each kanji that are *latent* in every learner's mind.

VI. LILES SYSTEM IMPLEMENTATION

We have implemented the LILES system as an adaptation of our LV System, which is based on our LV Approach to kanji learning. A brief functional description of the LILES System is as follows: While learning kanji using the LILES System, it encourages learners to explore a predefined set of "deconstruction layouts" for each kanji, and in doing so it guides learners in visualizing alternate deconstruction layouts which differ from the layout the learner initially preferred to visualize. The learning process, illustrated in Figure 1, can be summarized as follows: (boxes "a", "b", "c" etc, refer to the boxes attached to the figures): The system shows a certain kanji with its corresponding meaning, (boxes "a" and "c"), for example, the kanji for "to be surprised, to be astonished" = "odoroku" (驚). Below the kanji, the system shows a set of predefined possible deconstruction layouts into which the kanji can be divided. The user first selects the deconstruction that best matches the way he would naturally divide that kanji according to his own personal visual cognition. After selecting his deconstruction of choice, the system then allows the user to examine and learn more by clicking on the zone of particular blocks, (box "b"), within his chosen deconstructions as well as blocks within all the other possible deconstructions. When a user clicks on the zone of a block, (box "b"), the system gives relevant information about it, (box "d"). The system then suggests that the learner consider a new, larger and more complex block, (box "e"), which is constructed based on the block selected by the learner combined with an additional block also present in the same kanji, bordering the selected block. The new assembled block becomes a "superblock" in the kanji in study. While the user is working on the kanji 驚 and examining the block 苟, the system suggests the construction of a new block "敬", combining (苟) with adjacent block (攵), and shows some examples of other kanji that include this more complex superblock. Learners can explore any of the examples just by clicking on one of them. The core of the technique lies with the recommendation of a "next complex block". For example, if the learner selected the block '苟', the "next complex block" suggested by the system is '苟+攵' = '敬'. Alternatively, at the bottom of the learning environment users can choose to explore other kanji that include the block they selected, (box "f"). The kanji the user

has studied kanji appear at the top of the screen in case she wishes to review them, (box "g").

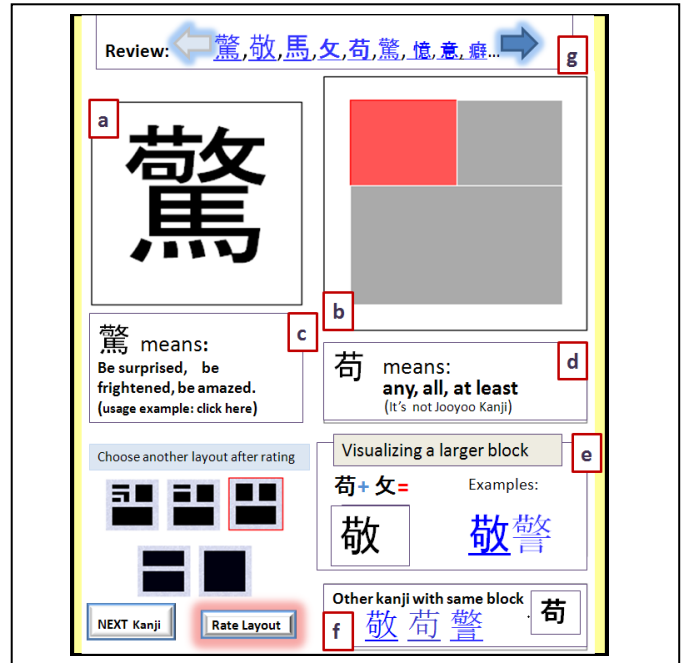


Figure 1. Functionality of the LILES system

VII. EXPERIMENTAL ANALYSIS WITH THE LILES SYSTEM

Experimental analyses were conducted via our LILES System to obtain necessary values for analyzing the possible cognitive difference in kanji deconstruction level after using the LV approach-based learning support system. A brief description of the experiments is as follows.

A. Evaluation questions

"Do intermediate and advanced learners deconstruct kanji differently?" "Does the LV Approach assist both intermediate and advanced learners equally in updating their personal way of visualizing kanji?"

B. Evaluation method

For the learning session learners used our LILES System, an implemented web-based system which is an improved version of our Learner's Visualization (LV) System. Learners were randomly assigned to one of two variants: the Control Group (G1), which used the kanji-learning software with only one possible deconstruction layout offered per kanji, and the Experiment Group (G2), which used the same software but with a function that allows the learner to choose her deconstruction layout of preference from a group of predefined possible layouts for each kanji.

C. Participants

A total of 96 university students of 17 different nationalities were evaluated and classified as "intermediate level learners" (48 students) and "advanced level learners" (48 students) following the criteria of the vocabulary knowledge scale developed by Paribakht and Wesche [11]. The mean length of

formal study (i.e. under a program with a plan, a goal and a way to measure progress) for intermediate students was 371 hours, and 537 hours for advanced students. The participants were exclusively speakers of languages that use an alphabetic script.

D. Instructional materials

□ **Global selection.** The kanji database obtained from the Asahi Newspaper published between 1985 and 1998 serves as the basis for the global selection: a total of 6,355 kanji out of almost 49,000 kanji included in the 13-volume Morohashi Dai Kanwa Jiten. The distribution of this database (being X =number of strokes) was obtained in Tamaoka's study. Its negative hypergeometric distribution has as parameters: $K=24.6877$, $M=6.8335$, $n=41$, $DF=26$, $(X)^2=45.63$, $P=0.01$, $C=0.0072$ [12].

□ **Specific selection.** The specific selection criterion was visual complexity which was found strongly positive correlated with the number of strokes [13]. This criterion was chosen based on the importance of form, stressed by Tollini [5], in the selection of kanji to be taught. The rating data was based on the negative hypergeometric distribution of the 6,355 kanji. From this database only a set of 200 were selected (73 percent belonging to the *jōyō* kanji list issued on October 10, 1981, and the remaining 54 kanji were the most common non-*jōyō* kanji that are either: (a) useful as building-blocks for other kanji (e.g. 吾, 勿, 頁, etc) or (b) very common in names (e.g. 藤, 岡, etc)). The sampling kanji were randomly selected proportionally to the distribution of the database, i.e., frequency of each value (number of strokes). This set of 200 kanji is called in this study: "database kanji" = dk .

□ Kanji deconstruction and deconstruction layouts.

Nara's study previously established a tentative set of kanji parts that non-native students see in kanji [14]. However, as different foreigners may have different ways of deconstructing kanji, in order to have a more comprehensive range of possible deconstruction layout options, a preliminary experiment was conducted. The goal was to obtain an experimental and open-to-consideration set of those kanji deconstruction layouts that are visually salient to nonnative learners. This experimental set has been elaborated based on the survey done in Nara's study on kanji visual salient parts [14]. Compared with Nara's survey which had only four participants, our survey was conducted with fourteen non-native speakers of Japanese who had enrolled in the Tokyo Institute of Technology's Japanese language course (7 intermediate learners and 7 advanced learners). They were given 200 randomly selected *jōyō* kanji and were asked to write down all the possible deconstruction layouts they visualize in each kanji that make sense according to their personal visual cognition, indicating at the end their preferred layout. The results showed that advanced learners tend to visualize substructures within a given kanji in a different way than intermediate learners do. The majority of the time, participants preferred to deconstruct the given kanji into 2 or 4 blocks (Intermediate students: mean=2.97, SD 'standard deviation'=0.71; Advanced students: mean=3.35, SD=1.33;

Global: mean=3.16, SD=1.062). The number of deconstruction layouts created per kanji mainly varied between 4 to 6 different layouts (mean=4.73, SD= 1.32).

□ **Unknown kanji selection per groups.** As the study examines the ability to visualize *novel* (unknown kanji selected according to preliminary test) kanji, the characters used in the target items were chosen kanji that are typically not well known. In order to confirm selection of *novel* (unknown) kanji to be used in the learning session of the experiment, a kanji test was given to all participants: Preliminary Test. Categories I and II of this preliminary test define a *novel* kanji. See details in sections VI-F and VI-G.

□ **Time for learning selected kanji.** All participants were instructed to learn the list of 100 kanji in 60 minutes.

E. Design

The experiment was design to evaluate the comparison of the means of kanji deconstruction level between intermediate and advanced learners. It was conducted as follows:

• Pre-tests:

1. Preliminary Test: 50 minutes for checking vocabulary of dk (database_{kanji} of 200 kanji) and building a database of 100 *novel* kanji.
2. Pre-test for Experiment: 25 minutes for selecting layouts for each of the 100 *novel* kanji (followed by a 7-minute break).

• Learning session:

3. Group 1: 60 minutes exploring one layout per kanji (100 *novel* kanji in total)
4. Group 2: 60 minutes exploring the different deconstructions layouts of the 100 *novel* kanji (with a 7-minute break).

• Post-tests:

5. Post-test for Experiment: 25 minutes for choosing the participant's final preferred visual deconstruction layout for each of the 100 *novel* kanji.

The design of the experiment was as follows:

Type of experiment: Research Experiment, 2x2x2 ANOVA Design. Three-way ANOVA with one RM (repeated measure). The RM factor has 2 levels.

Dependent variable: "Kanji Visualization Score" (KVScore), or "kanji visual deconstruction score", the mean number of blocks into which the user chooses to deconstruct given kanji).

Independent variables (factors): The two levels (Pre-Post) of the RM (within-group) factor called Tests. The two between group factors were Groups (Control Group or Experimental Group) and, Learners (Intermediate or Advanced).

Goal: Compare the performance achievements between beginning and intermediate learners.

F. Instruments

▽ *Kanji Visualization Test (KVT)*. A test with maximum score 1.00 was designed to measure the dependent variable, kanji visual deconstruction level, referred to as *Kanji Visualization Score (KVScore)*.

▽*Calculation method of KVT*. The dependent variable was calculated based on the mean of the normalization of the number of blocks mentally visualized per kanji. We used the formula $score_{sk} = (B - n + 1)/B$ where $score_{sk}$ represents the score in a given kanji, B represents the maximum number of blocks in that kanji, and n expresses the number of blocks mentally visualized per kanji. Consequently to visualize a kanji as a whole unit scores 1 point, and the mean of all the $score_{sk}$ makes the kanji deconstruction level in a learner.

△*Kanji Test(KT)*. As a preliminary test, a kanji vocabulary test was conducted. A careful criterion was included in order to correctly build a database of 100 *novel (totally unknown)* kanji.

△*Calculation method of KT*. Learners were presented with a list of target kanji and asked to choose their level of knowledge for each kanji according to the following self-reporting categories based on an adaptation of the Vocabulary Knowledge Scale (VKS) [11]:

- I I do not remember having seen this kanji before.
- II I am sure I have seen this kanji before, but I am also sure that I do not know what it means.
- III I think I know this kanji. I have seen it before, and I think it means ____.(translation or synonym)
- IV I know this kanji. It means ____.(translation or synonym)
- V I can use this kanji in context: ____.(Write an example).
(And please also do section IV)

Total score is calculated based on: Categories I and II represent score of 0.0 and 0.05 respectively. Wrong responses in levels III, IV or V lead to a score of 0.05. A score of 0.1 is given if there is a good response in category III, and 0.2 in category IV. For category V, a score of 0.3 is given if the kanji is used in the correct context but with incorrect usage and no translation is provided (and 0.4 when translation is provided). A score of 0.5 is given when translation was provided and the kanji has been used in the right context and with accurate usage, even if other parts of the sentence may have errors. It is worth mentioning that in the learning session participants learn only *novel* kanji from the set of kanji called “database”= *dk*.

G. Instructions and procedure

The sequence of instructions for the participants was:

• Pre-tests:

1. *Preliminary Pre-Test (Kanji Test, KT)*: All participants received 200 characters= *dk*, and they were asked to answer the Kanji Test (explained in section IV-F). Participants were instructed to check appropriately instead of guessing about their knowledge of kanji. When they checked either (I) or (II), the respective kanji were selected for the experiment, generating a pool of *novel* kanji for the experiment= *sn*. Learners were given 50 minutes for the test. In this experiment, the resulting pool of novel kanji was always over 100 kanji.

2. *KVT=Pre-test for Experiment*: Learners were given 25 minutes to choose their initial preferred deconstruction layout from a predefined list of possible deconstruction layouts for each of 100 novel kanji. The kanji used were randomly selected from the pool of novel kanji.

• Learning session:

3. *Control Group*: Learners were given 60 minutes to learn the set of 100 novel kanji *without* having the option to explore alternate deconstruction layouts for each given kanji. They were instructed to study each kanji by exploring the *blocks* of their sole *preferred layout* that was displayed beside each kanji. Learners need to explore at least half of the *blocks*.

4. *Experimental Group*: Learners were given 60 minutes to learn the set of 100 novel kanji from the LILES system *with* the option to *explore* alternate deconstruction layouts per kanji.

• Post-tests:

5. *Post-test for Experiment*: Learners were given 25 minutes to choose their final preferred visual deconstruction layout from a pre-defined list of possible layouts for each of the 100 kanji in study.

VIII. RESULTS

A. Cognitive processing of kanji vs. kana

All statistical analyses were performed using the PASW (Predictive Analytics SoftWare) Statistics 18 software version (the SPSS version between 2009 and 2010). The descriptive statistics results are summarized in Table 1. A comparison of the improvements of *KVScore*, by Learner and by Group, between pre-test and post-test was analyzed. Analysis of variance (ANOVA) was used to assess the changes in *KVScore*. However, prior to the ANOVA test, Levene’s Test for Equality of Variances was performed in order to assess the assumption that the population variances are equal. The Levene’s test was negative, i.e., not positive ($P > 0.05$): $P > 0.589$ for data for Experiment, meaning the variances in the groups were equal (homogeneous, i.e. homogeneity of variance).

TABLE I. RESULTS FOR EXPERIMENTAL GROUPS

| Factors | | | <i>KVScore</i> |
|----------------|-------------|--------------|----------------|
| <i>Learner</i> | <i>Test</i> | <i>Group</i> | <i>Mean</i> |
| Intermediate | Pre | Experimental | 0.647 |
| | Post | Experimental | 0.746 |
| Advanced | Pre | Experimental | 0.57 |
| | Post | Experimental | 0.64 |

The results of the ANOVA show that there is an interaction between all factors. This three-way interaction shows that two-way interactions vary across levels of the third variable. Additionally, since all of the factors in this three-way ANOVA are dichotomous (2 levels), there was no follow-up tests to perform on significant main effects. The dependence of *KVScore* differences between intermediate and advanced learners on Group factor (Control Group/Experimental Group) and Test factor (Pre-test/Post-test) was reflected in a significant Learner x Group x Test interaction in an overall ANOVA of these data, $F(1, 18) = 31.58, p < 0.001$. Our results further indicate that this three-way interaction was due in part to the presence of a significant Learner x Group interaction, $F(1,$

184)= 45.17, $p < 0.001$. The results are significant at the 0.1 percent of significance level. Therefore, one would reject the null hypothesis, concluding that there is strong evidence that the expected values in the groups differ.

As illustrated in Figures 2, as to kanji visualization level, although both the Control Groups and the Experimental Groups achieved better scores, the benefit was more significant for the Experimental Group learners who studied via our Learner's Visualization Approach. To sum up, ANOVA results of the comparison in scores for both groups of learners (i.e. intermediate and advanced learners) shows that their means are statistically different with the use of the LV Approach.

IX. DISCUSSION

Our results provide evidence that between intermediate and advanced learners, there are differences in the way they visually deconstruct kanji. Besides, although there is a significant *KVScore* ("kanji deconstruction level") improvement in both groups of learners, a statistical analysis to the improvement means shows that it is more significant in intermediate learners. This study began with a previous finding showing that the LV Approach assists beginning learners in accelerating their natural progression towards perceiving individual kanji in fewer numbers of blocks (as learners gradually gain the skill to recognize larger and more complex blocks within each kanji, they no longer need to "divide" that kanji into smaller blocks in order to recognize the blocks) [4]. However, this does not mean that the initial tendency of visualizing fewer blocks would reach a total holistic achievement. On the contrary, it is expected that advanced learners would eventually decrease their *KVScore* [15].

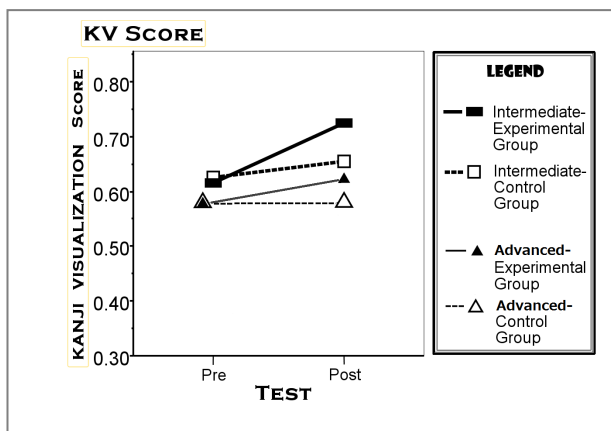


Figure 2. Comparison of KVS cores obtained in Pre-tests and Post-tests, by Learner and by Group factors

X. CONCLUSION AND FUTUREWORK

The educational technique of our LILES System lies in its strategy to help learners, through exploration of deconstruction layouts, to visually deconstruct kanji in ways they have not previously experienced. In doing so, LILES appears to foster learners' cognitive processing of self-generating memory aids that mentally link substructures (blocks) and the kanji that contain them, facilitating learning progress. As Felder stated, global learners should be given the freedom to devise their own methods of solving problems rather than being forced to adopt

the professor's strategy. Active learners do not learn much in situations that require them to be passive [1]. Research has shown that most students of engineering are active learners who learn best when allowed to harness their own creativity in tackling real challenges. Budding engineers would be better served by a more varied curriculum that allows them ample opportunity to actively experience tackling actual engineering challenges, rather than asking them to learn through passively absorbing facts and information. In today's modern world, we are constantly surrounded by innovative ideas in every field, discipline, and market. Our LILES System addresses the challenge of how to create a more effective learning support system in the field of foreign language education, specifically for learning the Japanese writing system, kanji. We believe LILES serves as an excellent example for engineering students of how systems design can be creatively applied to the latest research in most any field to produce an innovative and effective new learning tool or product.

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Standards-Based Grading:

Preliminary Studies to Quantify Changes in Affective and Cognitive Student Behaviors

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Abstract—Assessing student learning is a key component to education. Most institutions assess learning using a score-based grading system. Such systems use multiple individual assignment scores to produce a cumulative final course grade, which may or may not represent what a student has learned. Standards-based grading offers an alternative that addresses the need to directly assess how well students are developing toward meeting the course objectives. The course objectives are the focal point of the grading system, allowing the instructor to assess students on clearly defined objectives throughout the course. The system assesses how well students become proficient in the course objectives over the duration of the course. This study extends the use of standards-based grading at the K-12 level into the realm of undergraduate science, technology, engineering, and mathematics (STEM) education. Five STEM courses pilot tested the integration of a standards-based grading system to investigate how it impacts affective and cognitive student behaviors. The results suggest that a standards-based grading system increased student domain-specific self-efficacy, was perceived as valuable, and helped students develop more sophisticated beliefs about STEM knowledge.

Keywords – standards-based grading, assessment, student behaviors

I. INTRODUCTION

The traditional system to assess student performance in science, technology, engineering and mathematics (STEM) at the higher education level is a summative score-based grading system. Summative grading provides students and teachers alike with a cumulative score on a series of independent measures (e.g., homework, quizzes, and exams). While this assessment does provide a score associated with student performance, the system does not directly assess student development towards achieving the overall course objectives. The summative assessment instead minimizes what was intended to be measured, true student learning.

Standards-based grading is an alternative approach to assessment of student performance and learning. The system involves the direct measurement of student development towards achieving specific, clearly defined course objectives. Student development is tracked throughout the duration of a course using a standards achievement report rather than one-time individually scored assignments. Final course grades are then determined based on students' overall development toward achieving the course objectives, rather than being

based on how well the students' performed on independent (and often unconnected) assignments. The benefit to this approach is that it provides clear, meaningful and personalized feedback for both students and educators regarding student learning.

Although this approach has gained popularity at the K-12 level, there have been no empirical studies to date that analyze the effects of standards-based grading on undergraduate education. The following study discusses preliminary results gathered from an investigation of standards-based grading in undergraduate STEM courses. Our analysis focuses on how the grading system impacts affective and cognitive behaviors of students. Affective behavior was measured by assessing changes in students' self-efficacy and the value they place on standards-based grading. Cognitive behavior was measured by assessing students' epistemological beliefs of STEM knowledge. The intended goal of measuring affective and cognitive behavior is to identify how a grading system impacts the learning of both technical and personal/professional skills. The following paper will present: 1) the overall design and structure of the standards-based grading system and 2) a discussion of measured changes in student affective and cognitive behaviors resulting from the standards-based grading system.

II. STANDARDS-BASED GRADING

Grading systems have been used since the late 1700s to determine whether or not students are meeting relevant academic goals within their courses [1]. Most science, technology, engineering and mathematics (STEM) educators within higher education use the traditional, summative score-based grading system. These grading systems rely on assigning scores to multiple student assignments, which are subsequently summed and issued as a final course grade according to a predetermined scale. The system as it stands does not encourage instructors to stay true to the preset course objectives. As a result, course objectives become unconnected with the process and often are not mentioned beyond the course description and course syllabi [2]. This grading approach inherently fails to meet the conditions for sound assessment of student work and learning [2-4]. The final course grades that students eventually earn only display how

well the students performed on completing a series of separate course assignments.

A new approach is to directly measure the quality of students' proficiency towards achieving well-defined course objectives through *standards-based grading (SBG)*. SBG was first developed during the 1990s when all US states reformed public K-12 education by setting academic standards for what students should know and be able to do [5,6]. SBG utilizes a student standards achievement report (SAR) to track and provide feedback regarding individual student learning and development (a snapshot example is shown in Table 1). More detailed information regarding the standard achievement report is provided in the following reference [7]. Student development towards achieving the course objectives is directly tracked throughout the duration of a course, rather than simply assigning one-time individual scores to student work. The system allows for changes in their development levels to be directly reflected over time. Final course grades are then determined based on students' development towards achieving the course objectives according to an established grading policy.

Educators gain numerous advantages when they use standards-based grading, including but not limited to:

- clear, meaningful and personalized feedback,
- connections between assessment and the predetermined course objectives,
- fairness and transparency in the grading process, and
- a highly effective tool for program assessment [2].

When students are given useful feedback, it provides them with an opportunity to gain insights into their personal learning and development. The content they will learn throughout the semester shifts from being unclear to extremely transparent, which makes students aware of what to expect from the beginning. This provides fair and transparent grading that emphasizes the quality of their current work alone, regardless of how other students in the course perform or on the student's previous levels of development [2]. This in turn promotes the encouragement of student learning and

continuous improvement by placing responsibility for learning on the students themselves [5]. Standards-based grading can also provide detailed feedback for maintaining academic rigor and for assessing with great precision courses, curricula, and entire institutional programs.

Beyond the theoretical advantages, SBG provides tremendous ease of implementation and flexibility regardless of the institution, the course topics or objectives, the instructor, or even pedagogy. Instructors employing a traditional lecture-style approach and those using more progressive, even un-tested pedagogies can easily tailor the SBG system to meet their needs and expectations as necessary. The author's personal experience using SBG in our own classes suggests that the SBG system is even less time consuming to implement than traditional, score-based grading systems. Assessments of student work for each course objective can occur as often as an educator wishes to assess his or her students. Educators can use a one-time evaluation (e.g., homework, examinations, portfolios, a standardized test, etc.) or they can give students multiple opportunities to demonstrate development, i.e., the time allotted for student learning can be fixed or variable. There is also flexibility in how final course grades are determined. For example, a grade of 'A' could be earned if the students' overall average development ranges between 3.7 and 4.0, or if the students demonstrate strong development on a certain percentage of the course objectives. How the grading is best implemented into a course is completely up to the instructor.

Based on feedback obtained from our initial pilot studies [7] and this current study, we have developed a preliminary list of guidelines, or best practices, for implementing the standards-based grading system. In order to successfully implement SBG into your course, we suggest the following:

- establish well-defined course objectives and list them on the course syllabus,
- establish a clear course grading policy and a clear set of assessment rubrics and guidelines,
- develop a detailed standards achievement report and share it with your students at the beginning of the

TABLE I. SNAPSHOT EXAMPLE OF AN INDIVIDUAL STUDENT STANDARDS-ACHIEVEMENT REPORT (SAR)

| Standards Achievement Report (John, 02/15/2012) | | | | | |
|--|---------------|---------------|-----------|-----------|-----------|
| Development Towards Achieving the Course Objectives | Homework 1 | Homework 2 | Quiz 1 | Exam 1 | Quiz 2 |
| 1A: Understanding the concept of stress in a body | 2 | 2 | 2 | 3 | 3 |
| 2A: Analyzing members subjected to axial forces | 2 | 2 | 3 | 3 | 4 |
| 3A: Analyzing members under combined loads | - | - | 2 | 2 | 3 |
| Overall Average Development | 2 | 2 | 2.3 | 2.7 | 3.3 |
| Current Course Grade | C- | C- | C | C | B |
| Progress Level: 4 Strong development 3 Demonstrates appropriate development 2 Approaching appropriate development 1 Needs practice and further development | | | | | |

course, and

- center the course lectures, assignments, and schedule on the standards achievement report.

These theoretical and observed benefits of SBG in K-12 learning environments provide a foundation for our investigation of SBG in STEM undergraduate courses.

III. RESEARCH DESIGN

A series of pilot studies have been conducted to assess the effectiveness of standards-based grading in STEM courses. Students at two diverse institutions – one small private institution and one large public institution – were taught a variety of STEM courses ranging from engineering design to mechanics of materials to computer interaction design. A total sample of 120 STEM students in five different classes taught by four different instructors was obtained for this study. The impact of standards-based grading was assessed through an analysis of student affective and cognitive behaviors.

A. Affective Behavior

1) *Self-Efficacy*: Self-efficacy, or an individual's confidence about their ability, is shaped by experiences, social persuasions, and physiological states [8]. The resulting self-efficacy an individual possesses plays a large role in what tasks are undertaken and the expectancy for success. An individual's performance or behavior is therefore mediated by how efficacious they are in their ability to successfully complete tasks. It is important to measure self-efficacy before and after our standards-based grading intervention to assure that the grading system is not negatively impacting STEM confidence and achievement. This is particularly important for women in STEM who tend to out perform their male counterparts even though they display lower self-efficacy toward their abilities [9-12]. The inclusion of a measure of self-efficacy will provide a gage of how self-efficacy impacts student development and learning in a standards-based grading system.

2) *Value*: Our second measure of affective behavior assesses the value students place on standards-based grading. According to Expectancy Value Theory, behavior is a function of the value one places on achieving a goal [13]. The interest, attainment, utility, and cost associated with perceived individual value impacts the effort and level of responsibility put forth [14-16]. It is our belief that standards-based grading increases the value students place on learning, which consequentially encourages them to put forth more effort. An increase in effort is likely to increase a students' level of responsibility toward learning. The overall measurement of value will provide insights into whether or not the standards-based grading system impacts students' desire to be more responsible toward their education.

B. Cognitive Behavior

Understanding comes from an ability to learn through an active process of constructing a knowledge base from personal experiences [17]. As we gain knowledge, we increase our

ability to find and use it [18]. The understandings we have of a given context come from the adoption of schemata, which consist of the mental representations we use during perception and comprehension. How we learn and adopt new information is influenced by our preconceptions of the world and our metacognitively defined individual learning goals [19].

The SBG system is designed to more accurately measure what students actually understand after the courses. Instructor bias for the system precludes this research from using final course grades to assess student understanding. Instead, we will measure cognitive behavior through epistemological beliefs, or the beliefs we hold about the nature of knowing and learning. The analysis of epistemological beliefs provides a unique view of cognitive gains through the identification of how naïve or sophisticated the students' understanding is [20-21]. Course grades are too often representative of what a student was able to memorize during a course. By measuring epistemological beliefs, we can capture students' general understanding of what it means to actually know something in STEM.

IV. RESULTS

Changes in self-efficacy and epistemological beliefs were evaluated through the use of a pre/post-analysis. Instruments were developed, modified, and validated to assess the specific course objectives and the general domain of STEM. Our assessment of value was given as an added post-analysis component to analyze student perceptions of the unfamiliar standards-based grading system.

A. Self-Efficacy

The base instrument used to measure self-efficacy for each individual STEM course was a modification of a previously validated instrument used to measure engineering design self-efficacy [22]. The task-specific nature of self-efficacy requires an individual assessment of each course based on the course objectives. The base engineering design self-efficacy instrument was modified by each of the course instructors to create a course/content-specific survey. The self-efficacy item development was paired with the development of course objectives to ensure that the survey items and course objectives are clear, concise, and appropriate for the course. Individual pre/post course evaluations revealed self-efficacy toward the course content to improve for all students on all items regardless of subject matter (Table II).

TABLE II. SELF-EFFICACY AVERAGE SCORES.

| Course | N | Average Self-Efficacy | |
|-------------------------|----|-----------------------|------|
| | | Pre | Post |
| Engineering Design | 60 | 71.4 | 86.1 |
| Modern Web Applications | 18 | 15.7 | 81.7 |
| Interaction Design | 5 | 18.9 | 82.3 |
| Elements of Design | 20 | 64.9 | 84.6 |
| Statics | 14 | 40.8 | 93.4 |

A paired-samples t-test revealed increases from pre to post in self-efficacy to be significant to at least the $p \leq 0.05$ level for each individual item. This suggests that the pilot courses improved students' confidence toward the specific course topic.

B. Value

The instrument to measure value was developed specifically for this study. Developed items were theoretically based on Expectancy-Value theory and were presented using a 4-point Agree/Disagree scale. Items were first tested to ensure validity and reliability of the instrument. Three factors emerged from a factor analysis: 1) Interest/Attainment Value, 2) Utility Value, and 3) Cost. An overall Cronbach's α of 0.888 was found for the instrument, which is acceptable by social science research standards [23].

Students overwhelmingly responded with high interest/attainment value and utility value regarding SBG; low cost was also observed (Fig. 1). Written comments supported the quantitative findings and provided great feedback:

"The feedback is great and very explicit – this is a good system for educational growth."

"The primary benefit from standards-based grading was the clear statement and emphasis of learning outcomes. The direct correlation between my course grade and the course objectives forced me to pay attention to what I should be taking away from the course."

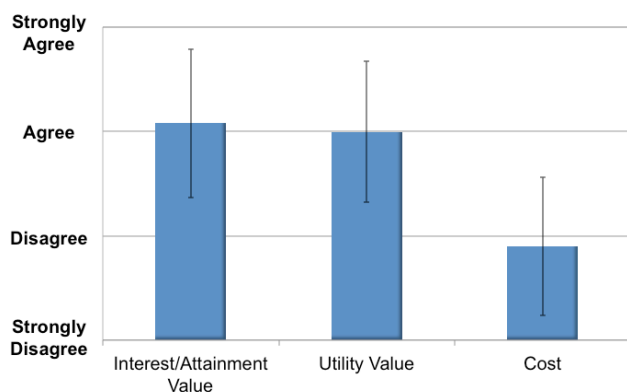


Figure 1. Average student scores for the three major areas of value of standards-based grading.

C. Epistemological Beliefs

The measure of epistemological beliefs was recorded before and after the standards-based intervention using a modified version of the Epistemological Beliefs Assessment for Engineering (EBAE) [24]. This measure identifies appreciated changes in epistemological beliefs.

The modified EBAE was presented using a 4-point Agree/Disagree scale. The items were first tested for validity using a factor analysis, which identified four factors: certainty, simplicity, source, and justification of knowledge and knowing. A Cronbach's α of 0.576 resulted. This value is below the acceptable level of 0.7, but was deemed viable for the pilot study. A pre/post analysis of epistemological beliefs

was conducted for the pilot cohort of students, who on average began their course of study with a far greater propensity for naïve beliefs about STEM, but later exhibited more sophisticated beliefs at the conclusion of their courses (Fig. 2). A paired-samples t-test revealed these increases to be significant except for their belief about 'professional opinions' and 'reciting information being equivalent to understanding.' These generally positive changes were all significant to the $p \leq 0.001$ level.

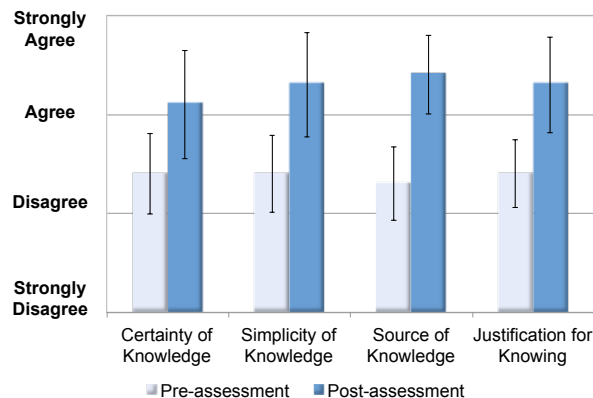


Figure 2. Average student scores for the four major areas of epistemological beliefs

V. DISCUSSION

Our preliminary analysis included an assessment of affective and cognitive behaviors for students participating in a standards-based grading system. We discovered that self-efficacy increased, epistemological beliefs became more sophisticated, and students found the intervention to be interesting without negatively impacting their learning.

The change from a traditional score-based system is intended to change student behaviors, while also helping students to improve their learning. The results suggest that the system does attend to these goals, but it is recognized that the foreign nature of the system causes some students undue stress and confusion. New systems that are unfamiliar to students may be beneficial, but until students open up to the new system and accept something different, the change may not have the intended impact. The observed benefits warrant that further analysis be conducted. The behaviors of the students participating in a standards-based grading system should also be compared to those of students participating in other grading systems to ensure the behaviors are not the same across classes.

VI. LIMITATIONS & FUTURE WORK

This preliminary study is a first step in providing reasoning to formally study and implement standards-based grading in undergraduate STEM courses. The study identified some deficiencies in the current instruments that will be addressed in our future analyses. First, the self-efficacy instrument will be tailored for each course and consist of two components:

1. A general item pertaining to the course, and

2. A set of items that specifically address the course objectives.

The general item will be used to compare courses that may have the same title, but vary in their execution. The implementation of such an approach will allow for more seamless comparison between courses.

The first time use of the value instrument was extremely successful for a newly fabricated instrument. The instrument was shown to be valid and reliable for the study sample. Further validation and reliability analysis will be conducted in future studies to ensure these trends persist.

The instrument to measure epistemological beliefs will continue to be modified to improve the overall reliability of the items. Our alpha value was below the acceptable level, but close enough for us to gain some preliminary insights into students understanding of knowing.

We will also add additional assessments beyond our current affective and cognitive behavioral instruments. Our future investigations of this system will keep a close eye on whether the system reduces student stress and concern over trying to get an 'A'. The current findings provide a solid foundation for more advanced assessments including a comparative analysis of standards-based grading versus traditional score-based grading and the impact of the grading system on the scholarship of teaching and learning.

VII. CONCLUSIONS & IMPLICATIONS

Standards-based grading represents an alternative to traditional score-based grading in STEM undergraduate courses. Our study suggests that implementing this alternative approach will positively impact students' affective and cognitive behaviors. Specifically, we discovered that self-efficacy increased and epistemological beliefs became more sophisticated after participating in a standards-based grading course. Students also displayed high interest, attainment, and utility value while not costing them valuable time and effort in order to learn.

The overall results of this study suggest standards-based grading to be a viable option for undergraduate STEM courses. The implications for switching from the traditional score-based grading system are not insurmountable and worthwhile if students continue to demonstrate improved confidence and knowledge. It is our desire that by switching to an SBG system we can help transform undergraduate STEM assessment by guiding learning with salient course objectives.

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Microwave Engineering Education over the Web

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Abstract—An online simulated Smith chart is designed as an aid to train students to perform impedance matching exercises and to easily follow amplifier design procedures. The tool enables the instructor to conduct classes remotely to a group of students in a broadcasting mode. Students have participated actively and regularly in the online Smith chart tool and their reactions have been positive.

Keywords—component; formatting; style; styling; insert (key words)

I. INTRODUCTION (HEADING 1)

Microwaves have played a considerable role in recent advances and developments in human civilization. As a backbone of modern communication systems, microwave engineering covers the application of knowledge and judgment to the development of components, devices, circuits, and systems involving the generation, transmission, and detection of microwaves. Teaching a microwave engineering course at the undergraduate level in universities worldwide requires instructors to devote a substantial amount of time to equip students with the necessary knowledge and skills to design circuit and systems using modern microstripline technology [1-5]. The course relies heavily on the use of Smith chart to carry out calculations of impedance and reflection coefficient associated with the standing-wave pattern created by multiple reflections of the waves on the transmission line. In addition, the complete design of a microwave amplifier, which occupies a considerable portion of the course, can be completely undertaken using the Smith chart. This requires calculation of several variables, based on the scattering parameters of the amplifier, and to follow rigorous procedures that lead to the ultimate goal of designing input and output matching networks. The procedures include plotting on the Smith chart a number of stability, gain, VSWR and noise figure circles which consequently allow the student to visually select a combination of appropriate conditions and design requirements.

However, working on the Smith chart directly using traditional paper version is tedious, elaborate and time consuming and extremely difficult to attend to every student in the class. In large classes, it is common for students to set idle or talk to each other while the instructor is busy with other students, which may eventually disturb the class. These problems may be solved with the help of teaching assistants or with the use of interactive boards or Tablet PCs. Practical, technical and financial considerations make these solutions difficult to adopt effectively. Although software packages for

designing using Smith charts are readily available, none may be programmed to allow on-line designs to be performed [6-8].

A computer-simulated Smith chart has been designed as a tool to provide online session operating at a broadcasting mode, to allow the instructor to conduct classes remotely to a group of students and give them access to the online session where they will have a screen that shows the entire instructor's work. The tool was incorporated into an open - source blended - learning environment for the microwave engineering course offered at the Communication Engineering Department in Princess Sumaya University for Technology.

II. MICROWAVE AMPLIFIER DESIGN

In the design of a single stage microwave amplifier with certain S-parameters, it is usually assumed that the transistor is driven by a source with impedance, and that its output is connected to a load, as shown in the schematic of Fig. (1).

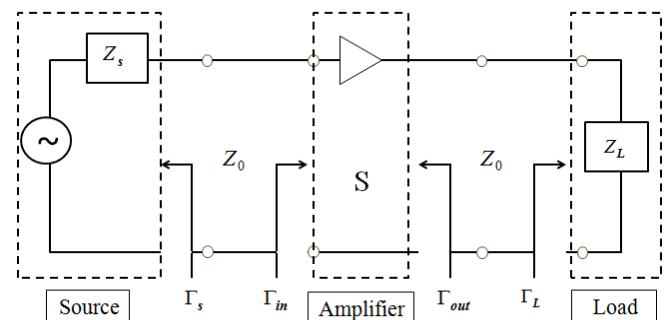


Figure 1. Schematic of a typical single stage transistor amplifier

Using appropriate signal flow diagram and applying Mason's rule to obtain the output/input transfer function, the transducer power gain can be obtained, thus [9]:

$$G_t = \frac{(1 - |\Gamma_s|^2) |S_{21}|^2 (1 - |\Gamma_L|^2)}{|(1 - S_{11}\Gamma_s)(1 - S_{22}\Gamma_L) - (S_{12}S_{21}\Gamma_s\Gamma_L)|^2} \quad (1)$$

where Γ_s and Γ_L are the source and load reflection coefficients respectively. The operating power gain, defined as the ratio of the power available from network to that delivered to the load, is given by [9]:

$$G_a = \frac{|I - \Gamma_s|^2}{|I - S_{11}\Gamma_s|^2} |S_{21}|^2 \frac{I}{|I - \Gamma_{out}|^2} \quad (2)$$

while the available power gain, defined as the ratio of the power available from source to that delivered to the network, is given by [9]:

$$G_p = \frac{1}{1 - |\Gamma_{in}|^2} |S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2} \quad (3)$$

where the reflection coefficients at the input and output are described by [9]:

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \quad (4)$$

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{11}\Gamma_s} \quad (5)$$

The stability of the amplifier may be described by circles at the input and output with radius and centre given by:

$$r_s = \frac{|S_{12}S_{21}|}{|S_{11}|^2 - |\Delta|^2} \quad (6)$$

and

$$c_s = \frac{(S_{11} - \Delta S_{22}^*)}{|S_{11}|^2 - |\Delta|^2} \quad (7)$$

while for the output stability circles, the radius is given by:

$$r_l = \frac{|S_{12}S_{21}|}{|S_{22}|^2 - |\Delta|^2} \quad (8)$$

and the centre is:

$$c_l = \frac{(S_{22} - \Delta S_{11}^*)}{|S_{22}|^2 - |\Delta|^2} \quad (9)$$

where the delta factor is $\Delta = S_{11}S_{22} - S_{12}S_{21}$.

The noise performance of the amplifier is also investigated in a similar manner and circles for certain values of noise figure are calculated and plotted on the Smith chart such that the centre and radius are respectively given by [9]:

$$c_{ri} = \frac{\Gamma_0}{I + N_i} \quad (10)$$

$$r_{ri} = \frac{1}{1 + N_i} \left[N_i^2 + N_i (1 - |\Gamma_0|^2) \right]^{\frac{1}{2}} \quad (11)$$

where Γ_0 is the noise reflection coefficient and r_n is the normalized noise resistance, and:

$$N_i = \frac{F_i - F_{min}}{4r_n} |I + \Gamma_0|^2 \quad (12)$$

where F_{min} is the minimum noise figure of the transistor.

Generally, a simple small-signal microwave amplifier design procedure begins with choosing suitable bias conditions for gain, linearity, noise, etc. The biasing parameters will then set the small signal S-parameters of the transistor. The next step is to determine the delta factor and stability factors as well as the values of radius and centre of the stability circles at the input and output and to plot them on the Smith chart to see if the amplifier is unconditionally stable or potentially unstable. Constant gain circles, operating power gain circles, available power gain circles and noise figure circles can be all easily plotted in the chart once their centres and radii are calculated according to the equations above. Once the designer chooses the gain, noise and VSWR values, matching networks (MN) at the input and output are selected to transform the source and load to impedances that will provide the required design parameters as shown in Fig. (2).

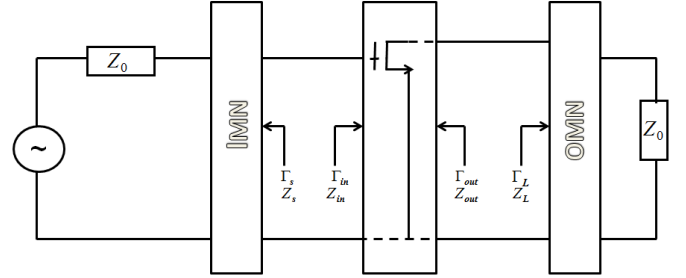


Figure 2. Schematic of a typical matched single stage transistor amplifier

III. ONLINE SMITH CHART

The Smith chart, created by Philip Smith in 1939, is a simple transformation of the equation that relates the reflection coefficient to the load impedance terminating the transmission line, given by:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (13)$$

where Z_0 is the characteristic impedance of the transmission line. Simple mathematical manipulations show that this transformation results in a series of resistance or r-circles and reactive or x-circles, where r and x are the normalized resistance and reactance and the resulting plotting of these circles is known as the Smith chart shown in Fig. (3).

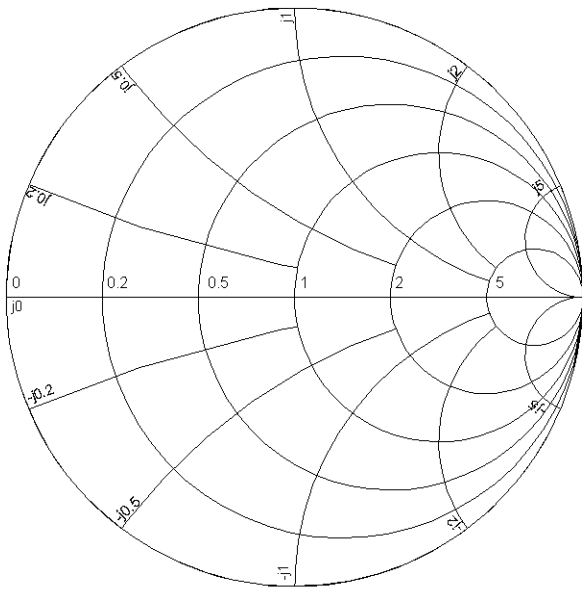


Figure 3. Simple Smith chart

The Smith chart is a useful graphical aid to the circuit designer that has been used extensively in recent years for the design of high-frequency transistor circuits employing strip transmission lines on high-frequency substrate materials. This graphical method is particularly effective for the design of microwave transistor amplifier which facilitates the demarcation of stable and unstable regions of operation on the chart, thereby allowing the proper choice of gain, noise-figure and VSWR and hence input and output matching networks for the desired mode of operation.

An online Smith chart was designed and launched at www.smithsimulator.com. The tool provides a simple interface to implement various applications such as impedance transformation, matching and microwave amplifier design. The tool also provides an online session operating at a broadcasting mode which allows the instructor to conduct classes remotely to a group of students and give them access to the online session where they will have a screen that shows the entire instructor's work. This allows the instructor to open and transmit a session to students who can follow a step-by-step procedure for plotting any required circle required in the design of the input and output matching networks. First, an interface page where S-parameters of the transistor are inserted, and then, according to a special menu, stability, constant, operating, available power gain and noise circles are selected and plotted.

The platform access simulator was designed with C# backend coding to function online via an ASP active page. This is considered as one of the most powerful web development methods. The programme was coded in such a way as to easily enable future development by creating each part of the system as an individual entity. The core of the system is the chart "object" since it is the part that should be used and called after making the appropriate calculations to display the results. This part does not do any calculations by

itself but rather accepts parameter from other functions that include a center of a circle, its radius, angle, and its description. The chart object is continuously refreshed to show the newly added circle. Some core functions are provided currently in the simulator as constant gain, stability circles, and demonstration circles. Other functions/circles can be added by user using the chart API. This may include the matching function which can be used to move/transfer from a point to another in the simulator. The interaction between this function and the chart object is made possible through API. This function can be considered as a part of the chart object itself, and the user cannot make such function using the API.

IV. RESULTS AND DISCUSSIONS

The eSmith chart was used over a period of 4 semesters in the academic years 2010-2012. It was constantly developed by the students themselves in order to improve its functionalities and to make it suitable for the purposes of teaching the "Microwave Engineering" class and to enhance its efficiency. Initially, students were trained to design a microwave amplifier following a step-by-step procedure using traditional hard copy Smith charts. Once they master these procedures, more complicated examples were solved using the eSmith chart. In this way, a complete comprehension of microwave amplifier designs was achieved. Fig. (4) shows a snapshot of an example of the stability circles and constant-gain circle of a transistor with specific S-parameters.

Other features were added to the system to improve the user experience such as allowing a student to save results in her/his own user history to be able to go back later to records and check out the results. In addition, the system was designed to support multiple classes/instructors each with a unique set of students. Using this feature, students were able to submit their work to the instructor by one-click. In such case, the instructor will receive an email with the student results and an image copy of the chart in the same manner as the in the process of saving history.

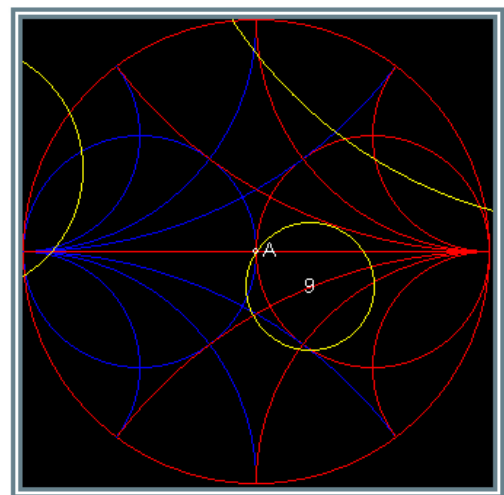


Figure 4. An online version of the eSmith chart with stability and a constant gain circles plotted

One of the main exciting features embedded is the broadcasting mode. This allows the instructor the opportunity to offer online lectures in to broadcast mode and to present classes remotely to online students as shown in Fig. (5). The instructor starts using the simulator by notifying students in the class in their main student page about an active broadcasting session. The functionality of the simulator in the broadcasting mode is no different than what students use, but just lacking some features like emailing, and saving to history.

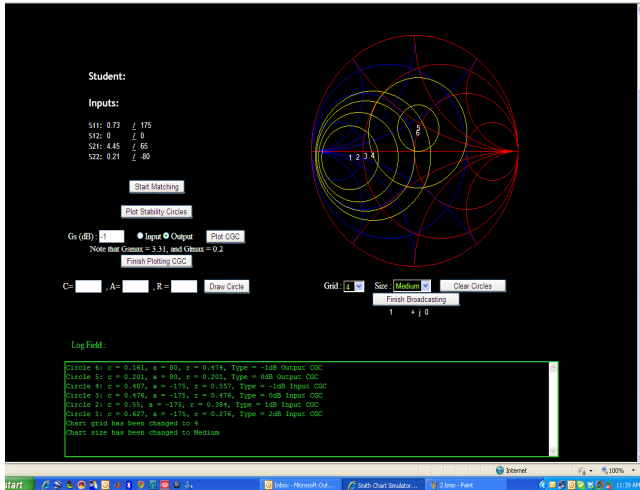


Figure.5. An online lectures in a broadcast mode

The feedback of students on the use of the eSmith chart was investigated through an online questionnaire conducted over the period of 4 semesters in the academic years 2010-2012. The questionnaire consisted of 8 questions aimed to cover a wide range of subjects posted online at www.psut.edu.jo/surveys. The following questions about the students experience in using the eSmith chart in a Microwave Engineering course were used for the survey:

Q1: The eSmith chart was well arranged and easy accessible.

Q2- The design procedures were clearly followed.

Q3- The eSmith chart helped making microwave amplifier design fast and efficient.

Q4- The eSmith chart was very valuable in the learning process.

Q5- Using the eSmith chart was a comfortable experience.

Q6- There was many difficulties in performing eSmith chart designs.

Q7- The eSmith chart has actually increased my interest in the course.

Q8- Overall, do you support the use of the eSmith chart in teaching the Microwave Engineering course?

The survey included 160 students enrolled in an undergraduate Microwave Engineering course, and the results of the survey are illustrated in Fig. (6), where the X-axis represents the question number and the Y-axis represents the overall percentage of the sample for each answer. As shown in the graph, there was a good agreement among students that they feel comfortable using the eSmith chart which helped making microwave amplifier design fast and efficient with clear design procedures. Over 80% of the respondents found

the eSmith chart valuable in the learning process and would support its use in teaching the “Microwave Engineering” course. Only 30 % of students faced difficulties in performing eSmith chart designs mainly due to internet connectivity, user-interface friendliness and accessibility. This low percentage was due to the fact that the system was designed by the students themselves who were constantly consulting each other during the design process.

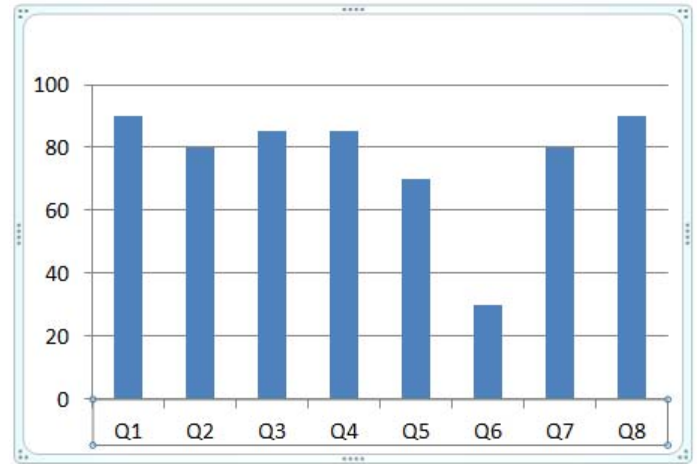


Figure 6. Results of the survey

The students’ perception of the proposed method seems positive and encouraging by their active and regular participation and reactions which shows that the eSmith chart is a user friendly that has a fast learning curve which may be useful to incorporate in a collaborative distance learning environment. Attempts for combining in the class and online technologies for teaching the microwave engineering course will continue to provide teachers and students with an active and participative role in the learning process.

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Distance Education with remote poles: an example from the Amazon region

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Abstract - The Amazon region is characterized by its low population density, with one large city, the capital Manaus, and the remainder of its population distributed in small and less economically developed towns. Most of these towns suffer from huge geographic isolation, as these are scattered in the forest and their access are only through rivers. With all these difficulties, taking education to this population consists of a real and daily challenge. To provide an opportunity for students of this region to enter into an upper-level course, one of the solutions devised by the Federal University of Amazonas, through its Center for Distance Education (CDE) was the creation of undergraduate courses in non-face mode. CDE project consisted of organizing headquarters, called poles, to receive courses in Administration, Public Administration, Fine Arts, Biology, Agricultural Sciences and Physical Education. This paper describes this educational experience and presents the structure of the pedagogical model supported by technology (PMT) which allows this scenario to become reality. The innovation of this model is to allow the 1,618 students, distributed in 17 different poles, assisted by CDE, to keep pace with their course through a structure of logistical and technological support adapted to their reality. Resources offered by a Course Management System (CMS), tutors and other specialized tools that support off-line activities make it possible for higher education to reach the most remote regions of Amazon.

Keywords - distance education; pedagogical model supported by technology

I. INTRODUCTION

Distance Education (DE) is a teaching modality, applied to any level of education, in order to extend the possibilities of access to knowledge, democratizing access to education. In DE, according to [1], “students and teachers are in different locations during all or most of the time they learn and teach”, providing benefits that create more flexibility to the student in terms of time and place of study.

In Brazil, a country with extensive territorial dimensions, with its strong economic inequality and cultural diversity, distance education is gaining importance and challenges, with many initiatives and incentives from the government. In this context, higher education institutions have implemented and adapted their models of distance education according to their reality and students needs.

This paper presents a DE model implemented by the Center for Distance Education (CDE) of Federal University of Amazonas, highlighting its physical infrastructure and personnel, its installed poles and associated pedagogical model. Some preliminary results of CDE along its five years of existence are presented.

II. CENTER FOR DISTANCE EDUCATION STRUCTURE

The Center for Distance Education (CDE) [2] is a supplementary unity of the Federal University of Amazonas (UFAM). CDE is responsible for providing initial and continuous education in undergraduate and graduate courses to many cities in the state of Amazonas. These courses are offered in distance mode and rely on technological and pedagogical support from a well structured and capable team. This team is responsible for applying information and communication technology in educational process.

The board of CDE has five coordinators to support the courses: Administrative, Design, Pedagogical, Undergraduate and Technology. About 50 direct employees work at its headquarters in Manaus.

CDE offers courses since 2007 and currently offers undergraduate courses in the following areas: Administration, Public Administration, Fine Arts, Biology, Agricultural Sciences and Physical Education. Besides those, the post-graduate courses are: Production of Teaching Materials for Distance Education, Public Administration, Municipal Public Management and Health Administration. All courses are free.

The undergraduate courses are distributed in 17 different poles. Fig. 1 shows the state of Amazonas and each town that has a pole. Manaus, the capital, is located in the northeastern part of the state. Amazonas is the largest Brazilian state, and the 9th largest country subdivision in the world. Its area is larger than Germany, France, United Kingdom and Japan all together.

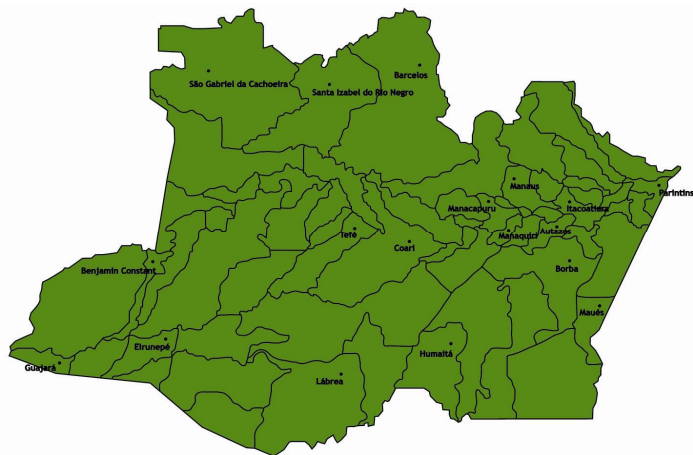


Figure 1. Amazonas state with its poles

Most towns suffer from huge geographic isolation, as these are scattered through the forest and its only access is by river. This situation makes population access to basic services, as Education, a difficult task [3].

| Distance between Manaus and poles | | |
|-----------------------------------|------|------|
| City | km | Mi |
| Manauquiri | 67 | 42 |
| Manacapuru | 102 | 63 |
| Autazes | 161 | 100 |
| Borba | 215 | 134 |
| Itacoatiara | 329 | 204 |
| Maues | 356 | 221 |
| Parintins | 420 | 261 |
| Coari | 463 | 288 |
| Barcelos | 496 | 308 |
| Tefe | 672 | 418 |
| Santa Izabel do Rio Negro | 772 | 480 |
| Sao Gabriel da Cachoeira | 1064 | 661 |
| Humaita | 1544 | 959 |
| Guajara | 1570 | 976 |
| Benjamin Constant | 1628 | 1012 |
| Labrea | 1672 | 1039 |
| Eirunepe | 5138 | 3193 |

Table 1. Distance between Manaus and poles.

Table 1 shows the distance between the capital and the poles. These data refer to distance by river.

In order to have a better vision of the dimension of the context, we present the courses offered in the different poles along with the number of the students, as it can be seen in Table 2. CDE currently has 1,618 students distributed in six undergraduate courses. Most students are in distant poles. Headquarters in Manaus also serves as a pole for three courses: Biology, Physical Education and Public Administration.

| Total active students – undergraduate 2011 | | |
|--|--|----------|
| Course | Poles | Students |
| Administration | Coari Labrea Manacapuru Maues | 106 |
| Agricultural Sciences | Coari Labrea Manacapuru Manauquiri Maues Santa Izabel do R. N. Tefe | 260 |
| Biology | Benjamin Constant Coari Humaita Itacoatiara Manaus Parintins São Gabriel da C. | 353 |
| Fine Arts | Coari Labrea Manacapuru Manauquiri Maues Santa Izabel do R. N. Tefe | 206 |
| Physical Education | All 17 poles | 453 |
| Public Administration | Coari Itacoatiara Labrea Manacapuru Manaus Maues | 240 |
| Total | | 1,618 |

Table 2. Distribution of courses and students.

III. PEDAGOGICAL MODEL SUPPORTED BY TECHNOLOGY (PMT)

According to [4], a pedagogical model adapted for distance education should seek for new paradigms in teacher-student relationship. Pedagogical, organizational and technological elements of this model should be harmonized so that learning happens interactively, collaboratively and autonomously.

CDE has a differential model of distance education which adapts to the reality of the poles to which undergraduate courses are offered. As large geographical distances from its

Due to these difficulties, PMT was structured considering the CMS, the administrative and logistical support of both coordination of undergraduate courses and technology of CDE in Manaus, the technical and pedagogical support of tutors, and specialist support of teachers. Fig. 2 shows the PMT in a simplified manner, outlining the teaching-learning process proposed by CDE. It is interesting to note that actors can interact with each other through the CMS and that, despite the hierarchical representation, the structure allows students, tutors and teachers to act collaboratively across lines of interaction.

Therefore, we note in PMT that there is harmony and cooperation between educational and technological elements, taking this model to capture, holistically, all the needs of CDE students. According to [7], teaching-learning models that combine these elements make up a new method within the concepts of different pedagogical proposals. This theory is called “blended learning” [7] and presents many advantages when there is a need to include features such as multimedia technology and virtual classrooms, as support for traditional learning approaches.

In [8], blended learning is defined as the “effective integration of various learning techniques, technologies, and delivery modalities to meet specific communication, knowledge sharing, and informational needs.” Thus, the innovation of PMT of CDE is right in the integration of features that are common to face-to-face education and distance education models, within the context of Amazonian reality.

IV. PRELIMINARY RESULTS

Undergraduate courses offered by CDE are still ongoing, and the forecast is that at the end of 2012, the first groups of courses in Administration, Fine Arts and Agricultural Sciences will graduate the first students. However, we can already analyze some preliminary results of the effort to take higher education to remote regions of the Amazon.

Because it is the case of distance education courses mediated by technology, dropout rates and failure are within the expected [9] and dropout rates are not directly related to the proximity of the pole with headquarters in Manaus, and consequently, better ease of internet access. As an example, and to illustrate these statements, Fig. 3 shows the percentage of students who passed the course, were not approved and the dropouts in Administration course, placing the poles in order of increasing distance from the headquarters in Manaus.

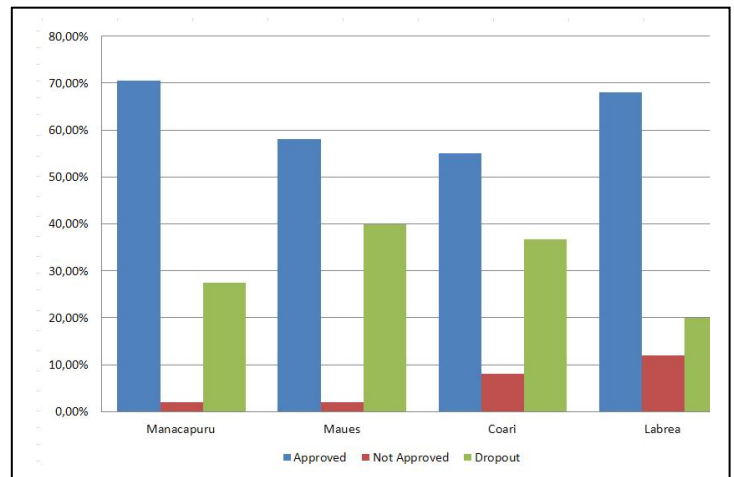


Figure 3. Index of Administration course

The Administration course was one of the first to be offered by CDE and needed adjustments during the course development. The presentation of an undergraduate course based on a mode different from the traditional was new to the poles and the students took a while to adapt to the pace of the demands of distance education.

At the beginning of the course, the major difficulty faced by these students was the paradigm shift from face-to-face to distance education. Distance education requires discipline and an autonomous construction of knowledge [1], making use of collaborative and interactive tools and resources. Furthermore, the insertion of the CMS as a learning support environment forced the students to acquire and enhance knowledge in basic informatics and internet use in their daily studies. In the first module, the scores were relatively low, being necessary adjustments and reassessments of the methods to avoid mass failure. One of the strategies was to offer summer school to the students who failed in some discipline. Other strategy was to be more flexible on deadlines and number of activities. From the middle of the course on, these problems disappeared and the levels of approval and failure are similar to courses offered in face-to-face mode [11][12].

V. FINAL CONSIDERATIONS

Population in remote regions usually suffers with precarious infrastructure and difficulty of access to basic services as Education. Distance education seems to be one of the solutions, although effective implementation is a real challenging task. On the other hand, it is really grateful to be part of this important process.

At UFAM, CDE has tried to do it with a pedagogical model supported by technology and a committed team. The model aims to give all necessary support and conditions to the students that cannot be always online. This model is based on

¹ GESAC – Program financed by federal government to digital inclusion in remote regions of the country [9].

blended learning theory to provide an educational solution supported by technology and combined with conventional educational schemes.

Surprisingly, opposite to what situation would suggest, distance does not seem to be a determining factor in performance, as it can be seen by preliminary results.

Even with an appropriate pedagogical model supported by technology, it seems that the intrinsic difficulties of distance education, such as autonomy and self organization, remain an important issue to be considered. Even in traditional education these are important aspects that sometimes students do not develop.

Future works may be on trying to motivate students to become more active learning through adaptive techniques.

VI. ACKNOWLEDGEMENTS

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Practical experiences on building structured remote and virtual laboratories from the student's point of view

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Abstract – Nowadays, the use of remote laboratories is a common feature in order to get students involved in practical experiences. This is particularly important in distance learning environment. The regular practice is to develop a particular laboratory, required by the student competence's curricula. Usually, this involves a lack of methodology or a standard procedure so, new developments must be done to include new laboratories, additionally so many “manual” procedures are required. RELATED (REmote LABoratory Extended) it's used to solve these issues. In this paper, a practical experience of the structured development process of a virtual laboratory, using RELATED framework, will be presented from the point of view of students. This virtual laboratory is a simple signal generator. This signal generator will be used to generate a reference position for the height of the ball of an electromagnetic levitation system in a control experiment. Finally, responses of surveys made by students will be presented, in order to get satisfaction results of using/development of virtual/remote laboratories using RELATED.

Index Terms - remote experimenting, virtual and remote laboratories, software development, services and facilities, practical experience

II. INTRODUCTION

Acquiring qualitative knowledge is one of the most important things in control engineering education [1-3]. Giving students a taste of real situations, the behavior of measure instruments and how does the control action work, is a vital aspect nowadays. All these things can be done with laboratory experiments although it can be tricky with a large amount of students or in distance learning environment, as it is proposed by UNED (National Distance University of Spain) in its official degrees.

The idea is for the students to be able to perform real experiments [4-5], in real time, on real equipment, but over the Internet. This idea is in fact a widely discussed issue. In this general context there are many works, but all these remote and virtual laboratories are punctual efforts of different research groups. The use of the software and

hardware of different universities is not contemplated in any case, not taking advantage of the work previously carried out by others. This is to say, a lack of methodology or a standard for the construction of networks of virtual/remote laboratories based on previous developments. Also, services and facilities for all of these laboratories are not present.

RELATED framework [6] proposes a structured methodology of remote/virtual labs development and, also, provides common facilities as user management, booking, basic visualization (trend graphs and direct interaction using interactive variables), data logging and experimental session's control. A RLAB (Remote LABoratory) system is defined using a formal specification (which is LEDML, based on XML). The main component is an experiment, which is defined on the laboratory XML specification. To integrate a laboratory as a RLAB system is only necessary to develop local access to laboratory equipment using Java technology and the “module” paradigm. These modules, which are run-able entities, are started by the RELATED facilities in order to get/set data from/to the laboratory equipment. This data will be sent over Internet to the RELATED client too.

As users need graphical interfaces in order to understand and operate with the remote/virtual labs, RELATED framework provides the concept of “view”, which is a coded entity with the purpose of showing widgets and other GUI components. RELATED also provides built-in graphical user interface facilities, defined in a basic way, as it will be shown in the next sections.

In the next section, the fundamentals of RELATED will be shown. Also, it will be shown how a laboratory can be described in terms of its components. This section will show the development cycle and the facilities which are automatically part of the framework. In Section III, the magnetic levitation system will be presented in order to apply the development cycle using RELATED methodology (Shown in section IV). In Section V, student's development procedure and results are explained and showed, and how their results are used as the building of a remote experiment using the remote levitation lab. In Section VI, results of a survey performed by students are detailed. Finally, conclusions will be presented in section VII.

II. RELATED BASICS

RELATED provides a structured way of developing remote and virtual laboratories, focusing in lab definition and built-in facilities. To achieve this objective, these are the steps which are defined in the methodology:

A. Defining laboratory structure

Structuring the lab is one of the main tasks a developer/teacher must do [7]. There are three main components in RELATED which are necessary to describe the laboratory:

a) *Modules*. They are the basic part of development and provide virtual/physical access to lab data. They are “black boxes” used to describe the component as a set of input/output variables. This paradigm allows the interconnection of modules, being possible to flow data between a module and others. Developers must provide read/write function to get/set data for these variables.

b) *Views*. They provide the visual information to the final user (students, teachers, etc.). GUI can be included in these views. These views use data from modules to update the experiments state, and it is possible to send to modules values changed in the GUI (Graphical User Interface).

c) *Experiments*. They define the behavior expected from the lab, so one or more experiments can be defined on the lab. Basically, it is possible to define an experiment by stating the set of modules and views that will be used in the experiment. Any convenient combination of modules and views can be used as an experiment.

In order to get a full description of lab’s components, a description file based on XML must be defined. In Fig. 1, the levitator example (explained in the next sections) is shown. Fig. 2, 3 & 4 show detailed components definition for a module, view and experiment in the remote lab.

B. Developing coded entities

Once the labs components are defined, a full implementation of modules and views must be coded in order to assign the attribute/tag `<implementation>` to these entities. To “pack” the modules for RELATED runtime use, it’s mandatory to create a jar file with a main class implementing the IRLABModule java interface, which define several restrictions needed to integrate the module with RELATED.

C. Publish laboratory

With the XML definition (laboratory structure) and implemented modules and views, the next step is to “publish” the lab (and its experiments) in the RELATED Web Server. For doing this and application is provided (RLAB Publish Application) in order to validate the XML file and publish the laboratory. In Fig. 5, the RLAB Publish Application shows how the XML for levitator system has been correctly parsed and published on RELATED Web [8].

Once the laboratory is registered on main server, the lab is available to registered users, who have authorization, in the RELATED Web Server. Managers of laboratories can

add permissions of use to the registered users in the RELATED web server, using authorization system associated to every laboratory published.

```
<?xml version="1.0" encoding="utf-8" ?>
<system name="MAGLEV" type="0" description="MAGLEV, Quanser Magnetic Levitator">
  <module name="PIV_MODULE">
    <module name="PI_MODULE">
      <module name="VIDEO SERVER module">Remote image JPEG access
    </module>
    <module name="SG MODULE">Signal generator module for SINE, SQUARE and TRIANGLE modes
    </module>
    <view name="ImageViewer">
      <view name="VirtualViewPIV">EJS developed view and libraries
    </view>
    <experiment name="Ball position" sampleTime="100">Ball position controller
    </experiment>
    <experiment name="Current control" sampleTime="100">Current PI controller experiment
    </experiment>
    <experiment name="Ball position (generator)" sampleTime="100">Ball position controller with
    generator
    </experiment>
    <manager name="rpastor"/>
    <manager name="demo"/>
  </module>
</system>
```

Figure 1. Levitator XML components definition

```
<module name="PIV_MODULE">
  <param name="TargetName" type="string" value="q_piv_maglev">QUARC Target Name (without
  extension)</param>
  <param name="FilePath" type="string"
  value="D://users/rafa/labs/quarc_levitador/modulos_simulink">File Path to Target</param>
  <var name="current" type="double" initial="0" max="3" min="0" units="I">Current applied for
  electromagnetic field</var>
  <var name="position_sp" type="double" initial="0" max="3" min="0" units="mm">Position setpoint
  measured from MAGLEV</var>
  <var name="position" type="double" initial="0" max="3" min="0" units="mm">Ball position</var>
  <var name="SP_OffsetPosition" type="double" initial="0" max="9" min="-.5" units="mm">Position
  setpoint sent to levitator</var>
  <var name="Kff_b" type="double" initial="142.9291" max="10000" min="-.10000" units="A/m">PIV
  Controller parameter for ball position</var>
  <var name="Kp_b" type="double" initial="-.229.0363" max="10000" min="-.10000" units="A/m">PIV
  Controller parameter for ball position</var>
  <var name="Ki_b" type="double" initial="-.192.3205" max="10000" min="-.10000"
  units="A/s/m">PIV Controller parameter for ball position</var>
  <var name="Kv_b" type="double" initial="-.3.7808" max="10000" min="-.10000" units="A.s/m">PIV
  Controller parameter for ball position</var>
  <var name="Kp_c" type="double" initial="182.875" max="10000" min="-.10000" units="V/A">PI
  Controller parameter for current</var>
  <var name="Ki_c" type="double" initial="24801.5625" max="100000" min="-.100000"
  units="V/s/A">PI Controller parameter for current</var>
  <implementation type="JAVA" jarfile=".../examples/MAGLEV/code/MAGLEVClientJavaApplication.jar"
  classname="es.uned.scc.rlab.modules.maglev.MaglevPIVModule">PIV Feedforward Controller: Ball
  position</implementation>
</module>
```

Figure 2. Ball Position Control Module

```
<view name="VirtualViewPIV" jarfile=".../examples/maglev/code/MAGLEV_EJSView.jar"
  classname="es.uned.scc.rlab.views.maglev.levitador.MAGLEVView"
  helperUrls=".../examples/maglev/code/ejs_levitador.jar">EJS developed view and libraries
  <use name="position" module="PIV_MODULE" as="ball_height"/>
</view>
```

Figure 3. Virtual View for Levitator

```
<experiment name="Ball position" sampleTime="100">Ball position controller
  <duration type="time" time="120" />
  <run module="PIV_MODULE">
    <interactives names="SP_OffsetPosition,Kff_b,Kp_b,Ki_b,Kv_b,Kp_c,Ki_c" show="true,true,true,true,true,true"/>
    <paint names="position,position_sp" colors="yellow,red"/>
    <paint names="current" colors="blue"/>
  </run>
  <run module="VIDEO SERVER module">
    <interactives names="command" show="false"/>
  </run>
  <open view="ImageViewer"/>
  <open view="VirtualViewPIV"/>
</experiment>
```

Figure 4. Ball Position Control Experiment

D. Run Experiments

The experiments can be started through the RELATED Web Server simply clicking on the experiment name. A JWS (Java Web Start) application will be downloaded and, if the Internet navigator is properly configured, the login control facility will start automatically (Fig. 7). User login data

must be filled in order to show the experiment control panel (see Fig. 8).

The experiment control panel provides automatically some facilities as:

- *Booking slot time*: For every experiment, a slot time is assigned to avoid multiple concurrent users. It is represented on the upper left corner of the experiment control panel, using a three color state clock. Green represents free time for using experiment, yellow indicates less than 10% of the booking time and red color is used to indicate the finishing of slot time.
- *Experiment time*. Values of experiment starting time and actual time are presented to users in order to know time evolution for its experiment.
- *Graphical trends*. In order to add this feature, there is the possibility of adding special <paint> tags in the experiment definition. It is possible to group several variables into the same tag, which is useful for related variables. The graphical trends are presented in the lower left part of the Experiment Control Panel.
- *Interactive variables*. Usually a view is used to change some variables in one or more modules but, in simple experiments it is possible to define a set of variables which can be modified directly from the Experiment Control Panel. There is a special tag (<interactives>) for doing this. The interactive variables are usually presented on the lower right corner of the Experiment Control Panel.

Once the experiment control panel is shown, users have to press the “Start experiment” button in order to run it. After pressing the “Start experiment” this button changes for a “Stop experiment” button. In order to stop the experiment, users need to press this “Stop experiment” button.

III. LEVITATOR ON-SITE LABORATORY

Quanser [9] has on-site didactical equipment called MAGLEV (MAGnetic LEVitation system), see Fig. 9(a). This equipment provides a magnetic field in order to get an steel ball levitating in air. The MAGLEV system consists in a rectangular enclosure which has three distinct sections.

First, there is a solenoid coil with a steel core, which provides the magnetic field. In second place, there is a chamber, with white walls, where the magnetic ball suspension takes place. And, in third place, there is a bottom place where a photo-sensitive transistor (with conditioning circuitry) measures ball position, also it has offset and gain potentiometers for proper calibration. There is a cylindrical post inside the middle chamber, which is empty in the inside, where the phototransistor is situated.

The MAGLEV system provides two experiments to be carried out: coil current control and ball position control. Both of them are based on the assumption that students will run these experiments in the same “location” as the

equipment is laid. It’s necessary to do some modifications in order to get a real remote lab.

The next section will show how it is the MAGLEV reconfigured and the control software is reused using the RELATED framework.

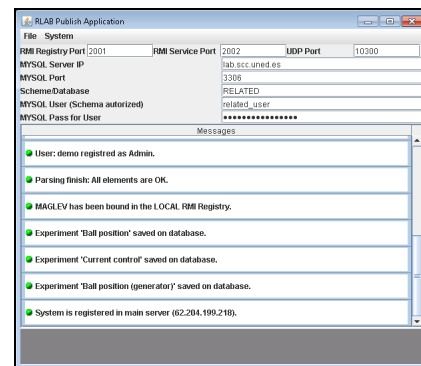


Figure 5. RLAB Publish Application

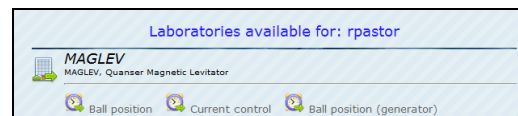


Figure 6. RELATED Web Server: Laboratory list for an user.

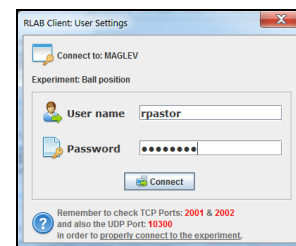


Figure 7. User login in the client application.

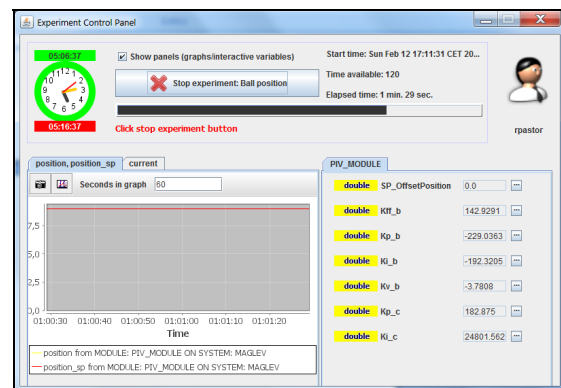


Figure 8. Experiment Control Panel

IV. REMOTE LAB FOR LEVITATOR

In order to reconfigure the on-site lab hardware, the first step is to avoid manual procedures associated with the on-site experiences. The main problem occurs when the ball falls outside the post. The solution is to surround the post with a plastic cylinder, in this way the ball never falls out. The next step is to define MAGLEV laboratory and to

reconfigure software procedures, as it is explained in the next sub-sections.

A. Laboratory specification

They are needed two modules for the two types of control experiences.

a) *PI_MODULE*: Coil current control experience which has several variables like coil current, voltage, command signal, and so. It is based in a PI (Proportional-Integral) controller, which parameters are named K_{c_p} and K_{p_i} .

b) *PIV_MODULE*: This is the ball position control experience, and the controller it's a bit more complicated than the anterior module. It's based in a feed forward plus velocity controller, and it has also the PI current loop control. Like the previous one, it has all the typical variables like coil current and so, and the specific ones of the controller (K_{ff_b} , K_{p_b} , K_{i_b} and K_{v_b}).

Also, two auxiliary modules are used: one associate to a signal generator for setpoints (*SG_MODULE*) and another associated to the video streaming (*VIDEO SERVER* module) which allows getting a real time image of the MAGLEV system. Additionally, to get a more detailed view of the remote MAGLEV system, two "views" are defined: one to represent the MAGLEV system (see Fig. 11(b)) and another to view a real time image of the steel ball.

Finally, a set of experiments can be defined using these last modules and views:

a) *Current control*: This experiment represents the coil current control experiences and its definition includes the use of *PI_MODULE* & *VIDEO SERVER* modules and the two views (*ImageViewer* and *MAGLEV Virtual View*).

b) *Ball position*: In this case, the modules which are used are *PIV_MODULE* and *VIDEO SERVER* module.

c) *Ball position (generator)*. Similar to the above experiment, but also include the *SG_MODULE* module in order to use the signal generator for the ball position.

B. Modules development

QUANSER provides QUARC software, which are composed of several modules, including some based on Matlab/Simulink models. As the Simulink models are implemented for on-site experiments, they need some modifications. The model needs to be modified with network specific blocks which allow get/set information from the model (see Fig. 10).

C. Views development

There are two views defined in the XML file. One of them is the virtual view [10] for MAGLEV system (see Fig. 9 (b)). The other view is associated to the video streaming of images from a network camera. Really, the view is supported by the use of the *VIDEO SERVER* module.

D. Final steps

Once the development steps are done, the final step is to publish the MAGLEV laboratory in the RELATED Web Server (as it was mentioned before, in section II).

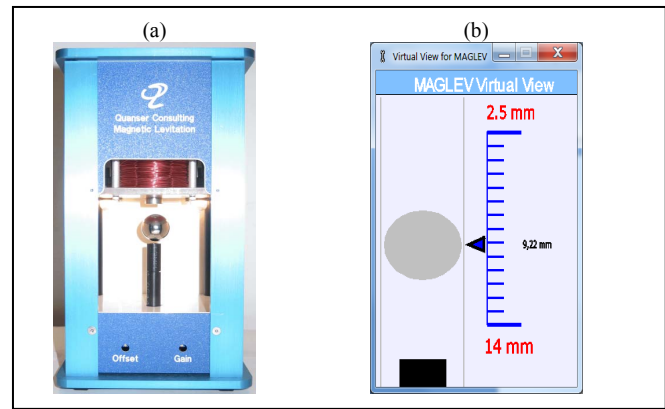


Figure 9. MAGLEV System: Real (a) and Virtual (b)

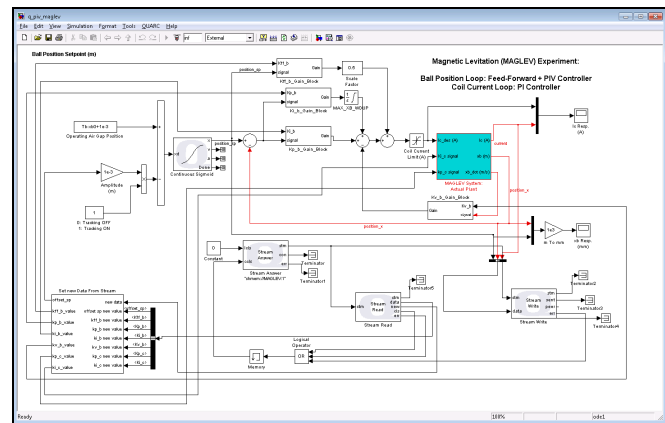


Figure 10. Re-Configured Simulink Model with network support.

V. STUDENT'S VIRTUAL/REMOTE LAB.

The practical experience which must be carried on by students has two different parts: development of a virtual signal generator and integration of the virtual lab with the remote lab (levitator). Students are enrolled in the subject called *Distributed Systems* on the Computer Science Degree at the National Spanish Distance University (UNED).

A. Development of the virtual lab.

In this part, first, students must familiarize with the publish process of a RELATED lab. For this objective it is used a predefined lab with its code available for the students (a simple random generator of 4 values). Next, they must develop a module for the signal generator and a simple view to change type, frequency and amplitude of signal generator. The development process is based on the procedures explained in Section II, in a similar way but more simple than the levitator system development. Fig. 11 details the developed view by student and the output computed in the RELATED client application.

Once the virtual lab is developed, a module component is available for reusing in other laboratories (module corresponding to signal generator). So, the next step in the practical experience is its integration with a remote lab (the MAGLEV system).

B. Integrating the virtual lab as a remote lab.

In order to create and publish the student's remote laboratory, the only task which must be done is the modification of the virtual lab XML specification (all the code is developed). This modification includes the definition of an experiment (<experiment> tag marked in green in Fig. 12) called "Remote experimentation". It is defined in a similar way that the virtual lab developed in the previous section, but the experiment must include references to the corresponding module in the remote lab (called MAGLEV). These references are located in the experiment definition:

- 1) First reference corresponds with the inclusion of a <run> tag which defines the remote execution of the PIV Module of MAGLEV system (this module get/set access to the data generated by the real equipment). It is marked in red in Fig. 12.
- 2) The second reference must be included in order to connect the output of the signal generator module with the set point for ball height defined in the remote module. This is done by using the <out> tag inside the <run> tag associated to the inclusion of the signal generator module in the experiment (to execute during the experiment). It is marked in blue in Fig. 12.

No more development must be done, so students simply need to publish the new remote lab. In Fig. 13 it is shown the views associated to the remote experiment running. As part of the experiment, a real time video image is presented to the user (represented as a module/view, and developed for the MAGLEV system). Again, reusing the code provides an efficient way of development of virtual and remote laboratories.

VI. STUDENT'S OPINION

Once the practice experience with virtual/remote laboratory is over, students must perform a survey used to get development/services satisfaction information. This survey is mandatory and it has 16 questions, classified in 4 main areas (questions/areas/ratings are shown in Table 1). The survey was performed by 78 students from 188 enrollment students in the subject. Due to the university's regulations, students can deliver the practical homework in two dates (February 2012 and September 2012), so only the first date surveys are included in this paper.

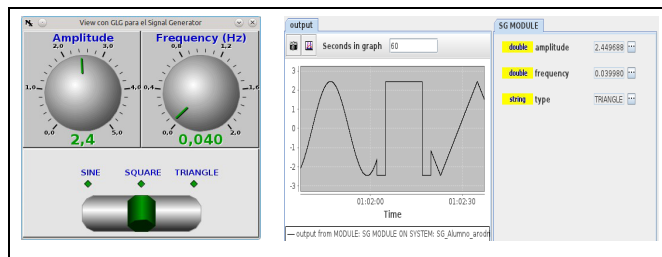


Figure 11. Virtual lab developed by an student.

```
<system name="REMOTE_MODULE_MAGLEV_arodrigue1089">
...
  <experiment name="Remote experimentation" sampleTime="100"
    logging="no">Ball position controller with signal generator lab
    developed by Student arodrigue1089
    <duration type="time" time="120" />
    <run module="SG MODULE">
      ...
      <out name="output"
        source="//62.204.199.218:2001/MAGLEV" module="PIV_MODULE"
        var="SP_OffsetPosition"/>
      </run>
      <run module="PIV_MODULE" type="remote"
        source="//62.204.199.218:2001/MAGLEV">
        ...
      </run>
    </experiment>
  ...
</system>
```

Figure 12. Remote experiment specification.

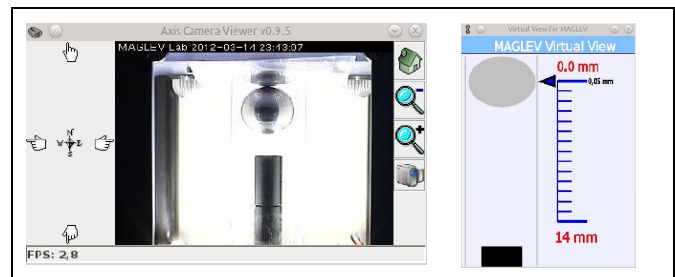


Figure 13. Running the remote experiment with visual feedback.

As it is shown in Table 1, the overall satisfaction and curricula adequacy ratings is over 4 points, so students describes RELATED as a useful tool for the learning process. Also, from ratings data can be concluded that reliability/quality of software must be improved, specially the development documentation for a RELATED laboratory.

TABLE I. QUESTIONS AND RATING

| Question (scored 1-5) | Code | Average rating |
|--|------|----------------|
| Overall Satisfaction (A1) | | 4.3 |
| It was interesting to develop the virtual/remote labs? | Q1 | 4.5 |
| Would you use this system in other subjects in the degree? | Q2 | 4.1 |
| Would you recommend the use of RELATED in a professional environment? | Q3 | 3.5 |
| What's your overall satisfaction rate about the practical experience developed? | Q4 | 4.8 |
| Development/Services facilities (A2) | | 4.0 |
| Consider the process of developing a virtual lab with RELATED, do you think it has been easy? | Q5 | 3.6 |
| Consider the publish process of laboratories, do you think is a simple procedure? | Q6 | 5.0 |
| Consider the development facilities provided by RELATED, do you think the learning process of these facilities is low? | Q7 | 3.9 |
| Consider the documentation about development/services facilities, do you think is enough to make the practical experience? | Q8 | 2.9 |
| Consider the services set provided by RELATED (data logging, booking, finding and accessing to laboratories), do you think that are appropriated to the virtual/remote labs development? | Q9 | 3.8 |
| The client runtime is intuitive and easy to learn | Q10 | 4.3 |
| Consider the used elements on views providing a visual feedback, do you feel that you are using a real on-site laboratory? | Q11 | 4.6 |
| Reliability/Quality of software (A3) | | 3.5 |

| | | |
|--|-----|------------|
| The modular approach in components (modules and views) separation facilitates the development of reusable laboratories. | Q12 | 4.5 |
| The number of errors found in the RELATED development facilities has been low or nonexistent. | Q13 | 3.0 |
| Code specification for modules and views is simple and clear. | Q14 | 3.0 |
| Curricula adequacy (A4) | | 4.4 |
| The practical experience allows me to learn more about the subject's learning objectives | Q15 | 4.2 |
| The learning objectives for the practical experience are a subset of the subject's learning objectives, expanding my knowledge of the subject. | Q16 | 4.6 |

VII. CONCLUSIONS

RELATED provides a standardized way of developing remote/virtual laboratories and useful services and facilities (users management, booking system, etc.). The clean separation between data and presentation (modules and views) has several advantages, but the main is the software reusing (code develop for this lab or others). In the case of the MAGLEV system, on-site practical experience software is reused and also, previous developed modules/views (for example, the video server and image viewer) are included with no extra development cost.

With these features, students can develop their own virtual and remote laboratories, using the structured methodology of RELATED. The "module" paradigm allows to students develop their own code, and integrate with "real" experiments simply creating/modifying the XML specifications which defines the behavior of systems/experiments. Survey's results from students indicate that the approach is easily adopted with minimum effort and it will be useful on practical experiences with other subjects.

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Reconfigurable electronics remote lab from the experiments and instruments point of view

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Abstract—A new model for building and measuring analog electronic circuits has been developed and validated in the area of remote laboratories. The goal of the proposed solution is to facilitate and improve the set-up, maintenance and update of the hardware used during the configuration, control and measurement of the instruments and experiments included in the lab. The experimental setup does not reduce the performance of the lab, allowing the users to carry out the same actions and activities as they were in a hands-on laboratory. Therefore, thanks to this new paradigm users can practice through Internet and transparently to the hardware that makes possible the remote configuration of the experiments obtaining the same results as in a hands-on lab

Keywords—component; instrumentation and measurement education, remote engineering education

I. INTRODUCTION

Practical exercises and experiments are fundamental in any technical discipline either in educational or investigation areas. To achieve that, the easier way to implement these activities is to go to hands-on laboratories, which offer real equipments and experiments. However, sometimes many of these experiments require special and expensive instruments or the number of needed equipments is not enough for all the potential users due to their size or maintenance requirements.

At a scenario like this, virtual laboratories or remote laboratories can play a key role in the teaching of specific areas of technical subjects such as analog electronics. While virtual laboratories can be used in certain experimental activities in which the simulation may be enough, they are not as effective as the laboratories in which users can play and interact with real equipment [1], according to the learning-by-touching or active learning approaches. Moreover, according to the Accreditation Board for Engineering and Technology (ABET), practical exercises should help the students to achieve a set of competences that virtual labs cannot satisfy [2].

Therefore, the manual remote laboratories (or simply remote laboratories) try to reproduce remotely and as faithfully as possible the actions that the user carries out at

local laboratories. Thus the advantages that these technology platforms of learning can provide respect for others are:

- Ubiquitous access to experiments through an Internet-based communication.
- They can play a complementary role to the theoretical sessions and classroom practices, so the student can return again and again on the learned concepts and practice by their selves.
- Remote labs help to improve the performance of the available equipments, increasing the accessing time 24d/7h.

Starting with these premises and on the basis of our experience in distance learning using WebLabs [3], on the particular topic of analog electronics remote labs, technical contributions can be made in the following aspects:

- Enable users to build electronic circuits such as if they were in a hands-on laboratory.
- Obtain consistency and reliability in the measurements are taken in a remote way.
- Make easy the maintenance and scalability of the laboratory regarding the instruments and experiments.

This paper describes a model for the design of a control, measurement and configuration system of electronic circuits to be deployed in remote learning platforms. Users can build real circuits and carry out measurements on them with typical instruments of an electronic workbench: oscilloscope, function generator, power supply and digital multimeter.

From the analysis of the role that remote experimentation can play in the practice of electronics, we introduce the application area of development of the proposed model, describing its main technical aspects concerning its implementation.

According to the described model, a prototype has been developed and deployed in a remote laboratory. In this way, the effectiveness and reliability tests can be carried out to check the validity of the model as a tool for remote prototyping and interactions

II. EXPERIMENTAL REMOTE SCENARIOS

Remote labs are currently deployed to allow users to interact with real physical systems. In the field of analog electronics, different approach has been developed:

- Remote labs in which user can control special instruments to carry out specific experiments. One example of these labs is the iLAB Microelectronics Device Characterization Lab [4].
- Remote labs in which the user can make practical exercises only with predefined or prebuilt experiments. This is the case of the ISILab [5].
- Remote labs where the user manages to modify certain predefined parameters in the Circuit Under Test (CUT) as in the RemotElectLab [6]
- Remote labs in which the user have the chance of building a CUT from the beginning using discrete electronic components as in the VISIR or NetLab [7][8].

Each one of these remote labs presents particular characteristics in its design and development which defines its use and application environment. Thereby, depending on the deployed control and measurement system, user can define and implement a complete CUT and instruments setup or he is restricted to monitor and visualize how the experiments are executed without any interaction activities.

The scope of the work presented in this paper is focused exclusively in the control and measurement system of the experiments of the labs. We do not have considered other systems that are critical in the design and development of a remote lab, such as the client or server's functions in charge of users and connections management. These issues have been discussed in deep in other works [3], so in the following sections and on the base of previously referenced works, we present a model to build, control and measure electronic circuits using real components and regular instruments.

III. REMOTE CONFIGURATION AND CONTROL SYSTEM

We define a control, configuration and measurement system as a set of technologies and developments that make it possible that the user to be able to build and measure an electronic circuit and setup the available instruments in the real lab remotely. Thereby, users can carry out experiments through Internet transparently to the required hardware and software infrastructure and bring off the same actions as they were in a hands-on lab.

In the above scenario, one of the problems that usually appears is that the hardware architecture and systems developed to succeed the remote experimentation might introduce errors in the measurements. These failures may happen because local experiments need additional hardware to replace the manual actions that the user would perform if he was at the local laboratory and to make the experiments accessible via the network.

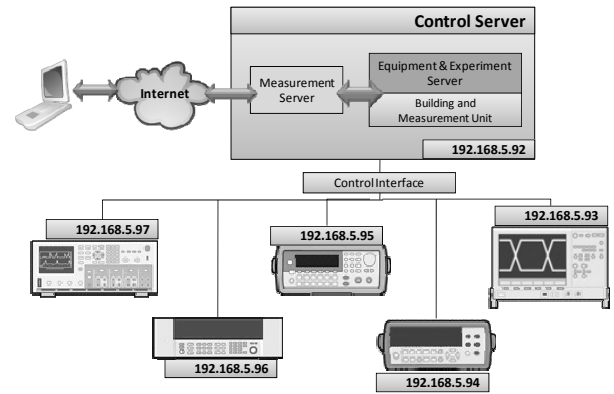


Fig. 1. Configuration and Control System architecture

Furthermore, in a typical remote session several users interact with the experiments at the same time and see the results of their own configurations and actions. So the control and measurement system has to manage different requests concurrently and in a short time slot to maintain the coherency of the system and the real-time feeling.

From the maintenance and scalability point of view, control algorithms defined and deployed at the Control Server should be transparent to the interface used to communicate the server with the experiments and independent from specific restrictions about the control of the instruments that depend of the manufacturer. These characteristics help the administrator of the lab to replace the experiments and instruments in case of updates or malfunction cases.

In summary, the main features which the proposed remote control, measurement and configure system brings are:

- 1) Allow users via Internet to create electronic circuits using real components and connections.
- 2) Through this remote system, user can setup real instruments and carry out measures performing the same actions as he was manipulating them by hand.
- 3) The measurement system brings the same results as obtained in a hands-on lab. To achieve that, the systems that make possible the remote control do not put significant errors in the acquired measures.
- 4) The proposed model is completely based on deploying regular instruments so it does not require specific equipments that could complicate the setup, maintenance and scalability of the lab.
- 5) Even in a concurrent scenario, the system is able to manage the request of each user in a short period of time, having the user the feeling of being controlling the experiment in real time.

These functionalities are regarding only to the control of the hardware of the lab: instruments and CUT. This control is based on the architecture shown at Fig. 1. It consists on a Local Access Network in which the Control Server and all the instruments are connected. The Control Server gathers the algorithms in charge of managing the communications and controlling all the equipments connected at this Instrument Network.

TABLE I
SPECIFICATIONS OF PROPOSED MODEL COMPARED WITH OTHERS

| Remote Lab | Independent of Instruments | Easy to add Experiments | Build CUT | No Proprietary Solutions |
|------------------------|----------------------------|-------------------------|------------|--------------------------|
| NetLab | No | Yes | Yes | Yes |
| RemotElectLab | No | No | No | No |
| ISILab | Yes | Yes | No | No |
| VISIR | No | No | Yes | No |
| LEDFE | No | No | No | No |
| iLab | No | Yes | No | No |
| Proposed Design | Yes | Yes | Yes | Yes |

IV. DESIGN AND IMPLEMENTATION

The choice of appropriate software architecture is key to obtain an easily scalable, maintained and managed control and measurement system.

If the solutions adopted in others remote labs are analyzed [8][9][10][11][12], we can find out different alternatives that provide each lab with different resources. That is, both the designed architecture and the developed algorithms determine the actions of the user in the lab and how the maintenance and updating tasks will be performed. In this regard, we obtain the Table I, in which it is shown how none of the analyzed solutions satisfies simultaneously all the specifications that we want to meet with the proposed model.

Therefore proposed design aims abstracting the control software from the hardware of the laboratory, both the instruments and the CUT. In this way add or replace components or equipments is simple and does not require a recodification of the software, keeping any benefits and possibilities of the remote lab closest to a hands-on one.

The result is an adaptable software architecture independent from the instruments and CUT and an Instruments and Experiments Control System that enables the remote implementation and test of the CUT without errors in the results offered to the users.

A. Adaptable software architecture

As it has been shown at Fig. 1, the functions of the Control System are divided in two logic entities. We have focused only on the functions related to the hardware control, so the Equipment and Experiments Server is the entity in which we have developed the proposed model.

We have chosen LabVIEW to develop the algorithms of this server basically because it is an instruments control oriented language that provides a set of services and applications that makes easier the access to specific functions to control the instruments through a communications interface. These functions are given by the instruments' drivers, so with the aim of satisfying the specifications described in Table I regarding the instruments, we have used IVI drivers. Thanks to these drivers, compatibility problems among instruments

due to the use of SCPI commands or VXIPlug&play drivers are avoided.

In the algorithms of the control software there is not any reference to specific instruments, only global variables are used to address the control commands of the instruments. These variables are called "Logical Names" which are valid for any family instrument defined by the IVI Foundation Specification (<http://www.ivifoundation.org/>). Once instrument's IVI driver is setup, the Driver Session is pointed to the Logical Name used in the algorithm and then the instrument can be controlled.

The control software of the communications interface, so even though in this model LXI has been the selected interface, other technology can be used based on the needs of each system. Along with IVI drivers, we have used the features of the Virtual Instrument Software Architecture (VISA) to abstract The selection of LXI has been due to the characteristics previously defined, but also because all the instruments that provide LXI interface can be controlled by IVI drivers. That is, if we deploy LXI instruments in the lab, on one hand we will benefit from the features of the Ethernet interface and on the other hand we could use the functions and services provided by the IVI drivers that make easier the software development.

To sum up, thanks to use IVI drivers we make transparent the control software of the instruments and using VISA, we get the same effect regard to the control and communications interface. The result is an adaptable, standard and easily scalable software architecture.

B. Instruments and Experiments Control System

This system is deployed in the previously defined Building and Measurement Unit, so it is the set of hardware and software technologies in charge of implementing physically the designed circuit by the user in the web client and of carrying out the measures according with the remote configuration of the instruments.

As it has been defined above, the main element is the 8x16 (8 rows and 16 columns) switching matrix. This configuration is obtained through the combination of the matrixes provided by the two modules that are connected in two slots of the mainframe. The resulting matrix is shown at Fig. 2.

The probe tests of the instruments are connected from C16 to C9 columns whereas the electronics components are plugged in the remaining columns. In this first approach only two-pins components are used, but the system is ready to manage components with more than two-pins as transistors or integrated circuits.

If it is required to increase the dimensions of the matrix, only one module has to be plugged in the free slots of the mainframe and provide one more expansion module to connect their matrixes to the existing ones. These modules do not carry any logic because they are built using only connectors, wires and sockets to place the electronic components (Fig. 3).

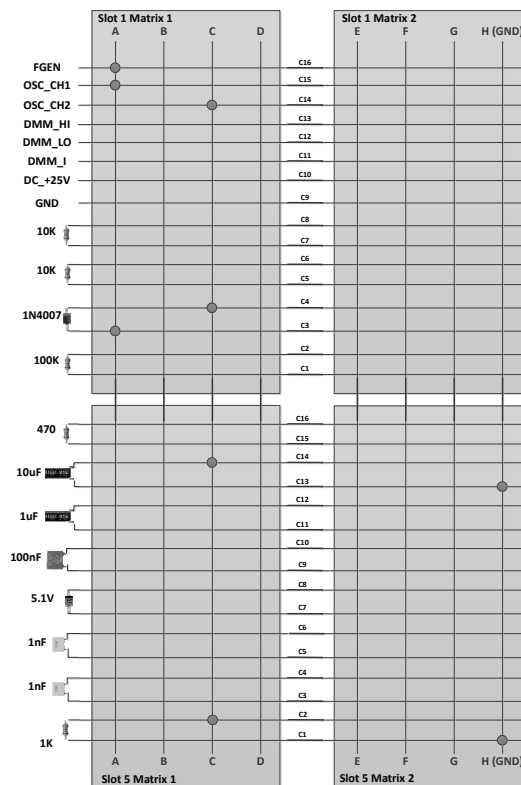


Fig. 2. Resulting switching matrix

In the Fig. 3 the upper and lower sides of the prototypes of these modules are shown. In the image on the left the sockets for the components can be seen at the top and the instruments connection points are at the left of the same image. At the bottom, the DB50 connectors used to connect these modules to the mainframe are also shown. The white connectors at the top are used to interconnect the matrixes through their rows, obtaining the matrix at Fig 2.

Regarding the control software of this system, the main thing to note is that it is included in the application that controls the rest of the instruments. As this model is not based on a proprietary solution, the control of the switching matrix is done with its IVI driver. The only thing that the control algorithm needs is two configuration files. These files are easily configured by the administrator of the system because he does not need to understand how the matrix works or how it has been designed:

- Circuit description files: using these files, the administrator determines the CUT that the user can implement in the lab. As a teacher in a real lab, these files specify how the components can be interconnected in the experiments. These files allow the administrator to limit the CUT in a practical session and avoid harmful circuits as shortcuts that could damage the lab.
- Components location file: this file describes where a component is plugged in the switching matrix. In example, this file defines that the 10uF capacitor is plugged at column 14 and 13 at matrix 1 of the module that is connected at the slot 5 of the mainframe

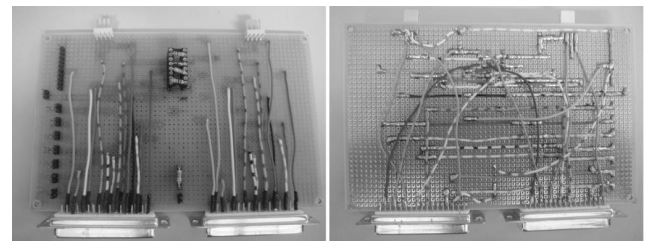


Fig. 3. Expansion Modules

Based on the information provide by both files, the algorithm that controls the mainframe generates the commands that open or close the corresponding relays at the switching matrix. The output of these actions is the CUT designed by the user at the web client.

One of the specifications of the proposed model is that the measurements taken remotely must be the same as those offered by the instruments locally. Considering that we need a switching matrix and the expansion modules which are not part of the CUT, we shall now proceed to measure the error resistance introduced by these elements in the experiment.

To characterize this error we have used a DMM to apply the 4-wire resistance measurement method. The values obtained in random points at the switching matrix are shown at Table II. The average of these results is 0,310Ω or 0,320Ω if the expansion modules are considered. We can affirm that the combination of the CTU and the expansion modules does not introduce considerable parasitic resistances in the CTU

Thanks to the configuration of the switching matrix, the parasitic resistances are placed in serial to the CUT components, so because of their small value, the introduced error is manageable, either in the measurement of resistances or in the voltage or current measurement because the voltage drop in a 0,320 Ω is really small.

In short, the use of a commercial switching matrix that is controlled as other instrument allows the user to build, setup and carry out measures in a remote way, performing the same actions as in a hands-on lab. We validate the results of these measures at Section IV

TABLE II
INSTRUMENTS AND EXPERIMENTS CONTROL SYSTEM CHARACTERIZATION

| Colum-Row | Slot | Matrix | Relay Resistance | Relay + Expansion Module |
|-----------|------|--------|------------------|--------------------------|
| C4 – R7 | 5 | 2 | 0,281Ω | 0,311Ω |
| C12 – R6 | 5 | 2 | 0,318Ω | 0,320Ω |
| C9 – R5 | 5 | 2 | 0,317Ω | 0,324Ω |
| C16 – R1 | 1 | 1 | 0,315Ω | 0,321Ω |
| C2 – R3 | 1 | 1 | 0,317Ω | 0,322Ω |
| C14 – R4 | 1 | 1 | 0,316Ω | 0,327Ω |

V. PROTOTYPE

A prototype for the proposed model has been developed with main objectives of validating its effectiveness as control and measurement system and setting up a framework to evaluate its performance in a real analog electronic remote lab.

This prototype allows the users to interact with electronics components and carry out measurements using a set of real instruments: oscilloscope, function generator, multimeter and power supply. As the scope of the proposed approach does not include a web client, in this prototype the one developed at the VISIR project has been deployed [12]. This web interface offers a set of front panels of all available instruments in the lab as well as a virtual breadboard in which the users build the CUT that later will be implemented physically using the switching matrix.

The others systems that are required to obtain a complete and functional remote lab are provided by the WebLab-Deusto.

With this software and communications architecture, we have provided the prototype with the following instruments:

- 33220A Function generator
- 34410A Digital multimeter
- DSO5012A Oscilloscope
- N5746A Power supply
- 34980A Mainframe with two 34932A switching matrix modules.

Once the instruments are deployed, these are connected by the LXI interface to a hub that also connects the computer in which the Control Server applications run.

VI. VALIDATION

The objectives of the validation phase are:

- 1) to check that the remote measurement and control system does not introduce errors respect the results obtained in a hands-on lab.
- 2) to verify that the system time response is suitable even when the measures are carried out in concurrent mode.

A. Measurements validation

In this test we want to validate that if a CUT is created remotely using the same components as in a hands-on lab, the measurements carried out using the proposed model are the same. To perform this probe, first we have made the measures in the local labs using a breadboard and some discrete components. After that, we have removed the components from the breadboard and placed them in the designed switching matrix. The measures also have been carried out with the same instruments in both scenarios. These are the test bench experiments:

- Periodic signal characterization: the oscilloscope has been connected directly to the function generator.
- Serial resistors configuration: some resistances area connected in serial. The equivalent circuit is measured using the digital multimeter.

- Parallel resistors configuration: some resistances area connected in parallel. The equivalent circuit is measured using the digital multimeter
- Voltage measures: using a voltage divider configuration.
- Current measures: in a 3 resistors network.
- Frequency circuits characterization: using a half wave-rectifier with a filter at the output and a function generator and the oscilloscope.

These experiments have been performed by ten users, some of them without skills in electronics. In the same way, some of them have never used a remote lab before. In this scenario, each user had to practice with 6 different experiments. The order of the experiments was random, so the control and measurement system had to set up different CUT and instruments in concurrent mode. The obtained measures are shown at Table III.

Analyzing these results, it can be said that:

- In the periodic signal measures, the remote system offers almost the same frequency values. In the amplitude measures, there is a little deviation.
- In the measurement of resistors configuration, the remote system provides valid results, taking into account that the tolerance of the resistances are the same.
- In the measurement of voltage and current, the remote system is a stable, providing results that are almost the same in both remote and manual scenarios.

B. System time response

The goal of this test is to estimate the system time response when users are acceding to the lab in a concurrent mode. We have developed a software application in Java that simulates until 60 users' requests at the same time.

TABLE III
REMOTE AND MANUAL MEASUREMENTS IN REAL EXPERIMENTS

| Experiment | Manual Measures | Remote Measures | Error % |
|---|------------------------|------------------------|---------|
| Periodic Signals $F_1=1\text{KHz}$; $V_1=20\text{V}$ | 999Hz | 999.4Hz | 0.04 |
| | 20.1V | 19.99V | 0.54 |
| Resistances Serial Conf. $R_1=1470\Omega$ | 1456 Ω | 1462.4 Ω | 0.43 |
| Resistances Parallel Conf. $R_1=448\Omega$ | 445.6 Ω | 447.2 Ω | 0.35 |
| Voltage Divider $V_1=12.59\text{V}$ | 12.59V | 12.59V | 0 |
| Current Measures $I_{T1}=6.911\text{mA}$ $I_{T2}=308.9\mu\text{A}$ $I_{T3}=30.89\mu\text{A}$ | $I_1=6.912\text{mA}$ | $I_1=6.947\text{mA}$ | 0.50 |
| | $I_2=307.9\mu\text{A}$ | $I_2=307.1\mu\text{A}$ | 0.25 |
| | $I_3=30.69\mu\text{A}$ | $I_3=30.59\mu\text{A}$ | 0.32 |
| Frequency Circuit $F_1=50\text{Hz}$; $V_1=5.6\text{V}$ | 50Hz | 49.99Hz | 0.02 |
| | 5.6V | 5.45V | 2.67 |

TABLE IV
SYSTEM TIME RESPONSE IN MILLISECONDS

| Users | Easy Circuit | | Medium Circuit | | Complicated Circuit | |
|-------|--------------|-----------------|----------------|-----------------|---------------------|-----------------|
| | VISIR | Proposed Method | VISIR | Proposed Method | VISIR | Proposed Method |
| 10 | 408,5 | 777,1 | 444,7 | 1129,4 | 631,7 | 1189,4 |
| 30 | 1195 | 2019,6 | 1287,4 | 3235,6 | 1874,4 | 3554,3 |
| 60 | 2347,9 | 4803,5 | 2662,2 | 6341 | 3679,9 | 6919,3 |

Each one of these requests includes a CUT configuration and instruments setup. Depending on the number of the connections that the switching matrix has to perform, the system time response is different so we have use three different CUT configuration: a simple circuit that consist on only connection, a medium circuit that implements a circuit with 2 components and a complex circuit that uses 3 components. The results of these experiments are included at Table IV. The obtained time responses have been compared with the times response of the VISIR lab in order to compare both control models. All the values are given in milliseconds.

If the circuit complexity or the number of simultaneous requests is increased, the system requires more time to response to the user's requests. Also it is noticed how the VISIR system is considerably faster than the proposed system because if a complex circuit must be implemented, its time response is less than the time required by the proposed model to build a simple circuit. According to [9] if a user has to wait more than 7 second, he will lose his attention an interest in it, so the system time response may be considered valid because the user will not be more than 7 seconds waiting for his answer. Anyway this feature should be improved in following developments.

VII. CONCLUSION AND FUTURE WORK

Control and measurement systems commonly used in remote labs must have some performance and reliability features closest as much as possible to those obtained in a manual laboratory.

We have presented a model to control and measure electronics circuits using real instruments through Internet using a remote lab. The model has been validated using a complete and operative prototype. The main advantages of the proposed model are that it can be easily update and its adaptability to new experiments and instruments. Its modular design guarantees the possibility of adding new instruments and components to the CUT easily without software or hardware reconfiguration. In short, the software is transparent to the experiments of the lab. The main features of the proposed model are:

- It is an scalable and open structure to add new instruments and components.
- It uses only commercial instruments. No proprietary and complex solutions are developed
- Using IVI and VISA technologies allow to make the control application independent from the hardware and the communications interface.
- Reliable measurements can be carried out because the hardware in charge of building the circuits do not introduce errors in the obtained results.

Regarding to future work, in one hand the system needs to improve the time response in concurrent mode. On the other hand the configuration of the switch matrix is one of the existing possibilities, so new configurations can be studied

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Work in Progress: Enhance CS/CE Student Learning in Computer Architecture and Organization through a Remote Instrument Control Lab with Mixed Reality

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Abstract—The paper presents our preliminary work on developing a remote hardware development lab using mixed reality technology (mRLab). The mRLab allows a group of students to remotely and simultaneously work on a VHDL project with an FPGA development board. All lab objects are created in 3D and an interactive layer on the 3D objects is added to host learning information along with caveats to assist learning.

Keywords—Mixed Reality; FPGA; Education; Remote Lab

I. INTRODUCTION

Large classes in the Computer Architecture and Organization curriculum are becoming more common as colleges and universities face budget restrictions. However, universities teach this core curriculum in computer science (CS) or computer engineering (CE) programs without any hands-on lab practices, with antiquated equipment, or with labs in which lab equipment is frequently damaged and drastically hinders student learning [1]. While remote labs have been studied over the past decade, how to reflect high fidelity of a remote lab is still a problem. Proposed in this project is a mixed reality enhanced remote lab (mRLab) which attaches real hardware such as field programmable gate arrays (FPGA) development boards for students to perform labs through a thin client or mobile devices. The mixed reality technology is used to overlay teaching materials on top of a board image and dynamically interact with students [2]. The network connected mRLab makes it possible to be broadly disseminated, and allows students to conduct labs at anytime and anywhere. The mRLab will enable students to interact with others online to create a sense of working together.

The mRLab is composed of a network connected computer, a set of FPGA development boards, a web server, and a series of supporting software. FPGAs have been widely used for prototyping digital systems and implementing proprietary embedded systems in industry. They offer a great opportunity for students to gain hands-on experience. However, our experience shows that: 1) FPGA development boards are easily broken if not operated correctly, 2) Time for software to translate a design to the FPGA chip is lengthy, 3) Few instructors have expertise in FPGAs, and 4) Lab materials are difficult to repeat in other institutions.

The mRLab was developed to overcome the aforementioned problems. The subtle settings on the board are presented in a different layer of the board image using mixed reality technology which guides students to a correct setting as if they were working on a real board. Students are able to avoid wrong configurations on their boards. This mixed reality also provides a high fidelity response of the remote lab with minimal network bandwidth. For example, a real-time image of the onboard display and LEDs is sent back to the students. Converting a design to configuration bits in FPGA involves synthesis, place and route, and a series of optimization, each of which demands computing resources. Practically, a successful hardware project requires at least tens of compilation rounds to get everything right. Shifting the computation to a high performance server will shorten the compilation time and enhance student learning. By packing together FPGA development boards and the supporting software tools in a server, the learning environment becomes consistent for every student. This will rule out unnecessary problems such as system related issues. The identical learning environment enables students to share their experience, and exchange ideas. The integration of hardware, software, and labware will allow instructors at any institution to repeat the developed curriculum at a minimal cost.

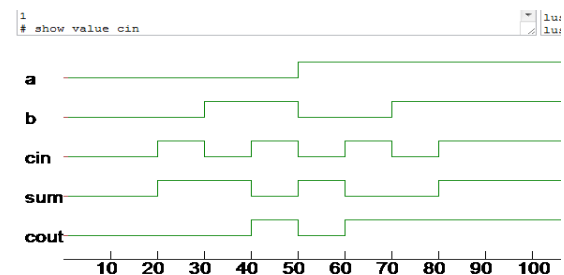
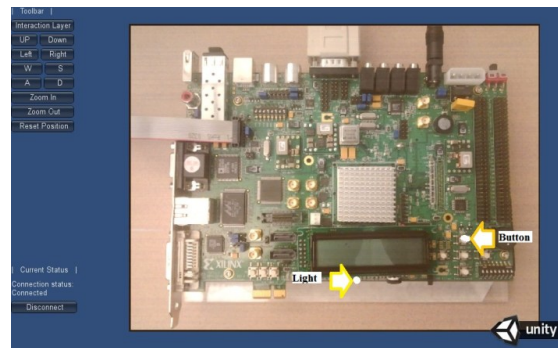
II. OVERVIEW OF THE MRLAB

The mRLab follows normal client/server architecture with open sourced or free software. This setting would allow the mRLab to be repeated and deployed in other universities with minimal support. Figure 1. depicts the overview of the mRLab architecture. The server is equipped with an FPGA development board and configured with support for hardware development. It provides services for users to synthesize, simulate, implement, and program a hardware design to the FPGA board. The simulation result is sent back to the user's browser via simulation waveforms. The response on the FPGA board including switch/light status is converted to 3D objects to be displayed on user's browsers. Virtually, a network device such as smart phones, mobile devices, laptop or desktop computers may connect to the server for receiving the service. This setting allows students to work on a project at anytime and anywhere. Moreover, a group of students may work on a project remotely and simultaneously. Students may share the

Smart phones that support a web browser

Mobile devices that support a web browser

Desktops that support a web browser



Work in Progress: STEM-Based Computing Educational Resources on the Web

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Abstract – This work in progress explores the landscape of computing learning resources and environments found on the web together with teaching and learning materials that can facilitate the integration of “computational thinking” into the K-12 classroom. In specific, this paper focuses in finding and describing existing learning environments that integrate computational thinking into a STEM discipline together with lesson plans, activities and other curricula.

Index Terms – Computational thinking, STEM, learning resources, supplemental materials.

INTRODUCTION

Computing is increasingly used to extend the capabilities and therefore findings of scientific research. For example, computing has further enabled scientific breakthroughs by facilitating researchers through computerized instrumentation and detailed simulations to generate, visualize, and understand large amounts of scientific data that have radically allowed new understandings. In tandem with the pervasive role of computing in science and engineering, there is a growing recognition of the importance of computational thinking.

Computational thinking [1] has been recognized as a collection of understandings and skills required for new generations of students proficient not only at using tools, but also at creating them and understanding the nature and implication of that creation [2]. Computational thinking refers to the combination of disciplinary knowledge (e.g., physics, biology, nanotechnology) [3] with thought processes (e.g., engineering thinking, quantitative reasoning, algorithmic thinking, systems thinking) involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent [4]. This requires using a set of concepts, such as abstraction, recursion, and iteration, to process and analyze data, and to create real and virtual artifacts [5, 6].

This paper explores the landscape of computing learning resources and environments found on the web together with teaching and learning materials that can facilitate the integration of computational thinking into the K-12 classroom. The guiding research question for this study is: *What is the landscape of web based resources that fall under the definition or are identified as resources that promote computational thinking?*

METHODS

We followed the approach created by Bagiati and colleagues [7] to identify resources that can be described as promoting computational thinking in STEM disciplines. We started by identifying a list of resources mentioned on national reports and in portals that compile resources related to computational thinking. The next step was to identify additional resources on the web. These resources were found using a combination of the following search terms in Google: “computational thinking”, “science”, “technology”, “engineering”, “math”, “STEM resources”, “simulations”, “lessons”, “supplement”, “K12”, “animations” and “teaching”.

Our analysis, and also the primary focus of this work in progress, consisted of identifying the primary type of instructional method and specific type of instructional planning provided in each of the identified websites [8]. For instructional method we identified whether the resources included demonstrations, discussions, simulations, games, drill and practice, discovery, problem solving, hands-on experiences and so on [8]. For instructional planning we identified those supplemental materials consisting of motivation, orientation, information, application or evaluation activities accompanying the learning resource [8].

RESULTS

Results from this study identified 64 resources that were classified as STEM-based computational educational resources, with 59 resources that can integrate computational thinking in the K-12 classrooms to support learning in other STEM disciplines. Percentages of resources found per each discipline were as follows: 32% fell in the *Science* category, 26% fell in the *Technology* category, 23% fell in the *Math* category and 19% fell in the *Engineering* category.

As described earlier, the identified resources were then classified according to the primary instructional method. Table 1 depicts the number of resources found for each instructional method. Resources utilizing multiple instructional methods were also noted.

TABLE I
TYPE OF INSTRUCTIONAL METHOD

| Instructional Method | Number of Resources |
|-------------------------|---------------------|
| Simulations | 21 |
| Programming environment | 6 |
| Games | 5 |
| Videos | 7 |
| Illustrations | 6 |
| Animations | 9 |
| Lectures | 4 |
| Books | 4 |

As shown in Table 1, eight different types of instructional methods were identified. Simulations refer to working representations of reality describing a model that may require some input parameters and then are executed by the learners. Programming environments refer to computing environments that embed a programming language mostly used for creating interactive stories and games. Games refer to electronic and interactive media played by means of manipulating images. Videos were defined as the reproduction of visual images. Illustrations refer to static pictures and drawings while animations refer to a sequence of images to create the illusion of movement. Lectures were defined as notes or presentations. Finally, books refer to electronic compendium of written materials.

TABLE II

| TYPE OF INSTRUCTIONAL PLANNING RESOURCE | |
|---|---------------------|
| Instructional Method | Number of Resources |
| Lesson plans | 17 |
| Learning modules | 14 |
| Tutorials | 8 |
| Activities | 17 |
| Sample code | 8 |
| Curriculum link | 7 |
| Assessments | 8 |
| Homework assignments | 2 |

We also identified if the resource included any supplemental material that could serve as instructional planning resource. Table 2 depicts the kinds and amounts of supplemental materials identified. Lesson plans refer to structured goal and objectives provided to teachers for a specific day's topic. Learning modules are organized collections of content that can range from a single lesson (i.e. a week-long activity with the goal of learning a single concept) to an entire curriculum (sets of week-long activities encompassing interrelated concepts, principles, procedures and problem-solving at for a specific course or grade level). Tutorials refer to instructions, in text or video form, which provide a teacher with a guide on how to integrate a particular resource into the classroom or how to use a particular resource. Activities refer to in-class interactions designed to teach students through doing. Activities are generally short term and cover a single concept. Sample code refers to code provided, by the resource, for a particular programming language. The goal of sample code is to teach by example. Curriculum links refer to ties made from the resource to a standard and accepted curriculum. Assessments refer to quizzes and tests that are used to gauge learners' progress. Assessments are generally monitored by the resource and results are provided to the teacher. Homework assignments refer to work that is given outside of the classroom to reinforce concepts learned in the classroom.

DISCUSSION AND CONCLUSION

Our research to date provides an in depth view of (a) available web-based STEM resources, (b) primary tools used to teach STEM and (c) supplemental instructional tools used by teachers to integrate the primary instructional tools. From the graphs and statistics listed in this paper, some

trends can be suggested. As more of an observational note, independent STEM resources are very difficult to find. Though there are several resource portals, many of them have either the same information or outdated and abandoned resources. Resources not found in portals are difficult to find. For instance, they had to be encountered through the right combination of search terms. This led to an abundance of unusable resources that had to be quickly sifted through and discarded. Central, up to date, resource hubs are needed to make finding computational thinking resources easier for teachers to find.

Though there were several K-12 resources, many of them were more geared towards the high school level. Very few resources were designed strictly for use in the K-8 range. Most of these resources combine multiple branches of STEM. In fact, math and engineering resources are significantly more likely to exist in combination with other STEM resources than without. Science resources were the most prevalent of all of the STEM resources.

There are almost 20 more occurrences of supplementary resources than there are of the primary tools. Further analysis shows that simulations are the only significant source of primary instructional tools. Though there is an abundance of simulations at 21 total occurrences, the other primary instructional tools are somewhat lacking. In the future, we will look further into the other primary instructional tools to understand this gap. It is possible that this gap exists due to the nature of STEM. Even though simulations were the most prevalent primary resources, they were the least explained. There were hardly any tutorials or guides on how to use the simulations. This leaves learners guessing at functionality at times.

FUTURE WORK

We are working on creating a compendium of all these resources that will be provided as part of an extended version of the paper. This catalogue will include the following information: (a) name of the website, (b) URL, (c) description of the website, (d) audience for the website such as grade level, (e) particular STEM discipline associated with the website, (f) identification of supplemental materials (e.g., lesson plans) for each of the websites, (g) learning objectives associated with the website, and (h) any evidence of assessment or educational research associated with the materials presented on the website. Any websites created for specific groups (such as females) will also be noted. Finally, we will also identify the scope of the instructional planning supplemental resources such as whether the learning resources consist of comprehensive curriculum for a course length experience, lesson plan providing specific guidance to instructors, or short learning activity that can supplement a class [7]. In resources that have limited supplemental materials, we will also explore the concept of communities. Often, lesson plans and activities are posted on forums and websites not linked to the respective resource. We will identify and qualify the communities used to teach these resources.

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Work in Progress: An Intelligent Tutoring System for Improving Student Learning in a Sophomore Engineering Dynamics Course

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Abstract—This paper presents our ongoing efforts toward developing an Intelligent Tutoring System (ITS) to improve student learning in a sophomore engineering dynamics course. An ITS module was developed to guide students applying the Principle of Work and Energy to solve particle dynamics problems. Pre-post tests, each including six technical questions, were administered to 74 engineering undergraduates who took a dynamics course in a recent semester. The assessment results show that the developed ITS module helps students master dynamics concepts and associated calculations.

Keywords: *Intelligent tutoring system; engineering dynamics; assessment; student learning*

I. INTRODUCTION

Engineering dynamics is a high-enrollment, high-impact, core course that nearly all mechanical, civil, aerospace, and biomedical engineering students are required to take. This sophomore gateway course covers a broad spectrum of foundational concepts and principles and is a fundamental building block for many advanced studies in subsequent courses. However, many students fail dynamics. In the standard Fundamentals of Engineering examination in 2009, the national average score on the dynamics exam was 53% [1]. In a recent survey conducted at Utah State University, students were asked to share their perspectives about the dynamics course. More than 60% of the students surveyed used phrases such as “much harder than statics,” “extremely difficult,” “very challenging,” and “I am afraid of it.”

An Intelligent Tutoring System (ITS) is an innovative learning tool that receives growing attention in the engineering education community [2]. In the ITS, students solve technical problems with the guidance of a virtual tutor. Students can ask the virtual tutor questions or request hints on what to do next during problem solving, similar to what occurs in a real classroom environment where students ask a human tutor questions or request hints. Research evidence [e.g., 2, 3] has shown that the ITS can significantly improve student learning, especially in large classes where instructor-student interaction and one-on-one tutoring time are limited due to class size. The ITS also enables students to learn anytime (24/365), anywhere (with access to Internet), and at their own pace.

The authors of this paper have performed an extensive literature review using a variety of popular databases, including the FIE conference proceedings (1995-2011). The results showed that all the existing ITSs (e.g., Cycle-Talk, Genetics Tutors, and Politeness Tutor [3]) were developed for courses such as computer-aided modeling and design, forensic biology, circuit analysis, mathematics, and physics. No ITS was developed for any engineering dynamics courses.

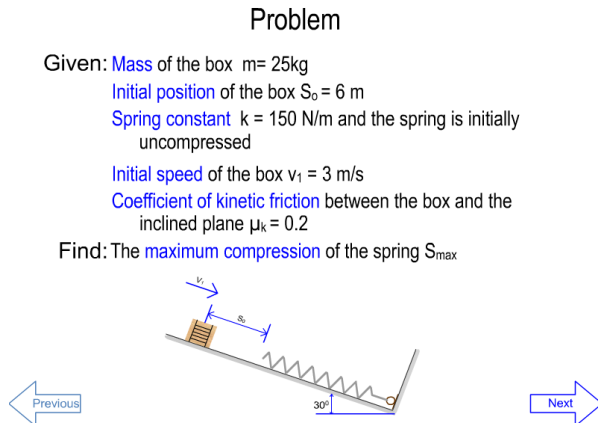
This study is the first attempt to develop and assess an online ITS for an engineering dynamics course. As a pilot study, we have developed an ITS module to help students learn how to apply the Principle of Work and Energy to solve particle dynamics problems. The ITS module was implemented in a dynamics course taught by the second author of this paper. However, no control group was involved in this pilot study yet. Student learning gains were calculated through pre-post tests that each included six technical questions. The central assessment question is: To what extent did the developed ITS module help students learn how to apply the Principle of Work and Energy to solve particle dynamics problems?

II. DEVELOPMENT OF AN ITS FOR ENGINEERING DYNAMICS

The ITS module was developed using the Cognitive Tutor Authoring Tools (CTAT) [3], one of the most popular tutor authoring software developed at Carnegie Mellon University for authoring tutor behavior. The CTAT provides a set of specialized tutoring widgets to create computer graphical user interfaces (GUIs) in Adobe Flash in a drag-and-drop manner. In the present study, the CTAT was employed to create example-tracing tutors. This type of tutors can be created quickly without programming, but requires problem-specific authoring. An author first demonstrates (to the virtual tutor) example solutions, generalizes the recorded examples, and annotates them with hints and feedback messages [3].

The ITS module developed from the present study contains a set of hints carefully designed to provide students step-by-step guidance, ranging from drawing a free-body diagram to solving mathematical equations. Thus, students not only understand what dynamics principle and associated equations should be used, but why and how they are used. Fig. 1 shows one of the computer GUIs of the ITS module, which guides

students through each of the following steps: 1) draw a free-body diagram; 2) calculate the total work done; 3) determine the initial and final kinetic energy; and 4) apply the Principle of Work and Energy to finally solve the problem. The ITS module contains a total of 13 hints that were developed based on students' common misconceptions. As an example, Fig. 2 shows one hint to help students calculate the work done by weight. The hint states, "The displacement is determined from its initial position, so it is $S_0 + S_{\max}$, not S_{\max} ."



• Work done by weight : $W_w =$

A. $mg(S_0 + S_{\max})\sin 30^\circ$ C. $mgS_{\max}\sin 30^\circ$
B. $mg(S_0 + S_{\max})\cos 30^\circ$ D. $mgS_{\max}\cos 30^\circ$

• Work done by the frictional force : $W_f =$

A. $f(S_0 + S_{\max})$ C. $-f(S_0 + S_{\max})$
B. $f(S_0 + S_{\max})\cos 30^\circ$ D. $-f(S_0 + S_{\max})\cos 30^\circ$

• Work done by the spring force : $W_s =$

A. $\frac{1}{2}k(S_0 + S_{\max})^2$ C. $-\frac{1}{2}k(S_0 + S_{\max})^2$
B. $\frac{1}{2}kS_{\max}^2$ D. $-\frac{1}{2}kS_{\max}^2$

• Initial and final kinetic energy : $T_1 \& T_2 =$

A. $T_1 = mv_1$, $T_2 = 0$ C. $T_1 = \frac{1}{2}mv_1^2$, $T_2 = T_1$
B. $T_1 = mv_1$, $T_2 = T_1$ D. $T_1 = \frac{1}{2}mv_1^2$, $T_2 = 0$

The displacement is determined from its initial position, so it is $S_0 + S_{\max}$, not S_{\max} .

Previous Next Done

Figure 2. An example hint.

III. DATA COLLECTION AND ASSESSMENT RESULTS

The developed ITS module was recently implemented in an engineering dynamics course. Pre-post tests were administered to 74 undergraduates, the majority of whom were from either mechanical and aerospace engineering majors, or civil and environmental engineering majors. After the pre-test, the module was uploaded to a website that students had access to, so students could run the module 24/7.

The pre-test and post-test each included six technical questions. Questions No. 1 to 5 involved one or two dynamics concepts and associated calculations. Question No. 6 required that students "synthesize" all they had learned in the previous steps to determine the final answer to the problem. Student learning gains were calculated for each student by using:

$$\text{Learning gain} = \frac{\text{Post-test score (\%)} - \text{Pre-test score (\%)}}{100 (\%) - \text{Pre-test score (\%)}}$$

Fig. 3 shows the learning gain of each student. The majority of students had positive learning gains varying from 33% to 100%. Eight (out of 74) students had negative learning gains because their post-test scores were lower than their pre-test scores. The class-average learning gain was 39%.

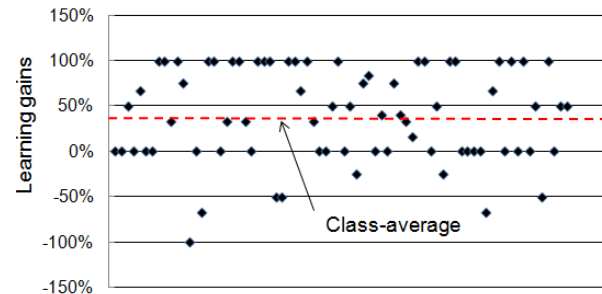
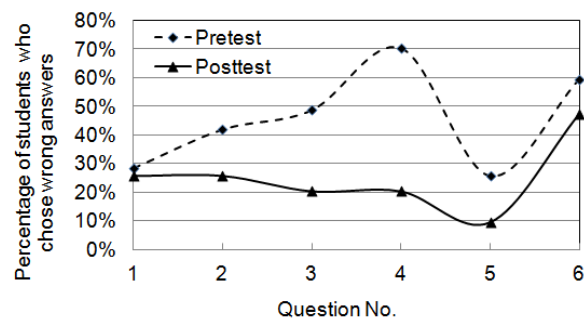


Fig. 4 shows the percentage of students who chose wrong answers for each of the six technical questions used in the pre-post tests. Except for Question No. 1, the ITS module improved student learning on all questions (Nos. 2-5) that involved one or two concepts and associated calculations. However, it is still a challenge to use ITS to improve students' skills for knowledge synthesis (Question No. 6).



IV. CONCLUSIONS

An ITS module was developed to help students learn how to apply an important dynamics principle to solve problems. The assessment results show that the ITS module helps students master dynamics concepts and associated calculations.

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Security Across the Curriculum and Beyond

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Abstract—Society's dependency on information technology has drastically outpaced educational curricula and the opportunities that universities and higher education institutes provide to students from both technical (e.g., computer engineering, computer science) and non-technical majors. To increase the opportunities for all students to learn how protect themselves as individuals and others as professionals from numerous cyber threats the focus of this work is to identify gaps in engineering curricula and present novel approaches to fulfill the growing and diverse needs of cyber security education.

The overall objective of this paper is to make security education accessible, relevant, and tangible across educational curricula, as well as to provide the framework to extend these efforts beyond university classrooms and into community colleges and high schools. While the predominant focus, research, and innovative practices in the area of cyber security have focused on technical students at the university level, this work instead concentrates on the demographic of students that desire to learn about cyber security without having to major in computer engineering, for example. In this paper we present a three-tiered framework that provides breadth and depth to security education across multiple education levels. This all-encompassing framework for security education includes providing (1) formal literacy-based training for students of all backgrounds, (2) inquiry-based learning through security- and technically-focused student groups and activities, and (3) classical technical-based initiatives. For each of these respective areas, previous research and efforts are discussed as well as the innovative practices that we have developed to address identified educational gaps.

Index Terms—security education; security literacy; inquiry-based learning;

I. INTRODUCTION

As peoples' lives and careers have become increasingly reliant on computers and the Internet, terms like "cyber attack," "hacktivism," "phishing," and "malware infection" have entered into the national lexicon and, rightfully so, as these undesirable events have become a part of everyday life for many. This dependency on information technology has drastically outpaced educational curricula and the opportunities that universities and higher education institutes provide to students from both technical and non-technical majors. To increase the opportunities for all students to learn how to protect themselves as individuals and others as professionals from numerous computer- and network-based threats, this work identifies gaps in both institutional and engineering curricula and presents novel approaches to fulfill the growing and diverse needs of cyber security education.

On one end of the spectrum, there exists an enormous gap between the diversity of students from both technical and non-

technical backgrounds that are interested in learning practical computer security knowledge and the courses or organized opportunities formally offered to students. If addressed at all, this gap is often filled with top-10 tips, advice lists, and security awareness campaigns. In this respect, as educators, we collectively need to move beyond promoting security awareness and begin teaching computer security literacy and best practices that provide context for students, enabling comprehension, application, and analysis of this material. On the other end of the spectrum, students of technical backgrounds are often afforded a limited set of course options that focus directly on computer security topics and many of these courses are only available as junior or senior electives. While fundamental aspects of security are often addressed as part of a general computer engineering or computer science curricula, often these topics are not covered in sufficient depth for students to achieve higher levels of cognitive learning. Thus for a large demographic of both technical and non-technically focused students, there are significant and unaddressed educational needs.

To address the mounting cyber crime epidemic, which is now fast approaching illegal drug trade in cost to the world economy [16], a wide range of students must be engaged and this broad engagement cannot be completed with limited awareness campaign or narrowly focused technical curricula. The overall objective of this paper is to make security education accessible, relevant, and tangible across educational curricula, as well as to provide the framework to extend these efforts beyond university classrooms and into community colleges and high schools. While the predominant focus, research, and innovative practices in the area of cyber security have focused on technical students at the university level, this work instead concentrates on the demographic of students that desire to learn about cyber security without having to major in computer engineering, for example. In this paper we present a three-tiered framework that provides breadth and depth to security education across multiple educational levels. This all-encompassing framework for security education includes providing (1) formal literacy-based training for students of all backgrounds, (2) inquiry-based learning through security- and technically-focused student groups and activities, and (3) classical technical-based initiatives. For each of these respective areas, previous research and efforts are discussed as well as the innovative practices that we have developed to address identified educational gaps.

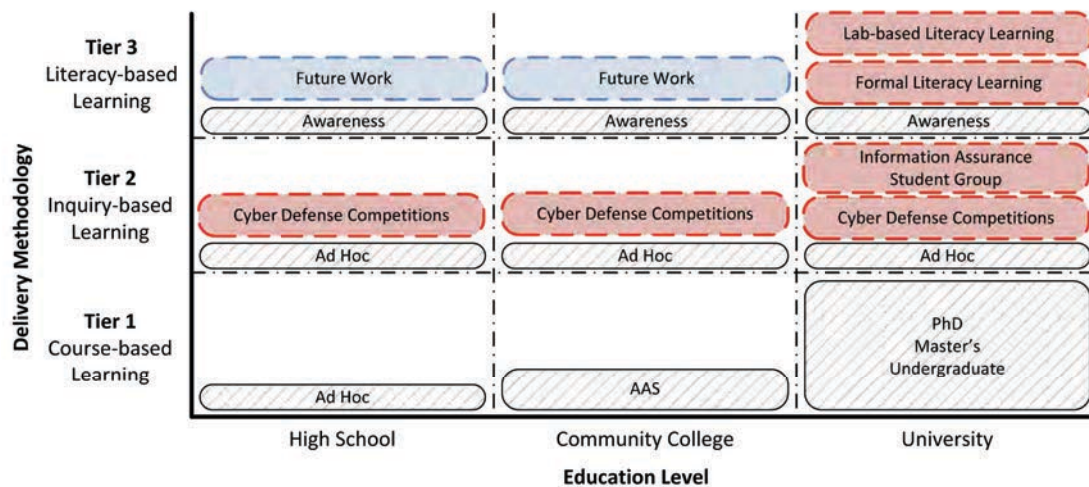


Fig. 1. Gap Detection for Cyber Security Education

II. GAP DETECTION

The remainder of the paper is organized as follows. Section II provides a gap assessment in current security education. Section III provides a literature review for the predominant body of security education research and innovation. Sections IV and V present innovative approaches to addressing the identified gaps through inquiry- and literacy-based learning, respectively. Finally, Section VI discusses conclusions drawn from this work.

As is often the case in the world of technology, innovation tends to out-pace security. The same general statement is true of university curricula and the collective efforts of security educators, researchers, and professionals in respect to addressing the educational needs of their respective communities. While positive advancements have been made in select areas, the broad analysis of security education opportunities afforded to all students presented in this section highlights that there is much work to be done. In order to truly affect change in the way students view and understand computer security, it is our belief as engineering educators that solutions must encompass more than just technically-focused students and instead target a broad audience. This section will explore the current state of computer security education taught at the university, community college, and high school levels. The three-tiered approach presented for the delivery methods of educational content will serve as the organization for the remainder of the paper.

Figure 1 presents a two-dimensional assessment of current security education efforts and innovations. The x-axis denotes the education level (i.e., High School, Community College, University) and the y-axis represents the methodology used to deliver educational content. Populated within the array shown in Figure 1 are past and current security educational efforts (denoted by diagonal slashes) and the current gaps that are being addressed (denoted a solid blue shading) and future work

being proposed (denoted a solid blue shading) at Iowa State University.

Each identified tier and corresponding educational level represents different motives and learning objectives for each of these respective bodies of students. The learning motives for students that gravitate towards the stated delivery methodologies (course-based, inquiry-based, literacy-based) are as follows:

Tier 1 - Course-based Learning - The focus of course-based learning at both the university and community college levels is to provide students with the educational foundation and security skill-set with which to enter the cyber security workforce and/or continue learning through advanced degrees. High school students that are fortunate enough to be afforded the opportunity to study security-focused classes often have the desire to continue the pursuit of technical and security focused degrees and employment opportunities after graduation.

Tier 2 - Inquiry-based Learning - Inquiry-based learning [3] allows students to explore cyber security issues and resolve problems by reviewing learning materials about cyber security, evaluating what they know, seeking out additional information about specific problems, and coming to a conclusion or resolution based upon evidence they have gathered. The focus of all activities is on critical and logical thinking, as well as exploration of creative and alternative solutions [15]. It is an effective way to shape students' ability to apply their knowledge, search for new information, and critically synthesize material. Students studying cyber security in this manner gain valuable hands-on experience in mitigating cyber security threats and develop a valuable understanding of practical cyber security knowledge and skills.

Inquiry-based learning provides two types of opportunities for students. First, since computer-related courses are nearly non-existent in high schools across the U.S., it allows high [28] school students a non-threatening environment to

explore the topic of computer security without the restrictions and pressures of a graded course. Secondly, for community college and university students, it provides a way to engage in practical and hands-on experience that is either augmented by students' current coursework or in lieu of any computer security coursework. The open-ended nature of inquiry-based activities enables students of all backgrounds and knowledge levels to explore and learn at their own pace and as well as in teams.

Tier 3 - Literacy-based Learning - Students desiring to pursue literacy-based learning options are in search of practical computer security knowledge. Whether these students have technical or non-technical backgrounds, the goal of these students is to gain a firm understanding of security concepts, the identification of security threats, the purpose, strengths, and weaknesses of security mechanisms, and to develop confidence in the execution of security best practices.

These three delivery methods presented in Figure 1 provide a range of opportunities for students of all backgrounds to explore and learn about computer security. Although each of these methods is necessary, individually, none are sufficient to truly address both the educational desires and needs of all students.

III. TIER ONE: COURSE-BASED LEARNING

The predominant focus of current security education is taught in traditional classroom and lab settings by means of course-based learning. The programs or degrees that facilitate these security-focused courses are typically housed in computer engineering or computer science departments and often require that students first pass a number of technical prerequisites. However, as is argued in this paper, this traditional delivery method and its corresponding restrictions precludes students from non-technical backgrounds the opportunity to learn about computer security in a formal setting. Past research, innovation, and both course and curriculum development have focused heavily on course-based learning. This section presents a brief review of these works to better understand the current climate of computer security education across multiple education levels.

As seen in Figure 1, course-based and security-focused learning initiatives have been primarily addressed at the university level through multiple levels of degrees. Efforts such as [1] have created a two-semester program that enables undergraduate students to learn about the technical components of cyber security through focused learning modules and laboratory environments. Similarly, Hazeyama et al. proposed a learning environment for software security education [10]. Others have sought to develop lab environments [7], simulations [17], analysis frameworks [18], [19], and reconfigurable course modules [2], [27] to facilitate technical learning of specific and hands-on cyber security topics. More novel approaches include the use of Second Life [24], hacking competitions [4] and capstone design courses [9].

Technical security education is also becoming a more common component of community college curricula [8]. National

Science Foundation sponsored efforts like CyberWatch [6] are committed to improving cyber security education and have a primary focus on community colleges by providing support for curriculum development, faculty professional development, student development, career pathways, and public awareness. Opportunities are also provided to high school students by means of structured cyber defense games [5] and ad hoc courses or extra curricular activities.

Because the predominate bulk of the cyber security work force is technical in nature, the educational opportunities that support this career path have followed a similar technical emphasis. Although technical course-based initiatives are necessary, they are not sufficient to address current cyber security problems as they provide little opportunities for students of non-technical majors or for those who do not wish to pursue a career in cyber security with an opportunity to learn. As a result, an objective of this paper is to address the gaps in Figure 1 by presenting alternative methods for students to learn about cyber security.

IV. TIER TWO: INQUIRY-BASED LEARNING

Inquiry-based learning is the backbone of cyber security outreach programs offered by Iowa State University. In our implementation of inquiry-based learning in cyber security, students are given access to learning materials, as well as a set of questions to explore and open problems to solve. They are then asked to provide solutions to challenges presented to them based upon their own exploration, additional resources they find, and experimentation. The materials provided focus on security-based concepts for designing, implementing, configuring, securing, and protecting a network, its servers, and end users from a diverse set of realistic threats.

At Iowa State University, we use inquiry-based learning as the primary delivery method of cyber security learning for high school [13], [20], [23], community college [21], and four-year university students [12], [14]. The most popular inquiry-based learning activities are the four annual cyber defense competitions (CDCs) that we host each year. In a CDC, students design, configure, and maintain a set of servers and a network in a secure manner prior to the competition. Such efforts are performed through inquiry-based learning and not by means of formal security courses. The culmination of this learning is a day-long competition in which students work to prevent security breaches and to remediate any exploits that occur at the hands of hackers (i.e. grad students) while maintaining a fully-functional network for their end users.

The experience participating in a CDC provides valuable hands-on experience with cyber security that goes beyond anything a student could learn in a classroom. For both the high school students and the college undergraduate students that do not have access to formal cyber security education, these events give them experience in an area of which they had little or no previous knowledge. For students with previous coursework experience in cyber security, a CDC allows them to move beyond what they have learned in the classroom by putting theoretical concepts into practice.

In addition to the CDCs, Iowa State University has an Information Assurance Student Group (IASG) [22] for undergraduate students in any major who are interested in cyber security. The need for such a group was spurred by the lack of security courses offered for lower-division undergraduate students. While upper-division undergraduate students may take the offered graduate courses in Information Assurance (IA), the lower division undergraduate students do not have enough hardware, operating systems, or networking background to fulfill the prerequisites to enroll in these graduate courses. Therefore, for many lower-division undergraduate students, their enthusiasm and interest in cyber security are “put on hold for two to three years while they work through the general engineering curriculum that would allow them to take formal IA and computer/network security courses in their senior year. For those students who have interest in cyber security, these two to three years of engineering foundation building present significant obstacles and disincentivizes them to continue to pursue IA as a focus. The creation of IASG was one answer to keeping students who desire to pursue careers in cyber security engaged during their undergraduate coursework. IASG now has a membership of more than 130 students who attend weekly meetings in which upper-division undergraduate and graduate students deliver content and provide hands-on activities in an inquiry-based learning environment. Meetings are a combination of lecture content, demonstrations, discussions and hands-on activities where the students can explore and create their own solutions to cyber security topics and problems for a given weekly topic.

As illustrated in the gap analysis presented in Figure 1, the use of inquiry-based learning and CDCs affords students two valuable opportunities. First, for high school students who have no access to computer-related courses, it provides an opportunity to explore cyber security as an educational path in a non-threatening environment. Second, it allows students who are studying cyber security, at the high school, community college, or four-year level, to experience hands-on, practical applications of theoretical security topics. For those students in colleges and universities that do not have access to formal courses due to lack of prerequisites, such as lower-level undergraduates, it provides an avenue to keep these students engaged and excited about pursuing a career in cyber security.

V. TIER THREE: LITERACY-BASED LEARNING

For students of all education levels, the most immediate and tangible sources with which to learn about practical computer security knowledge is through the formulation of top-ten lists [25], awareness campaigns [26], and disparate collections of websites and online articles. As a result and as depicted in Figure 1, these past efforts have predominantly focused on providing general awareness of many cyber security issues. While awareness is undoubtedly important, simply being aware of a problem is inherently limiting. Even though tip lists and *awareness* campaigns provide knowledge, they lack the context and depth for students to achieve comprehension, application, or analysis of the material. The goal of literacy-based

learning is to elevate a student's knowledge beyond that of simply being aware of the problem so that students and future professionals are able to successfully consider their actions and new events in the context of security and subsequently make informed decisions as to what they should or should not do to protect their personal and private information as well as safeguard their reputations.

At Iowa State University, we have addressed this gap in security education by developing a course entitled “Introduction to Computer Security Literacy.” The specific purpose of this 8-week, 16-lecture course is to provide both students from *technical and non-technical* majors with the opportunity to formally learn about the many facets of practical computer security knowledge. An emphasis is placed on technical and non-technical majors because previous research on this topic has discovered that despite the perceived advantage of students from technical majors (i.e., computer engineering, computer science, management information systems), students from non-technical majors are, on average, on an equal playing field with their non-technical cohorts when it comes to practical cyber security knowledge [11].

Because the goal of practical computer security is to provide security context to students concerning activities they already engage in on their computer and/or the Internet, the course topics and objectives of the corresponding lectures strive to keep the content focused and at a tangible level for all to learn. Below are the course topics covered and a brief description of the learning outcomes for each:

- **National Cyber Security** Understand our society's and nation's dependence and reliance computer computers, networks and security.
- **Password Threats** Identify and state the threats, methods, and corresponding motivations of how attackers and malware learn passwords.
- **Password Best Practice** Recognize the importance of having a secret, strong and unique passwords in the context of password threats.
- **Cryptography** Understand the purpose, strengths, and limitations of cryptography, especially as found in wireless networks and HTTPS.
- **Malware** Conceptually grasp how malware infects a computer, how it propagates and the objectives of malware once it established a foothold.
- **Defense-in-Depth** Learn how the coupling of firewalls, antivirus software, data backup, patches, and user education provide security protection as well as the purpose, strengths and limitations of each individual component.
- **Surfing the Web** Discover the many web-based threats and resulting security mechanisms that focus on web-based content.
- **Social Engineering/phishing** Learn and recognize social engineering techniques and how these attacks are manifested in emails, ads, and social networking content. Student further learn the skill of dissecting URLs in the context of security.
- **Wireless Networks** Through demonstrations, student are

presented with the threat of sniffing and subsequent mitigation techniques for both users and administrators of wireless networks.

- **Social Networking** Recognize that content is not truly private as well as understand the benefits and consequences of public information sharing.

Based on these high-level topics, the need this literacy-based course addresses is answering the question “why?” for students and to give students the proper context to better understand the purpose, strengths, and limitations of security mechanisms and best practices as well as the manifestation and motivation of the many threats that lurk on the Internet. To achieve this overarching goal, the stated learning outcomes of the course are:

- Define computer security terms and mechanisms
- Describe fundamental security concepts
- State computer security best practices
- Describe the strengths, weaknesses and limitations of security mechanisms and concepts
- Give examples of common security threats, threat sources and threat motivations
- Explain their role in protecting their own physical and non-physical computing assets
- Discuss current events topics and read security articles in the popular press
- Assess computing actions in the context of security

What makes this course particularly effective at accomplishing its stated course outcomes is that students have the opportunity to apply the knowledge learned in lecture immediately when they leave the classroom and begin to interact with their computing devices. Furthermore, this constant interaction with technology increases the students repetition leading to the goal of synthesis so that students can act in a safe manner when presented with a novel situation. Lectures are also incorporated with current event topics so that students can see a direct connection to what they are learning in the classroom, often with an event that has occurred within days of the presentation of the lecture content.

Having taught this class 10 times to over 250 students, the gap that this literacy-based course addresses is clear. There exists a vast amount of students that heavily rely on computers and the Internet and the number of opportunities that they can go forth and learn how to use these technologies safely. Universities and community colleges provide a number of literacy-based learning opportunities in the areas of financial planning, health and wellness, research methodology and utilizing a library. It is time that academic curricula evolve with technology and afford students the same type of opportunities to learn practical computer security knowledge.

A. Lab-based Literacy Learning

Throughout the development and delivery of the Introduction to Computer Security Literacy, it has become apparent that the effectiveness of this literacy-based course would be greatly enhanced by an accompanying lab. As a result, we are

currently developing lab-based components to accompany the previously discussed course topics to provide students with hands-on experience and to increase their understanding of threats, security concepts, and how to better understand and interact with their computing environment in the context of security. The following topics and descriptions summarize the future work in this area and the lab-components that are being developed:

- **Lab 1: How the Internet Works** - Through the use of tools and commands such as `ipconfig/ifconfig`, `ping`, `tracert/traceroute`, `nslookup`, and `wget`, students will discover the very basic workings of the Internet including IP addressing and routing as well as the purpose of the Domain Name Services. The synthesis of these concepts will exemplified through the use of browsing the web. The objective of this introductory lab is to develop the foundation of concepts and use of tools to provide context for future lectures and labs.
- **Lab 2: Passwords** - To better understand password threats and reasoning behind choosing strong and unique passwords, student will learn how to create password hashes and subsequently use password cracking tools to discover the limitations of password hashes.
- **Lab 3: Cryptography** - Building on cryptography lecture, student will get hands-on experience with both symmetric key and public-key cryptography in order to understand the purpose, strengths and limitations of cryptography in modern day computing.
- **Lab 4: Firewalls, backup, antivirus, patches** - Using their own laptop computer, students will discover the settings and security best practices to keep their own computer environments current, secure, patched, backed up.
- **Lab 5: Web browser technologies** - In addition to features that are inherent to a web browser (saved passwords, HTTP, private browsing, cookies, cache, etc.), student will explore the functionality and purpose of a number of popular web browser add-ons such as link scanners, ad blockers, and script blockers.
- **Lab 6: Wireless security** - Student will learn first-hand how to configure a wireless router as well as the perils of sending data over an unencrypted network connection. Further, building on the tools learned in Lab 1, the concept of Network Address Translation will be discovered and discussed.
- **Lab 7: Social Networking** - By means of course-registered social networking accounts, students will gain a working knowledge of the implications of various social networking platforms. Students will further perform a public-data analysis of themselves using popular search methods.

In addition, as shown in Figure 1, we have also engaged in preliminary efforts to expand literacy-based learning in both community college and high schools. The current challenge exists in finding engineering faculty and/or teachers

that have a deep understand of security, stay abreast of current security issues, and are able to express such knowledge to a diversity of non-technical audiences.

VI. CONCLUSION

As a result of society's dependence on information technology coupled with a lack of focus on security education, it is our strong belief that the educational gaps identified in this work need to be addressed by security practitioners, educators and researchers. While there will always be a need for course-based learning methodologies targeted at technically-focused students, this paper provides evidence that both literacy-based and inquiry-based learning methods can effectively address current security shortcomings. While course-based education provides a direct route for those highly interested in cyber security, inquiry- and literacy-based learning allow many students who may have never considered cyber security as a career an opportunity to explore this career track. Providing less formal inquiry-based learning provides students an opportunity to explore cyber security as a career option and evaluate whether it holds interest for them. Furthermore, students who participate in literacy-based learning can also be inspired to pursue the topic of cyber security further through inquiry-based or course-based learning methods. Even if the students who participate in inquiry- or literacy-based learning do not select to formally pursue cyber security as a career option, these students have broadened their knowledge of cyber security and provide much needed security-conscious employees, whether as business professionals, software programmers, or design engineers.

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An Educational Visual Prototyping Environment for Real-Time Imaging

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ABSTRACT

This paper presents the results of a comparison study using the Visual VIPERS interface, a graphical interface which can be applied as an educational tool for novice computer vision students. The goal of the study was to evaluate the change in usability of the interface after the addition of a monitor tool, which can be used to view intermediate image results at specific stages of an algorithm. A user study was conducted in which participants were asked to find an error in a pre-assembled algorithm. Results indicate that participants using the older version of the interface (with no monitor tool) took, on average, less time to find the error than participants who used the monitor tool. However, interview responses indicated a greater level of understanding of the algorithm from participants who used the monitor tool. Interview responses also demonstrated a clear desire from users of the old interface for the addition of a debugging tool (such as the newly introduced monitor tool). Our belief is that participants using the monitor tool performed a more thorough search of the algorithm, and thus gained a greater understanding of how the algorithm operated, while attempting to determine the source of the error.

Index Terms: Education, Graphical User Interface, Computer Vision.

I. INTRODUCTION

Computer Vision is an exciting and information rich field. Human motion analysis, object identification, remote sensing, technical diagnostics, autonomous vehicle guidance, biomedical imaging (2-D, 3-D, and 4-D) and automatic surveillance systems [1] are a few of its applications.

The main goal of this field is to duplicate or mimic the human visual system with algorithms that understand images by extracting information from an image for a particular purpose, such as controlling an autonomous vehicle.

The prevalence of computer vision in areas of research and development as well as in corporate and consumer technologies, has created a wide range of career opportunities for engineers, computer scientists, and for other types of experts, such as psychologists. As a result, the amount of computer vision courses offered in universities is growing. However, learning computer vision algorithms can be very challenging for students new to the field. There are many well written and clear textbooks in this area, and qualified professors to teach the material. Nonetheless, education in the field of

computer vision suffers from a lack of alternative teaching tools. This underlies the importance of products such as Visual VIPERS, a graphical user interface implementation for the Video and Image Processing Environment for Real-time Systems (VIPERS) C++ library, designed for use by students learning computer vision.

Section I-A will discuss challenges faced when studying and teaching computer vision. The remainder of this paper is structured as follows: Section II summarizes work related to education in computer engineering. Section III will give an overview of the Visual VIPERS interface. Section IV introduces the methods of our study. Section V illustrates the results obtained using the Visual VIPERS interface. Section VI provides conclusions and a discussion of possible directions for future work.

A. Challenges of studying computer vision

The field of Computer Vision is exciting and diverse, but it also possesses its own unique challenges. Some challenges of studying and teaching the field of Computer Vision, according to [1] include: Loss of information from 3-D to 2-D, interpretation of images, and noise. The level of prior programming experience acquired by each student also plays a large role in their learning performance. Each of these will be discussed in detail below.

1) *Loss of information from 3-D to 2-D:* When a photograph is captured with a digital camera, one dimension is lost in this process. In other words, a photograph is a 2-D (x - y plane) representation of a 3-D real world environment (X - Y - Z volume). This is a geometric property which can be approximated by a pinhole model. The pinhole model corresponds to projection geometry. In other words, the projection transformations that occur while a camera takes a picture “maps points along rays but does not preserve angles or collinearity” [1]. This means that objects in an image that are close to the camera, may appear similar to objects far from the camera. Therefore, we need some sort of reference point or context to measure the size of objects.

2) *Interpretation of Images:* Humans have no problem interpreting images. We base our interpretation of images on *top-down* and *bottom-up* processing. *Top-down* processes refers to interpreting images based on knowledge we already have about what we are looking at, whereas *bottom-up* processing refers to data-based processing where we base our interpretations on

images of incoming data. The problem is that humans do not just use one or the other means of processing information. Rather, we combine *top-down* and *bottom-up* processing for different scenarios. We make these discussions unconsciously, and as such, it is difficult to develop algorithms that mimic these complex but primitive processes. It has been noted by the Computer Vision community that a "quantitative representation of human perception with scientific basis has been a problem unsolved for a long time" [2].

3) *Noise*: In computer vision, as with more general image analysis fields, noise is regarded as an undesirable by-product of the image capture process, which causes distortions in the image that can obscure the desired relevant information. Noise is most commonly characterized by random variations in the brightness or color of an image. This can lead to reduced quality in measurements obtained from an image using computer vision methods, or in extreme cases (when high amounts of noise are present) can make such measurements impossible. It is important to accurately measure features in images if we aim to interpret an image accurately. However, it is often impossible to completely eliminate the presence of noise. This fact speaks to the necessity of mathematical tools that can manage the uncertainty associated with noise [1].

4) *Programming Experience*: The above points are only a few challenging factors that may intimidate undergraduate students in pursuing and education in this field. For these reasons, alternative teaching tools are in great need for undergraduate students who are interested in the field of computer vision. Typically, computer vision courses are offered as an upper-level undergraduate or graduate level course at most post-secondary institutions. This is due to the technical requirements which often necessitate the need for numerous prerequisites, such as calculus, image processing, data structures, linear algebra, and numerical methods. In many cases, computer vision is taught using a "traditional style", which involves lectures that teach theory and concepts combined with assignments that offer practical experience by asking students to implement specific algorithms in order to complete a given task.

Students new to the field often find that there is a steep learning curve, as they are required to learn a large amount of theory, combined with specific implementation details for each algorithm. In addition, they must be able to implement these algorithms in the given programming environment required by the course, such as C++ or MATLAB, which in some cases may also be new to them.

Course content in computer vision is inherently visual, thus intuition would suggest that course material should be more approachable than other courses where material is more abstract. However, theoretical concepts and algorithms are often discussed in lectures with little or no demonstrations or exercises. Krotkov from Carnegie Mellon University, Pittsburgh, PA, said in his statement at the 1996 CVPR panel [3]: "As every computer vision scientist knows, it is difficult to understand how a particular algorithm works without actually applying it on various images, using various parameters. It is

hard to convey this experience to the students using only a few images. Even more difficult is trying to demonstrate to the students how algorithms that operate on video sequences perform."

II. RELATED WORK

Teaching computer vision topics should, ideally, be tailored toward the students learning styles. LEGO MINDSTORMS robots were introduced as hands-on educational tools that provided students feedback on effectiveness of using LEGO MINDSTORMS robots [4]. Learning through the senses, as a hands-on teaching style, can have positive results on students. For example, learning while doing something that requires their senses (i.e.: Sight) [4], ensures that the course material is being absorbed on multiple levels. In [4], they used a hands-on approach to learning robotics and embedded systems design. In addition, a hands-on approach is an alternative way to hold the attention of students at the introductory level in computer science and engineering faculties. Barnes [5], suggests that "LEGO MINDSTORMS models are a particularly convenient way to build physical programmable models without having to know anything about hardware". Since this approach uses the RCX processor, students can program in JAVA, a common computing language. Robotics inspired projects can provide students with programming options other than a desktop [6]. Many current and past students would likely agree that hands-on learning is invaluable. The motivation to learn increases when students are able to comprehend the final outcome of all their hard work. The ability to apply one's knowledge towards building robotics is exciting and challenging for student. This motivation and drive, however, is unfortunately curtailed by some practical factors. For example the high cost of robotics-inspired projects in undergraduate computer science departments is not reasonable, at \$5,000 per robotics kit in the early 1990s [6]. Therefore, even though the hands-on approach to learning computer programming is desirable, it is not always the most cost efficient alternative.

As a hands-on approach seems intuitive when learning with robots, a visual approach to algorithm design would seem intuitive for computer vision, given the inherently visual nature of the field. As discussed in section I-A4, this is normally not the case, but there are some cases where visual methods of development have been employed.

The use of image graphs have improved efficiency when searching for desirable rendering parameters for a dataset of medical images [7]. They provide a visual means of representing the data exploration process. An image graph begins when a user accesses a given image. When they change a rendering parameter (i.e.: Color map, rotation, opacity, zoom, sampling, shading) a new version of the image is created. Different image results form the nodes of the graph, while changes in parameters form the edges of the graph. If the user reverses a parameter change and decides to change a different parameter instead, this is depicted by a branch in the graph from the original image. Successive parameter changes form a path in the graph. In this way, the image graph represents a record of

all parameter changes made (and intermediate images created) before arriving at a final result, and also maintains a record of alternative parameter choices that were explored but discarded. This ability to view intermediate steps in development can be very useful for collaborators, enabling them to view the entire development process at a glance and see not only the design choices that were kept, but also those that were abandoned.

Graphical user interfaces designed to aid people in developing computer vision algorithms have received little attention from the computer vision community. According to Lomker et al. [8], building a good computer vision system should be characterized by: ease of use, online parametrization of algorithms, flexible visualization of processing results, simple integration of 3rd party libraries, and rapid prototyping through reuse of existing algorithms. The literature is vast regarding how GUIs work, but the focus is on functionality rather than usability. Little attention seems to be paid to the requirements listed above. Attention is instead focused on aspects such as the number of implemented functions, or increased computational efficiency through parallelization of algorithms. The authors also note that, there seems to be no vision-related graphical environment that has been widely accepted by the vision community, although attempts have been made.

One example of a vision-related graphical environment is VisiQuest, by AccuSoft. VisiQuest is a collection of data and image analysis software tools that allows for fast development of applications regarding imaging tasks for areas like document imaging, photo processing, or medical applications. This visual programming environment gives users access to functions and algorithms simply by the click of a button. Similar systems have been created by MVTec., a manufacturer of machine vision products, which has created ActivVisionTools and HALCON. HALCON has a library of more than 1600 operators for blob analysis, morphology, matching, measuring, identification, and 3-D vision. ActivVisionTools has tools that are based on the HALCON library. These two software products have been used in the semiconductor industry, inspection application, and surveillance systems. The iceWing architecture is used in [8] due to its ability to quickly display intermediate results. In addition it allows for easy and flexible modification of parameters. Regarding the ability to quickly view intermediate results of an algorithm, iceWing enables multiple windows to display results. This system helps in developing and testing algorithms, and it has the ability to build more complex algorithms. iceWing has been used in areas like camera configuration or camera grabbing, gesture recognition, and interactive object learning.

Only one previous attempt was found for the creation of a graphical user interface with the specific goal of aiding students in the design and implementation of computer vision algorithms. This interface, referred to as a visual programming environment for the distributed image processing (VPEDIP), was based on the synchronous data flow (SDF) module [9]. The interface uses a directed data flow graph for the workspace, in which computational elements (i.e. functions) are represented by nodes. Edges connecting the

nodes represent data flow paths. In addition to the workspace, the interface includes a list of icon buttons on the left side, which allow the user to edit and execute their algorithm. The message window and server icons are located on the bottom part of the interface. The message window displays processing and error information, while the server icons indicate the status of servers in the network. While the VPEDIP interface demonstrates a strong attention to computational efficiency and functionality, little or no attention seems to have been paid to evaluating the usability of the interface. This could serve as an example that previous works in the field of interface design for computer vision have focused almost exclusively on the functionality of designed interfaces, and not on usability. This underlies the need for such studies to be performed.

The Visual VIPERS interface is a novel environment for computer vision students to explore algorithms through a modular architecture, where each module instance performs a pre-specified task [10]. This system is ideal for universities and students because it is open source, and it gives students hands on experience building algorithms and visualizing intermediate results. This interface allows for software systems design and prototyping, which is a shift from algorithm development [10]. The Visual VIPERS interface will be described in more detail in the following section.

The primary contribution of this study will be an evaluation of the usability of the Visual VIPERS interface for novice users. We attempt to assess the benefits of providing users with a visual means of interacting with algorithm designs, and thus underscore the need for further advancement in this area (usability evaluation for educational tools).

III. VISUAL VIPERS

One approach to facilitate computer vision education is to develop design tools which allow students to gain more hands-on experience with how computer vision algorithms operate, and how their operation is affected by changing parameters. The Video and Image Processing Environment for Real-time Systems (VIPERS) C++ library is designed for use by students and researchers in the computer vision field. Visual VIPERS is a graphical user interface designed for the VIPERS library, which consists of a modular architecture. The interface provides a user-friendly environment for students studying the development of computer vision algorithms.

Figure 1 presents the Visual VIPERS interface, which allows users to select functions (modules) to include in their algorithm simply by dragging them into the workspace. Any function-specific parameters can be set by selecting the appropriate module in the panel on the right side of the interface. The user can then connect the inputs and outputs of the modules as needed to form a larger algorithm. The interface includes an additional feature, called a monitor. When enabled, the monitor is displayed in a separate window from the rest of the interface, as shown in Figure 2. Using a drop-down menu the user can select a specific module in the workspace that they wish to track with the monitor. When the algorithm is executed, the monitor window will display the output for

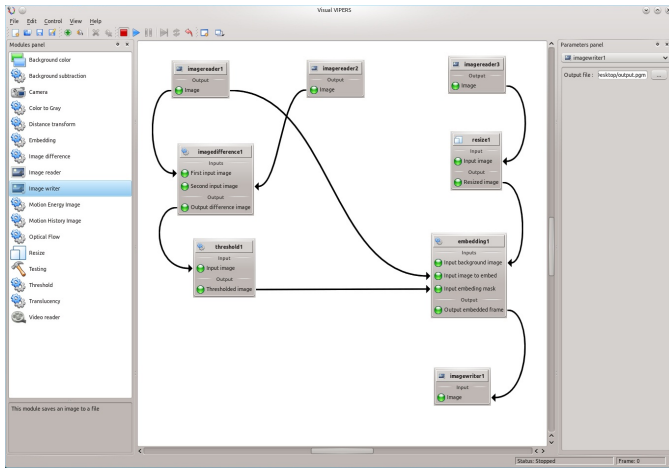


Fig. 1. VIPERS Interface, which illustrates what the participants in this study were presented with.

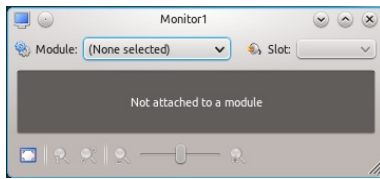


Fig. 2. VIPERS Interface monitor in its initial state, before selecting a module's output image to display.

the selected module. The user can create as many monitor windows as they wish, and assign them to display the output of various modules.

The monitor feature is believed to have greatly increased the usability of the Visual VIPERS interface. It gives students a fast, easy method to view the data flow, in image format, at each stage of their algorithm. This is useful for gaining a greater understanding of the underlying concepts that they are applying. It is also a useful tool for debugging, as it makes it much easier to detect when the output of a particular module is not what was intended. This ability to visualize both the correct and incorrect operation of an algorithm will help students to develop a better intuition both when designing and debugging algorithms.

By using Visual VIPERS to implement computer vision algorithms, students are no longer required to program (and debug) functions in detail before implementing their algorithm. This allows more time for students to experiment with their final algorithm by changing parameters and observing the results. By eliminating the need for advanced programming experience, it is also possible that the prerequisite requirements could be lowered, opening up the course to students who possess little programming skill.

In our study, we will perform a comparison study of two versions of the Visual VIPERS interface: one with the monitor feature enabled, and one with the monitor feature disabled. We hypothesize that the addition of the monitor tool will promote

a greater understanding of how algorithms operate, and will help students to locate errors in an algorithm more quickly. We will validate the usability of the Visual VIPERS interface by assessing the ease of use for students to identify a error in a pre-assembled algorithm. Our assessment is based on a combination of qualitative and quantitative findings.

IV. METHOD

Eleven participants (ten male, one female) were selected from a population of university students enrolled in computer vision and/or engineering program (undergrad or graduate level) at the University of Victoria.

Participants were assigned randomly to either the monitor or no-monitor group. At the start of each session the participant was given an introduction to the important components of the interface. They were then presented with a pre-assembled algorithm which appeared in the workspace of the interface.

The algorithm took as input 3 images. Images A and B were pictures of the same scene, consisting of a desktop with several objects placed on it. The scene in image A possessed one object not present in image B (a whiteout bottle). Image C was a picture of a completely different scene, consisting of a tabletop with two objects placed on it. The purpose of the algorithm was to perform image differencing followed by a threshold on images A and B in order to create a binary mask of the whiteout bottle. This mask was then to be used to copy the whiteout bottle from image A, and paste it into image C. The correct output of the algorithm would therefore be an updated version of image C with the whiteout bottle added to it (See figure 3).

An error was introduced to the algorithm in the form of an incorrect threshold value used to create the binary mask. The threshold was set to a lower value, which resulted in a mask that covered almost the entire image, save for a few sparse pixels. Instead of copying only the whiteout bottle from image A, the mask copied nearly the entire image, which was then used to almost completely overwrite image C. As a result of this error, the output took the appearance of image A, with what appeared to be noise consisting of sparse pixels (See figure 4). These sparse pixels were the few remaining pixels from image C not overwritten by the masking process.

Figure 1 shows the pre-assembled algorithm that the participants of this study were presented with. The purpose of the algorithm was described, and participants were shown the current (incorrect) output of the algorithm as well as what the correct output should look like. Participants were then instructed to identify the error in the algorithm. Subjects were timed during their completion of the task, and each session was recorded using a video camera for further analysis.

After completing the task, participants answered a short verbal questionnaire. Once the final questionnaire was completed, participants were debriefed about the purpose of the study.

V. RESULTS

The completion times for the monitor and no-monitor group can be seen in Table I and a plot of the data can be seen



Fig. 3. Correct output of the algorithm, which participants in this study were presented with.



Fig. 4. Incorrect output of the algorithm, which participants in this study were presented with.

in Figure 5. The no-monitor group appears to have a shorter completion time.

When reviewing interview responses, there was a noticeable overlap observed between the participants' feedback and comments. All participants had positive feedback on their overall experience with the interface, with the lowest rating at 3.5 out of 5, with 1 indicating that they found the interface hard to use and 5 indicating that they found it easy to use.

| Monitor | No-Monitor |
|---------|------------|
| 6 | 3.5 |
| 7 | 4 |
| 8.5 | 5 |
| 12 | 11 |
| 13 | 12 |
| | 12.5 |

TABLE I
TASK COMPLETION TIME (MINUTES).

All participants expressed a high level of satisfaction after testing. Participants had several constructive criticisms for possible interface changes. One common comment was that people had difficulty selecting a linkage line. More specifically, they found it difficult to select a linkage by clicking

it. They expected to be able to modify a linkage simply by dragging and dropping it, which was not the case. Another expectation many of the users had was the lack of help menus or examples of module operations, which are common in other programming environments. Lastly, participants from the no-monitor group expressed a desire for some sort of debugging tool to show intermediate results.

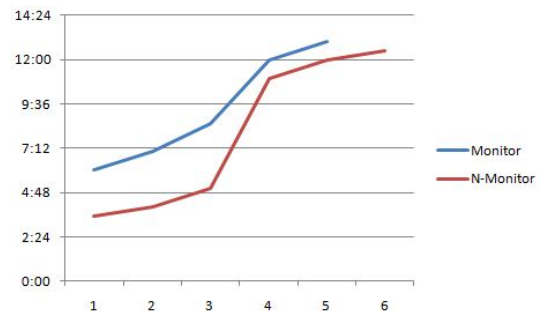


Fig. 5. Participants task completion time (minutes).

VI. DISCUSSION

Results indicate that participants who made use of the monitor tool typically took as much, if not more, time to complete the assigned task than those who did not have access to the monitor tool. This might seem counter-intuitive, given that the monitor tool is intended as an aid to help with debugging of algorithms. However, it was observed that having access to the monitor tool resulted in participants studying the visual output of the algorithm more thoroughly while searching for the error. This is not a reflection on the monitor group's ability to find the error, it simply shows that the time taken to find an error is not necessarily representative of a participant's level of comprehension for the task. The monitor group demonstrated a better comprehension of the algorithm, likely because they spent more time studying it with the aid of the monitor tool. This was noticeable when participants were asked to explain the operation of each stage of the algorithm. We observed that the monitor group was able to express the rationale behind each of the algorithm stages, whereas the no-monitor group simply stated the basic objective of each algorithm stage, with little justification for the necessity of each step.

All participants had a positive reaction to a graphical design interface used to build computer vision algorithms. Many made the comment that they wish they had a tool such as this for algorithm design. It is interesting to note that the no-monitor group commented on the lack of a debugging tool with similar operation to that of the monitor tool. This demonstrated a desire from users of the interface for the ability to scrutinize the algorithm functionality more closely.

Participants were instructed to notify us when they felt confident that they had found the error in the algorithm. However, later we discovered that many participants attempted to fix the error in addition to identifying the error. This may

account for some of the longer times that were observed. A participant may have found the error in 3 minutes, but then had taken up to 13 minutes to fix it before reporting that he was finished. Interview responses indicated that some participants were not certain of the precise nature of the error until they had corrected it. In other words, they needed to fix the error in order to confirm for themselves that they had indeed found the error.

The task itself was tailored toward a novice user. However, due to its simplicity, participants felt that they were unsure of how to rate the entire interface. This is because the participants felt that they had not been sufficiently exposed to the VIPERS interface in terms of its functionality. Our motivation for the simplistic algorithm was based on the fact that we did not want an error which was so complex that it required a significant amount of background knowledge in computer vision in order to find it.

Lastly, we felt that recording interactions with the interface would have been useful for allowing us to realize exactly how participants made use of the interface and its tools. For example, we observed one participant in the no-monitor group reconnecting modules to create additional image outputs. Essentially, this allowed the participant to simulate a debugging tool such as the monitor. In this way, we may have discovered discrepancies between what participants said they did, and what they actually did during the study. It would be interesting to see if the monitor group interacted with the interface differently than the no-monitor group. We felt that the interview questionnaire may not have revealed these interactions if they were present.

VII. CONCLUSION

In this study a comparison was done between two versions of the Visual VIPERS interface. The first version possessed a monitor tool which participants used to view intermediate results of a pre-build algorithm. The second was an older version of the interface, which did not have the monitor tool. A user study was performed, in which participants were asked to find a error in a pre-built algorithm using one of the two interface versions. We found that there was a noticeable difference between the two groups in terms of the time taken to complete the requested task. The no-monitor group had an average completion time of 9.3 minutes (st.dev.=3.07) while the no-monitor groups took an average of 7.1 minutes (st.dev.=4.07). We feel this difference may be due to the monitor group using the monitor tool to do a more thorough search for the error. Based on interview questions all participants gave positive feedback regarding their overall experience with the interface.

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Work in Progress: Building Bridges in Our Backyards:

Engineering, Service Learning, and Our Elder Neighbors

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Abstract—A novel partnership with community organizations serving older adults creates the opportunity for engineering students to practice design in a meaningful and unfamiliar but local service learning context. Students benefit from contextualization and user-centered design lessons typical of foreign design projects. Community members gain significant relationships and pride through these interactions.

Keywords—service learning; engineering design; community

I. BACKGROUND: DESIGNING FOR PEOPLE

Service learning – an increasingly popular approach to engineering design projects – motivates students, connects engineering theory to practice, and attracts diverse populations who may find the human connection more compelling than whiz-bang technology [1][2]. Many recent engineering service learning efforts focus on the needs of the developing world, communities whose experiences and needs typically differ from those of the participants. [3][4]. These experiences have the additional benefits of pushing students to recognize the importance of user needs and context: the field of *appropriate design* takes into account the needs and context in which the solution must work, and not all users and contexts resemble those of the engineering student. Indeed, the very unfamiliarity of the developing-world can be an important and eye-opening catalyst to student learning. Thus, appropriate design projects teach students about engineering, leverage their interest in solving real problems and serving real needs, and motivate engineers to appreciate the importance of a human-centered and contextually informed perspective.

Unfortunately, connecting with user populations in the developing world is often expensive, logistically complicated, and therefore infrequent. Some service learning projects are instead based in local communities, including work with nearby community development organizations [5], partnerships with rehabilitation institutes [6], or engagement with not-for-profit organizations [2]. These experiences provide many of the benefits of appropriate design, though often without the radically different context of the developing world: students can extrapolate from their own needs, desires, and contexts to those of the clients they are serving, leading them to dismiss rather than appreciate the importance of understanding clients.

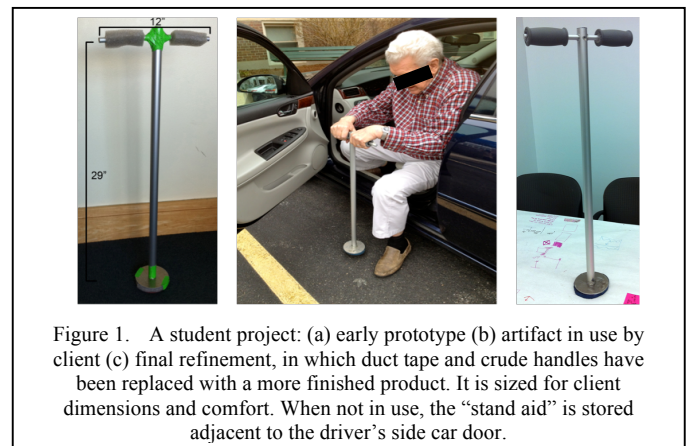
In this paper, we present our experiences in an engineering design service learning course that engages a compelling and unfamiliar population close to home: senior citizens in our own communities. Students in our semester-long project course experience ethnographic and pedagogic benefits of designing

for an unfamiliar population while simultaneously building meaningful and often transformative community connections.

II. ENGINEERING FOR HUMANITY

Engineering for Humanity, an interdisciplinary engineering design and anthropology course at the Franklin W. Olin College of Engineering, is a semester-long partnership between the college and the Councils on Aging in two neighboring communities, Needham and Wellesley Massachusetts. Each year, older community members are recruited to partner with our students in a series of discovery, design, and community-building activities. The Councils on Aging play a crucial role in recruiting and providing ongoing support to our elder partners – beyond what the College and our students might normally undertake – thereby helping to ensure that the experience is a rich and rewarding one for our volunteers.

During the semester, our students and their elder partners engage in a series of activities crafted to bring them together and to create a community. Initially, these include a set of every-day activities, such as grocery shopping, luncheon, or a trip to the movies, in which the community is built and students also learn (through conversation and observation) about difficulties and triumphs of our partners' lives. Next, students synthesize what they have learned into project ideas, refining these briefs into robust, targeted, and manageable projects through consultation with experts and co-design with our elder partners. A series of standard design stages – specification, prototyping, testing, refinement – are accompanied by visits with our partners for feedback, continued learning, and continued community building, including guest speakers and media of mutual interest. By end of semester, several of our



This project received support from the Metrowest Health Foundation and from the Franklin W. Olin College of Engineering Innovation Fund.

volunteers have received specific, custom-designed artifacts intended to solve particular problems (see Figure 1, Table 1). All of our volunteers report increased sense of belonging and value gained from being a part of this community.

III. OUTCOMES

A. Impact on Students:

Beyond the expected benefits of a hands-on engineering design curriculum, this service learning experience is transformative for our students. In end-of-semester surveys collected in the first year of the course, all students expressed an increased understanding of the everyday lives of elders and pointed to specific attitudes or assumptions that changed during the semester. In addition, approximately one-third of students involved expressed a specific change in career trajectory or major activities as a direct result of the class, including one who intends to explore a career in occupational therapy and several others who will focus on issues of aging or work with elders. Evidence in the current – second – course offering suggests that this trend of impact on life plans continues; by the conference we will be able to report on these outcomes as well.

Increases in everyday understanding are evident in student bloggings (a required course activity). For example, course activities provide first-person authentic experiences for students to experience some of the physical disabilities that may be associated with aging. After watching a fellow-student enter a bathroom in a wheelchair, a student reflected: *The door is really heavy to push open plus there is a slight lip to enter.... Sue couldn't get in by herself.... Thinking about it, I've never seen a bathroom door anywhere with a handicapped button. How does society expect people in wheelchairs to be able to get into bathrooms?* After wearing earplugs during a discussion, another student told her elder partner that she had perceived a “barrier” between herself and the rest of the world. Her partner, who experiences a range of physical disabilities related to a neurological illness, noted that this is how he always feels. The student later reflected on opportunities that enable membership rather than alienation for elders.

In another case, a student drew design-related lessons from her observations when observing an elderly couple grocery shopping: *The man was using a cane and following a woman (who I assume was his wife) who was leaning on a cart. The man was helping the woman to push the cart along. That made me think about how carts are designed. They are big and bulky, and relatively hard to maneuver. The man was trying to use a cane and push the cart, which was a real struggle for him. The woman didn't have the strength to push the cart herself. Perhaps we could make a smaller cart that is easier to turn and requires less strength to handle. But then, would an elderly person want to use this special cart, or would that again be a problem because of their desire to remain the same – unchanging over the years and never 'growing old'?*

B. Impact on Community Partners:

Eight months after the completion of the first run of our course, an independent evaluator interviewed the community volunteers from that semester. The evaluation report notes: *All participants looked back upon the program as an extremely positive experience. The elements that remained important to*

TABLE I. ENGINEERING FOR HUMANITY SYLLABUS

| Unit 1: Empathy and Ethnography | | |
|---|--|--|
| Partner interactions: Lunch, Shopping, Every-day activities | Design Activities: Goal-Setting, Contextual Inquiry | Guests/Field Trips: Assistive devices, Occup. therapy |
| Unit II: Lives: From People to Project Definition | | |
| Partner interactions: Co-Design, Design reviews | Design Activities: Synthesis, Translation, Brief Development | Guests/Field Trips: Designers |
| Unit III: Supported Independence: Many Versions | | |
| Partner Interactions: Fall prevention workshop | Design Activities: Prototyping, Testing, Iteration | Guests/Field Trips: Assisted Living, Community Centers |
| Unit IV: Community and Context/Looking Forward | | |
| Partner Interactions: Celebration | Design Activities: Refinement, Delivery | Guests/Field Trips: Alzheimers Assn |

them were most commonly, the students, involvement with something meaningful, attention paid to them, and connecting with others.... One respondent commented, "It was one of the best things I have ever done." Further, these participants describe the experience with pride and describe the course itself, as well as participation in the design project, as a positive influence in their lives.

The outside evaluator is currently measuring impact of Year 2 of the course on the new batch of volunteers. Because one of the goals of this project is to improve the quality of life and emotional wellbeing of the community partners, we are using tools to measure social isolation, feelings of loneliness, meaning in life, and overall satisfaction with life., including pre, mid, and post-semester measures of the volunteer's perceptions of the program and themselves. The preliminary report of Year 2 mid-year interviews includes significant volunteer enthusiasm about the personal importance of this program. As the evaluator noted in informal communication to us: *They are really interested in finding some way to continue this type of engagement, and also with the specific students. Bonds seem to be made so quickly with this program.*

ACKNOWLEDGMENT

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Civil and Geological Engineering Service-Learning Projects as Part of a Pre-Engineering Education Collaborative

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Abstract—Three educational institutions in South Dakota are collaborating to develop pre-engineering courses to increase the enrollment and success of students transferring from Oglala Lakota College (OLC) to 4-year bachelor degree programs in science and engineering at South Dakota School of Mines and Technology (SDSMT) and South Dakota State University (SDSU) through a grant from the National Science Foundation Tribal Colleges and Universities Program (TCUP). In addition to the development and delivery of these courses, an aggressive summer schedule of service learning projects has been incorporated into the program. The objectives of these projects is to provide a hands-on introduction to science and engineering topics, promote community involvement and service, and to stimulate student interest and motivation to pursue these fields of study. This paper describes the activities of the OLC/SDSU/SDSMT Pre-Engineering Education Collaborative (OSSPEEC) program and two service learning projects related to civil and geological Engineering. Results indicate a high level of mentor involvement and coordination at each institution is an important component to a successful experience for the students. The first year of the program also indicates that student collaboration, variety in project related activities, and active community involvement help support student motivation and interest in their science and engineering related activities.

Keywords—service learning; pre-engineering education; constructivist philosophy

I. INTRODUCTION

The Pre-Engineering Education Collaborative is an effort by Oglala Lakota College (OLC), South Dakota State University (SDSU), and the South Dakota School of Mines and Technology (SDSMT) to develop a pre-engineering curriculum that will enable students graduating from OLC with associate degrees to continue their degrees in 4-year engineering programs at the junior level. Summer research and service learning projects are incorporated into the program to provide a hands-on introduction to science and engineering topics, promote community involvement and service, and to stimulate

student interest and motivation to pursue these fields of study. The specific project goals are: 1) Establish collaborative offerings of gateway and bottleneck courses that occur in the first two years of engineering curricula coupled with on-reservation hands-on laboratory experiences and recitation sessions at OLC, 2) Transform classical engineering program curricula to follow the constructivist philosophy of learning through vertical integration of the first two years by incorporating service-learning and research project learning experiences, 3) Increase the pre-engineering and engineering recruitment, retention, and graduation rates for South Dakota Native American students.

At a time when the United States is facing unprecedented global economic competition, not enough young people are preparing to enter the critical Science, Technology, Engineering, and Mathematics (STEM) fields. Encouragement and support for enrollment and retention of qualified US citizens in STEM fields is critical to the long-term success of the US economy [1]. The gap between the demand and availability in the area of engineering is particularly striking for Native communities. Nationwide, Native Americans represent about 1% of the US population and about 0.5% of engineering enrollment. In South Dakota, where Native Americans represent about 10% of the population, disparity within engineering programs is even greater. In 2009, Native Americans represented about 2.1% of engineering enrollment at SDSMT and 1.5% of engineering at SDSU. The low retention rate of Native American college students may be partially responsible for disparities in engineering disciplines. The overall Native American college student retention rates were between 7% and 25% in 1995 [2], with the lowest retention rates in STEM disciplines. Tribal colleges, which tend to have higher overall retention rates for Native American students, still have lower overall retention rates when compared to state institutions.

University-level curricular materials have typically been designed to improve understanding of topics in a linear but not interrelated or integrated fashion. The linear cognitive development model [3] has become a very popular and well used model within STEM disciplines, while Bloom's Taxonomy [4] has provided the active-voice language for developing, assessing, and evaluating the success of STEM programs of study in the linear cognitive development model [5]. STEM curriculum design has also typically followed the linear development pattern of a Piagetian [3] theoretical framework [6]. That is, material designed to specifically improve understanding in one area typically is not assessed for its impact on other areas.

In contrast to the Piagetian learning model, other researchers [7] focused on the structure of the field explaining that the "grasping of the structure of a field" is understanding it in a way to permit many other meaningful relationships to be established. Student learning experiences need to be facilitated in a manner that allows them to construct complex interrelated understandings of STEM fields. The development of knowledge is a complex process including stimulation, reflection, abstraction, and experimentation [6] [8]. In general, constructivist pedagogy emphasizes the importance of knowledge gained through experience [9]. Also, it has been stressed that one of the most important ideas is that students must construct their own knowledge structures and that basically correct preconceptions can be used to help the student learn [10]. Thus, the integration of learning activities is important because mastery of the fundamental ideas of a field involves both the grasping of general principles and the development of an attitude toward learning and inquiry, guessing and hunches, and the possibility of solving problems on one's own [7].

Although hands-on learning experiences are ubiquitously considered to be platforms for enhancing conceptual understanding [11], little consideration has been given to optimizing the timing of the hands-on experience in the overall learning scheme as explained in Kolb's theory. It has been shown that poor knowledge retention in hands-on laboratory experiences can be explained by inefficient activation of the prehension dimension of Kolb's learning cycle [9]. Kolb's learning theory distinguishes between apprehension and comprehension as independent means of grasping knowledge while intention and extension are independent modes of transforming experience. These four modes are equally important to contributing to the learning process. Traditional teaching models for STEM education that have relied on Piaget's model emphasize theory taught in classical lectures followed by reflection through written exams.

The OLC/SDSU/SDSMT Pre-Engineering Education Collaborative (OSSPEEC) is made possible through a grant from the National Science Foundation (NSF) Tribal Colleges and Universities Program (TCUP). OSSPEEC relies on an integration of activities including the traditional classroom setting and individual homework assignments delivered face-to-face or at a distance combined with laboratory, service learning, and research internship experiences on the reservation. The initial collaborative learning activities are used to establish the prehension necessary for the

transformative learning experience to occur in the project based internship experiences, while the structure of the learning experience enables the student to develop a risk-taking attitude toward learning and inquiry, toward guessing and hunches, and toward the possibility of solving problems independently.

OSSPEEC was initiated with objectives focused on enhancing the capability of OLC to deliver the first two years of a Bachelor of Science degree program in engineering. The collaborative offering of these courses by OLC, SDSU, and SDSMT will result in students completing a 2 year AA degree in Science, Engineering and Math (SEM) at OLC with the ability to transfer to a 4-year degree program at the junior level. All eight of the proposed classes have been offered at least once and improvements for subsequent offerings are being made.

The OSSPEEC program, which began in Fall 2010, initiated eight service-learning projects during the summer of 2011. This paper describes 2 projects related to Hydrogeology and the restoration of a Veteran Wall, their relationship with pre-engineering courses, and engagement with the community beyond the participating academic institutions. A discussion of identified challenges and successful methods that will be implemented during the continuation of the projects in future semesters is also included.

II. SERVICE LEARNING AND PRE-ENGINEERING COURSEWORK

Results of the OSSPEEC program to date include the successful initiation of eight service-learning projects (Table I) and the delivery of eight SEM courses using a variety of delivery methods during the 2011 summer and academic year (Table II). Of the sixteen undergraduate students leading these projects and enrolled in the SEM classes, three were from SDSMT, three from SDSU, and ten students from OLC.

Many of the service learning projects provided a discovery phase that complemented the material in the SEM courses delivered. In particular, the hydrogeology and Memorial Wall projects introduced students to relevant concepts in the Geology for Engineers and Materials and Laboratory courses, which will be further developed when the projects continue during the summer of 2012. These projects consisted of three students from SDSMT and two students from OLC and are described below to demonstrate the integration between classroom instruction, laboratory, and project experiences.

A. Hydrogeologic Mapping

One of the project-based service-learning activities during the first summer was the initiation of a detailed hydrogeologic unit map of the Pine Ridge Indian Reservation and the White River watershed (Fig. 1). Compilation of this type of map will provide a powerful tool and information source that can be used for analysis of source waters for drinking, recreation, irrigation, wildlife, riparian ecosystems, and other vital purposes. It also will provide information on the mechanics of the local hydrogeologic system, especially with respect to ground water and surface water interaction and to the location and behavior of aquifer recharge areas for Reservation water supplies.

TABLE I. PROJECT LIST

| | |
|--|---|
| Memorial Wall | Restoration of a Memorial Wall honoring World War I and II veterans. |
| Hydrogeology | Compile existing geologic maps and identify existing ground water data sources. |
| Wind Energy at OLC | Review existing meteorological data and replace damaged anemometers for future monitoring. |
| Pine Ridge Aquatic Ecology | Development of a physical and biological assessment program to measure non-point source pollution impact in Pine Ridge Reservation streams. |
| White River Uranium | Survey for uranium and arsenic hot spots in streams and springs to develop a more comprehensive sampling program. |
| Heavy Metals/Plants | Measurement of bio-uptake of heavy metals in traditional food plants. |
| Surveying and Detention Pond Design at OLC | Survey and design of water detention pond to reduce peak flows and erosion. |
| GIS Support Projects | Download existing base data in support of Aquatic Ecology, Hydrogeology, and Uranium projects. |

TABLE II. PROGRAM CURRICULUM

| | |
|-------------------------------------|--|
| Principles of Environmental Science | Lecture developed by SDSU and OLC and offered in hybrid-distance mode. |
| Surveying and Laboratory | Lecture developed by SDSU and OLC and offered in hybrid-distance mode with an onsite laboratory component. |
| Freshman Design Experience | Developed by OLC and SDSMT, and offered in hybrid-distance mode with an onsite service-learning component. |
| Sophomore Design Experience | Developed by OLC and SDSMT and offered at OLC with an onsite service-learning component. |
| Statics | Developed and offered by OLC. |
| Geology for Engineers | Lecture and field trips developed by OLC and SDSMT and offered in hybrid-distance mode. |
| Materials and Laboratory | Lecture and laboratory offered at OLC by SDSMT faculty including professional material-testing certifications. |
| Computer Aided Design | Developed by SDSU and OLC and offered in hybrid-distance mode. |

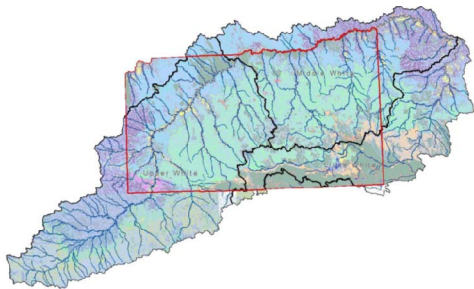


Figure 1. Geologic units within the White River watershed and the Pine Ridge Indian Reservation. Red outline denotes Reservation boundaries.

B. Restoration of a Veterans Memorial Wall

Community members in Wanblee, SD were interested in repairing a Veterans Memorial Wall located on the school grounds. As shown in Fig. 2, settlement has caused the wall to lean and many of the names are deteriorating due to weathering. Two students from SDSMT and one from OLC

used the opportunity as a service-learning project during the summer of 2011. Students visited the site and met with community members, including descendants of John High Horse, who coordinated the original construction. The students discovered the wall was originally constructed in 1947 [12] and contains the names of over 230 Native American Veterans that served in World War I and II. The names are carved in sandstone panels and are embedded in a concrete wall. Sometime during the late 1970's, the wall was moved by helicopter to its current location in front of the Crazy Horse School in Wanblee.

The components of the wall in need of repair include the sandstone panels, where portions of the lettering have eroded (Fig. 3), the deteriorated concrete wall (Fig. 3), and foundation settlement. After investigating several repair and restoration options and receiving community feedback, a final strategy was identified. The less-durable sandstone panels will be replaced with cast-in-place concrete, the deteriorated concrete will be

patched, and the material surrounding the foundation will be excavated to raise the foundation to a level position.



Figure 2. Veterans Memorial Wall, Wanblee, SD



Figure 3. Sandstone and concrete damage

C. Assessment

Students completed pre-program and post-program service learning surveys at the start and end of the summer program respectively. At the start of the summer program, students were asked to indicate the magnitude of their agreement or disagreement with eight statements about service learning. These same statements were slightly modified in wording to reflect activity completion, and students again indicated the magnitude of their agreement or disagreement at the end of the summer session. Participating faculty also completed the post program service learning survey at the end of the summer. A ninth statement was added for the post-program survey asking students and faculty to indicate the magnitude of their agreement or disagreement with a statement about the effort that they had made throughout the summer for service learning reflection. Reflection was generally accomplished through private journals maintained by the students. The eight questions asked at the beginning of the summer along with the reflection question and summary statistics for the sample results are presented in Table III for the pre- and post- student surveys and for the post-faculty survey.

III. DISCUSSION

A. Project and Course Integration

The Hydrogeology project provided an excellent opportunity to expose students to compilation of fundamental geologic and hydrologic data, and to the importance of this type of scientific information to their communities with respect

to the quality and quantity of water supplies on the Reservation. These topics provided a connection with the relevance to their daily lives and to the well-being of their communities. The students could clearly see the benefits and importance of the concepts that they were learning in the Geology for Engineers course which improved their level of comprehension of the fundamental geologic and hydrologic principles. Activities in continuing projects will include more intensive field experiences in mapping geologic contacts and geologic structures such as faults and folds, and measurement of stream flow gains and losses due to interaction with different geologic formations and features.

Investigating the repair strategies for the Memorial Wall introduced students to the topics of strength, durability and the constitutive materials in concrete (i.e. water, cement, aggregates) in addition to properties of the soils supporting the foundation. These material-related subjects were covered in the most recent course delivered through the OSSPEEC program during the 2012 Spring semester. Properties of aggregates were covered to understand the effects of particle-size distribution on the strength of concrete and settlement of foundations on poorly graded/organic materials. Laboratory exercises included determining soil sample size distributions, and designing concrete mixtures. A test batch of concrete was made and cylinders and beams were cast for strength testing.

The initial exposure of the concrete and soil in the Memorial Wall project, followed by the Materials and Laboratory course has provided students with an application-based experience for soils and concrete. Knowledge gained through the laboratory and classroom instruction will enable the students to design the concrete mixture for the foundation and wall repair, cast and test representative specimens and will increase their sense of ownership for the project.

B. Assessment Results

Data from the student and faculty surveys provided some initial insights into the developing OSSPEEC service learning component. Overall, the data from the OSSPEEC faculty indicated strong preferences (magnitude of the mean) and consistent responses (small standard deviations). A strong and consistent preference to learning by completing hands-on projects as opposed to traditional classroom learning (statements 1 and 2) was obvious. The faculty were also strongly and consistently positive about the outcomes of the service learning projects (statements 3, 4, 5, 6, 7).

The students are not as homogeneous in their responses. Some of them were just starting in engineering, may not have been sure of engineering as a program of study choice, and may have been unfamiliar with service learning concepts. The students did indicate a preference for hands-on learning versus traditional lecture style classrooms which became stronger and more consistent after participating in the summer projects (statements 1 and 2). However, the students did become more positive about classroom learning through the summer, also. The students' expectation that they would be able to apply their previous course work to the summer project experience was confirmed (statement 3), and their participation in community service learning projects became more regular (statement 4).

TABLE III. SERVICE LEARNING SURVEY SUMMARY

| Question No. | Question | Pre-Student Survey | | Post-Student Survey | | Post-Faculty Survey | |
|--------------|--|--------------------|---------|---------------------|---------|---------------------|---------|
| | | Mean | Std Dev | Mean | Std Dev | Mean | Std Dev |
| 1 | I like to learn by doing hands-on projects. | 1.08 | 0.29 | 1 | 0 | 1 | 0 |
| 2 | I prefer to learn in the classroom rather than through field projects. | 3.50 | 1 | 2.86 | 0.69 | 4.25 | 0.96 |
| 3 | I expect my summer projects to apply to what I have learned in the classroom. | 1.67 | 1.07 | 1.57 | 0.79 | 1 | 0.82 |
| 4 | I regularly participate in community service projects. | 3 | 1.60 | 2.57 | 0.53 | 1.25 | 0.50 |
| 5 | I hope to better understand the customs of others through my summer experiences. | 1.50 | 0.80 | 1.57 | 1.13 | 1 | 0 |
| 6 | My summer projects have the potential to make a lasting difference. | 1.17 | 0.39 | 2 | 1 | 1 | 0 |
| 7 | My summer projects may help local communities in important ways. | 1.25 | 0.45 | 1.71 | 0.95 | 1 | 0 |
| 8 | I expect my summer projects to challenge some long held beliefs. | 2.92 | 1.16 | 2.86 | 1.07 | 2.50 | 1.29 |
| 9 | I made a genuine effort to reflect about my work this summer. | | | 1.29 | 0.49 | 1.25 | 0.50 |

1=AGREE, 2=SOMEWHAT AGREE, 3=NEUTRAL, 4=SOMEWHAT DISAGREE, 5=DISAGREE

The students' hope to better understand other customs was not confirmed through the summer program and the standard deviation of their response also increased (statement 5). The hope that their summer projects would make a lasting difference, and that they would be able to help communities in significant ways (statements 6 and 7) were also not confirmed. The expectation that the summer experience would challenge long-held beliefs was confirmed (statement 8).

Although the students' responses for statements 5, 6, and 7 did not show improvement through the summer program and indicated increasing disagreement, they were still in the "somewhat agree" range rather than moving to a neutral or negative position. The faculty responses were in complete agreement for these statements. The student responses may have been indicative of the fact that they were gathering field samples and data and completing laboratory analyses throughout the summer, but had not yet had the opportunity to move on to a design or implementation phase of the project. The faculty responses may have indicated that they could see the long range possibility or probability of design and implementation more clearly.

C. Successes and Challenges

The courses offered through the OSSPEEC Program have resulted in a number of successes and challenges. The Geology for Engineers course was offered through hybrid delivery which was very beneficial to reducing student travel time and therefore improved student participation. Like other geology classes, field trips were enjoyed and appreciated by the students and were an important component of the class. The field trips sparked the most interest from the students and future course

deliveries will attempt to integrate more field work with classroom exercises. The course was co-taught by faculty from SDSMT and OLC and scheduling adjustments were necessary. Future efforts for this course include improving the correlation with the content of Introduction to Geological Engineering offered at SDSMT to increase student preparation for transferring to this program.

The Materials and Laboratory course was offered at OLC, which increased travel for instructors and students, however the face-to-face lecture and laboratory exercises were beneficial. A valuable component incorporated into the class were two certification programs, where students took written and performance examinations related to aggregate and concrete field testing. These exams resulted in 80% and 20% pass rates respectively and will qualify students for field-testing summer internships. Future offerings of this course will incorporate hybrid-delivery for the lecture to improve course efficiency. Additionally, a recitation session will be considered to help students with writing lab reports.

The organization of activities for the courses described above was an important component to a positive learning experience for the students. Challenges included the logistics of lectures, laboratories, and field activities between students and instructors from two institutions located 80 miles from each other and a third institution approximately 300 miles away.

The service-learning projects were also successful in many ways. The association of these projects with the community was an important component. For the hydrogeological project, a realization of the potential benefit to the water quality

heightened student appreciation and motivation for pursuing these subjects. The excitement from the Wanblee community for repairing the Memorial Wall emphasized the significance of student efforts. Observations from the summer projects suggest that a high level of mentor involvement and coordination at each institution are an important component to a successful experience for the students. The first year of the program also suggests that student collaboration, a variation in project related activities, and increased community involvement help maintain student motivation and interest.

Improvements in organization of all summer activities would lead to greater productivity and student satisfaction. Finally, a mid-summer evaluation of all projects and team activities will be implemented so that appropriate changes can be made for achievement of summer objectives.

IV. SUMMARY

The OSSPEEC program is a collaborative effort between OLC, SDSU, and SDSMT to develop pre-engineering courses at OLC. Through the first summer, 18 students and eight faculty mentors have been supported to initiate eight service-learning projects. Completing the second year of the program, eight courses have been developed and offered through hybrid-delivery from the three institutions. Two of the service-learning projects related to civil and geological engineering have complemented the Materials and Laboratory and Geology for Engineers courses which will benefit the continuation of these projects during the summer of 2012. The hybrid course delivery has shown to be an effective instruction method and is well suited for the long distances between institutions. The service-learning projects have resulted in high levels of student engagement and appreciation for societal benefits as well as the potential for pursuing careers and research in science and engineering.

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Work in Progress-HOMER: An Educational Tool to Learn About the Design of Renewable Energy Systems at the Undergraduate Level

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Abstract—This paper is about how the uses of computer software's are such valuable tools for undergraduate engineering education, specifically in the design and analysis of renewable energy systems. Right now, there are many programs in the area of design of renewable energy systems, some more complexes, others user-friendlier and others too simple. For this work, the software HOMER (Hybrid Optimization Model for Electric Renewable) has all the tools necessarily to make a good work and it is not too complicated for undergraduate engineering students without previous knowledge in the area of energy systems. As part of this work, three educational modules were developed. The first module is about how to use and interact with HOMER. Second, how to design a residential photovoltaic system to lower energy cost. The last module can be considered as a guide on how to use renewable energy to secure a sustainable grid. The paper presents the technical skills gained by the students using the software HOMER. Finally, undergraduate students had the exposure to non-technical engineering skills, like economic feasibility, logistic and decision on energy security.

I. INTRODUCTION

With fuel constantly raising its prices and the energy demand growing every day, there is no doubt that renewable energy systems are quickly becoming the most popular alternative source of clean energy. Many countries, especially islands, are dealing with energy problems, because of the dependency of liquid fuels, derivate of the petroleum [1]. Professionals, especial students that will be the next generation of professionals start to think and act to solve this problem.

Undergraduate engineering students with professionals and non-professionals alike should be aware that there are several available resourceful software that simulate hybrid energy systems to provide a cost efficient solution for the high priced fuel demands. By interacting and learning to use these software students are exposed to new non-technical engineering skills like economic feasibility, logistics and decision on energy security. With no previous knowledge of these systems, students will be able to simulate and get a feasible projection on the benefits renewable energy systems have to offer [3].

The software used for this presentation is called HOMER. Homer energy is a program that simulates and analyses a hybrid power system that can include generators, cogeneration, solar photovoltaic, batteries,

turbines, wind, hydropower, fuel cells, biomass among other inputs [4]. HOMER beta version can be downloaded at <http://homerenergy.com/>. With a simple registration to the website one may be able to download and use the beta version for a free trial. Once downloaded, users can start designing and simulating hybrid energy systems [5]. Homer also makes an analysis of the energy supply by the system in every hour of the year (8,760hours) and compares it with the electric demand. The program studies the costs of all the equipment necessary in a project, bringing the opportunity to know if the project is going to be cost-effective.

The inclusion of renewable energy systems could provide an additional added value to the HOMER analysis by providing a more realistic simulation. Also, to obtain a realistic simulation or to be sure that the simulation done is adequate for a specific geographic region, it is important to follow the codes and standards of interconnection for a specific geographic region. For example "Freeing the Grid 2011" reports the practices in solar systems in the U.S. which gives some recommendations to the states that need to improve their net-metering and interconnection practices. Net metering policies are a simple billing agreement that ensures solar customers receive fair credit for the electricity their systems generate during daytime hours [2]. Interconnection practices are rules and processes that customers must follow to connect their distributed generated systems to electric grid.

The next sections of this paper will show to the potential users how to interact and learn about energy systems through simple simulations using HOMER software. Since HOMER is an excellent tool for the designing and learning of renewable energy systems because of its user friendly methodology, any undergraduate engineer student could use it without any or little previous knowledge in the area of energy system. Also, it will be discussed how HOMER can bring technical skills related to energy systems to undergraduate students or professionals interested to learn and expand their knowledge in the area of energy systems. Finally, an example of how HOMER could be integrated as part of an existing energy systems curricular sequence. For this example, the authors will use the energy systems curricular sequence that it is used at the University of Puerto Rico-Mayaguez [6].

II. INTERACTING WITH HOMER SOFTWARE FOR RENEWABLE ENERGY SYSTEMS

A. Equipment to consider

Once the program is open the user may start by pressing on the add/remove button on the upper left corner of the page. This button enables the equipment to be considered for the simulation. For this paper in particular we will explain some of the most basic and common equipments used in renewable energy systems.

Photovoltaic panels, wind turbines, converters, batteries, generators are among many of the systems to be considered. The type of load used is one of the most important inputs since it determines the energy demand of the system that wants to be considered. A deferrable load will be used when the charge is constant, otherwise a primary load will do when the charge varies from time to time. Renewable energy systems have the option to be connected or secluded from the grid. For grid tied systems we have the option of net metering to sell back the excess generated energy to the electric authorities.

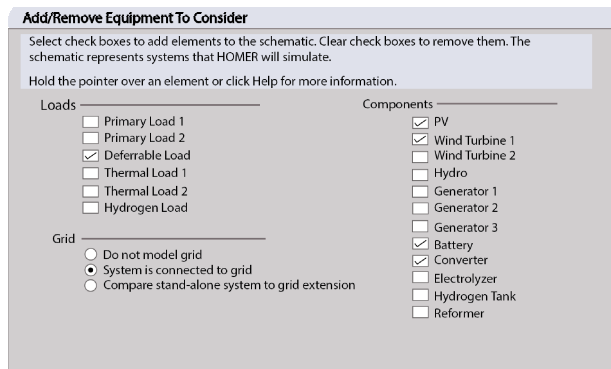


Fig.1: Equipment to consider

The following schematic represent basic PV-Wind Tied Connected System. All the components that this system has will be explained.

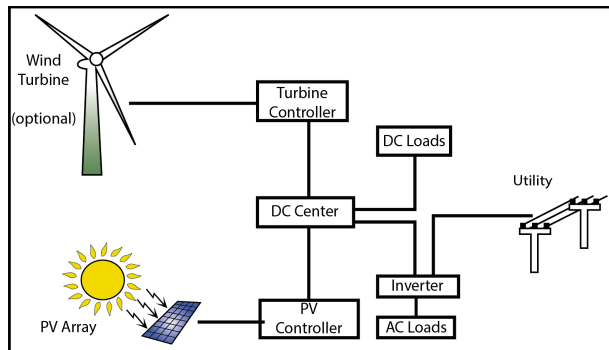


Fig.2: System PV-Wind Tied Connected System

B. UTILITY

The grid (utility) is another name for the electric authorities that supply the energy demand to houses, buildings, industries, etc. When using HOMER, the user must gather the information necessary to determine the cost of energy of the country or area where he or she resides since it varies. This may be done by checking the electric bill of the establishment where the renewable energy system wants to be installed.

Required inputs for grid (utility):

- Cost of energy. (In Puerto Rico, currently 0.29 \$/kWh [7])
- Sellback price for excess generated electrical charge, also known as Net Metering (0.075\$/kWh based on Energy policy Act of 2005 [8])
- Net metering option. (Calculated monthly or annually).

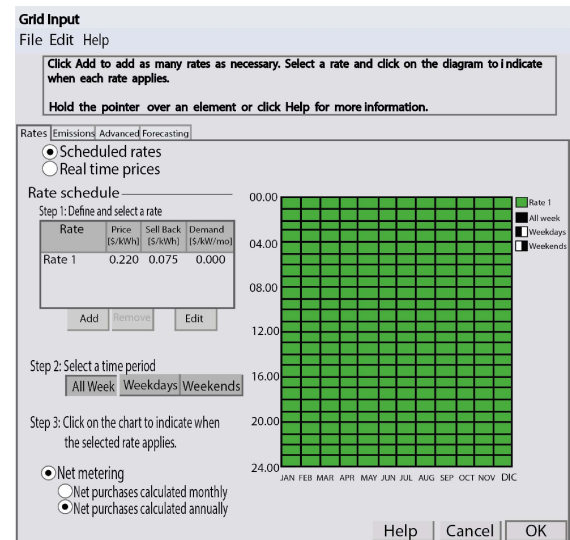


Fig.3: Utility inputs

C. Solar Resource

The solar resource is where we enter the coordinates of the area where the photovoltaic panels are going to be installed (latitude and longitude). The time zone of the country where the system will operate is also an important factor.

The software itself has its own database that gives the annual average radiation [9]. After all inputs are correctly entered it can be determined if it's worth installing photovoltaic panels as a renewable solution for the load based on the average hourly radiation. To have a substantial use for the photovoltaic panel it is necessarily from 5 to 6 hours of annual average radiation.

D. Wind Resource

The wind resource is little bit more complicated than the solar resource since the software doesn't have a database for wind speeds because of their variation and inconsistency [10]. To determine the wind speed we require an anemometer to measure the average annual wind speeds for the area of study and determine whether it is convenient or not to install wind turbines. Other inputs such as the height of the anemometer and the areas height above sea level are required for the study.

E. PV (photovoltaic panels)

PV's come with a set of properties to fill in. The output current must be in DC (direct current). The lifetime of the panels is usually from 20 to 25 years. The degrading factor varies from 80% to 85%. The slope is the angle at which the panels are mounted with respect to the ground. The azimuth is the angle at which the panels are deviated from south to west.

For the photovoltaic panels the required inputs are:

- The size of the panel array
- Cost of the panels
- Operation and maintenance cost
- Replacement cost

PV's can be classified in three types: mono-crystalline cells, poly-crystalline cells and amorphous cells. Each one have it's own efficiency: mono-crystalline around 25%, poly-crystalline less than 20% and amorphous cell only 10%. But as higher the efficiency, higher is the cost. The program do not let the user to choose between this types, so the user have to take the decision on what type of PV the system will have.

PV Inputs
File Edit Help

Enter at least one size and capital cost value in the Costs table. Include all costs associated with the PV (photovoltaic) system, including modules, mounting hardware, and installation. As it searches for the optimal system, HOMER considers each PV array capacity in the Sizes to Consider table.
Note that by default HOMER sets the slope value equal to the latitude from the Solar Resource Inputs window. Hold the pointer over an element or click Help for more information.

Costs

| Size (kW) | Capital (\$) | Replacement (\$) | O&M (\$/yr) |
|-----------|--------------|------------------|-------------|
| 6.000 | 20000 | 20000 | 20 |

Sizes to consider

| Size (kW) |
|-----------|
| 0.000 |
| 2.000 |
| 4.000 |
| 6.000 |

Cost Curve

Properties

Output Current: ☐ AC ☒ DC

Lifetime [years]: 25

Derating factor [%]: 85

Slope [degrees]: 18.325

Azimuth [degrees W of S]: 0

Ground reflectance [%]: 20

Advanced

Tracking system: No Tracking

☐ Consider effect of temperature

Temperature coeff of the power [1/C]: 0.5

Nominal operating cell temp [C]: 47

Efficiency at std test conditions [%]: 13

Help Cancel OK

Fig.4: Photovoltaic inputs

F. Wind Turbines

HOMER has a list of commercially available wind turbines to use for simulation. Important information about wind turbines that must be included is the height of the wind turbine tower and the lifetime (usually from 20 to 25 years).

The required inputs for wind turbines are:

- Quantity of turbines
- Initial cost
- Replacement Cost
- Operation and maintenance cost

Wind Turbine Inputs
File Edit Help

Choose a wind turbine type and enter at least one quantity and capital cost value in the Costs table. Include the cost of the tower, controller, wiring, installation, and labor. As it searches for the optional system, HOMER considers each quantity in the Sizes to Consider table.
Hold the points over an element or click Help for more information.

Turbine type: SW Whiper 500 Details New Delete

Turbine Properties

Abbreviation: W500 [used for column headings]

Rated power: 3 kW DC

Manufacturer: Southwest Windpower

Website: www.windenergy.com

Costs

| Quantity | Capital (\$) | Replacement (\$) | O&M (\$/yr) |
|----------|--------------|------------------|-------------|
| 1 | 6000 | 6000 | 100 |

Sizes to consider

| Quantity | Cost (\$) |
|----------|-----------|
| 0 | |
| 1 | |
| 2 | |

Power Curve

Cost Curve

Help Cancel OK

Fig.5: Wind Resource inputs

G. Converters

Converters are a necessary tool to have when working with photovoltaic panels and wind turbines [11]. Since these systems produce an output DC current, converters can work as both inverters (transform current from DC to AC) or rectifiers (transform current from AC to DC) to meet the necessary electrical energy demands of the power supplied. House hold items usually work with AC power supply.

Required inputs for converters:

- Size of converter
- Capital
- Operation and maintenance
- Lifetime
- Efficiency
- Replacement cost

Converter Inputs
File Edit Help

☒ A converter is required for systems in which DC components sense an AC load or vice-versa. A converter can be an inverter (DC to AC), rectifier (AC to DC), or both.
Enter at least one size and capital cost value in the Cost table. Include all costs associated with the converter, such as hardware and labor. As it reaches for the optimal system, HOMER considers each converter's capacity in the Sizes to Consider table. Note that all references to converter size or capacity refer to inverter capacity.
Hold the pointer over an element or click Help for more information.

| Costs | | | | Sizes to consider | |
|-----------|--------------|------------------|-------------|-------------------|-----------|
| Size (kW) | Capital (\$) | Replacement (\$) | O&M (\$/yr) | Size (kW) | Size (kW) |
| 5.000 | 1000 | 1000 | 10 | 0.000 | 5.000 |
| { } | { } | { } | { } | { } | { } |

Inverter inputs

Lifetime [years] { }

Efficiency [%] { }

☐ Inverter can operate simultaneously with an AC generator

Rectifier inputs

Capacity relative to inverter [%] { }

Efficiency [%] { }

Help Cancel OK

Fig.6: Converter inputs

There are many types of converters commercially available [11]. Some of the most popular ones are:

Static-Phase Converters: These are the first phase converters that have been around for the longest time. Their uses are limited since they do a good job when working with small motors. Static-phase converters do not convert one-phase power to three-phase power, nor do they generate three-phase power. These converters will not power any type of machinery with three-phase circuitry.

Rotary-Phase Converters: A rotary-phase converter is designed to power larger equipment and higher HP motors, and a single unit can provide a continuous reliable source of three-phase power to more than one machine. These converters are a popular choice when a continuous source of three-phase power is needed. A rotary-phase converter uses its own motor to generate the third, high leg of power as well as passing on the other two legs of power provided by your single-phase power source.

H. Economics

HOMER applies the economic inputs of each system it simulates to calculate the net present cost of the project [12]. Required inputs:

- Annual real interest rate percentage
- Project lifetime in years

Other inputs are left blank by default since they don't affect the outcome of the simulation.

I. Calculation and Analysis of Results

After all inputs and resources are entered we press the calculate button to obtain the feasibility study and economic analysis. The program will analyze and

compare all the variables of the systems entered. Depending on the NPC (net present cost), we can determine the capital of each option given and decide if the system is right for the energy demand. By pressing on the sensitivity results the program will present a list of the best configurations for each of the different energy prices entered on the grid.

By double clicking on any of the results a new window will open with the details of the configuration. To compare one configuration with another and determine the time, the configuration will pay for itself the user must click on compare. To obtain a summary of the configuration selected the user must click on HTML report.

III. SIMULATION: RESIDENTIAL PV SYSTEM FOR PUERTO RICO

The cost of electricity in Puerto Rico has reached its highest peak in the last few years since the prices of fossil fuel keep increasing. By this means we have resorted to other methods like renewable energy systems to reduce energy cost. A photovoltaic system interconnected with the grid (utility) is consider for this simulation since Puerto Rico is an island that receives an average of 5 to 6 hours of sun radiation.

The primary load AC required by a residential is 15,000 Watt(hr)/days. The residential is located in Mayaguez, Puerto Rico and it specific location is: 18° 12' north and 67° 8' west; this is necessary to obtain the average sunlight per hour that the system required. To obtain the size of the panels it has been divide the primary load over the average sunlight radiation of the area. To determine the cost of the panels it is necessary to multiply the size of the array by 5 dollar per watt. The cost of the inverter can be determined by multiplying the size of the array by 1 dollar per watt. HOMER does not let the user enter additional expenses like wires, fuses and installation [12]. To take into consideration this additional cost they must be added to the cost of the panel array by adding the cost of the panels and converter and multiplying that value by .2(20%). It is very important to consider this additional cost, to obtain a good projection of the project's total capital.

IV. RESULTS

After all the information was entered the calculated button is pressed to obtain the results and see what the most economically feasible system for the simulation is. The results came up with two options: the stand alone grid system and the photovoltaic panels with converters interconnected to the grid. The NPC (net present cost) for the standalone grid was about \$21,000 and for the renewable energy system about \$25,000. The panels weren't the most cost efficient solution by a matter of a few thousand dollars.

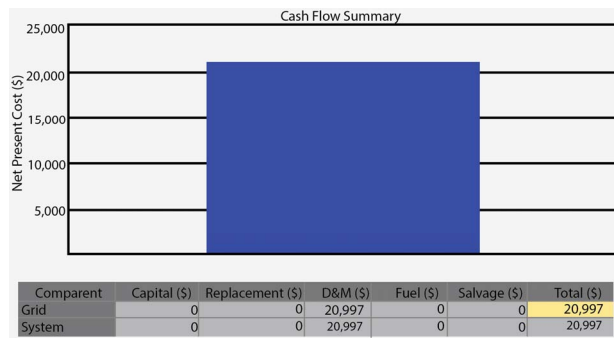


Fig.7 Cash flow for stand alone grid

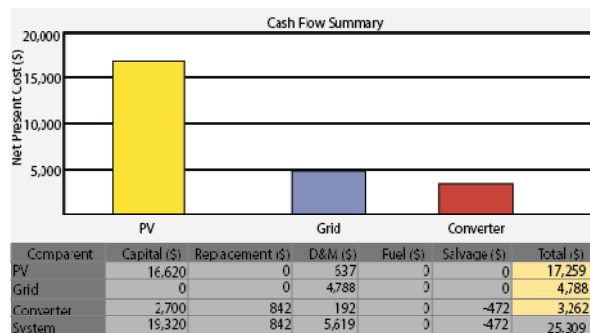


Fig.8: Cash flow for PV and converters interconnected with grid

After this simulation, another simulation was made using the same system but cutting in half the prices for the equipment of panels and converters since. This was done because the government provides incentives for the uses of green energy, to lower prices for communities and other establishments. The new simulation resulted with the renewable energy system being better energy solution for the residential with a NPC of \$15,464 and as a matter of fact being \$6,000 less than the grid stand-alone. The grid remained with the same price since the costs of energy of the electric authorities remain constant.

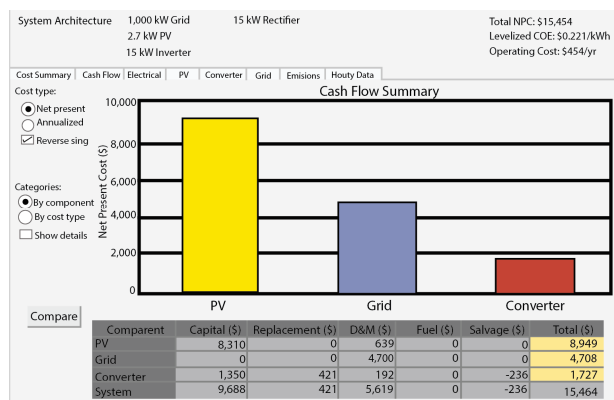


Fig.9: Cash flow for PV and converters after government incentive

V. HOMER FOR UNDERGRADUATE EDUCATION

This generation has a lot of responsibility on finding new alternatives resources of energy production. Everything that we use and do requires energy. Unfortunately the ways that countries generate the electricity are affecting the world. The reason is that the majority of the systems use fossil fuels and this resource emits gases that produce pollution to the ambient. Another disadvantage of the fossil fuel is that can be found only in certain countries. This is a problem because they control the prices and right now fossil fuel specially the petroleum is in a very high cost. Hence it is necessary to find the way to produce our own energy.

One way to produce our own electrical system is using renewable energy. Some types of Renewable energy are: solar, wind, ocean, biomass, hydropower, fuel cells, etc. These resources can be found naturally, so almost every country is capable to use it. Sometimes it is a little complicated to understand renewable energy systems, especially if the user does not have a background in energy systems. For our convenience a lot of programs are developed to help people understand this complex systems and even any student at undergraduate level is capable to use it.

Homer is a great program that simulates and analyzes renewable energy systems. This research was developed without a full knowledge in the area of energy systems, but as soon as the program HOMER was put into good use the research purpose became easier. The program helps the user answer some basic questions like: Which technology is more efficient in terms of cost? What renewable resource is more suitable for the system?, and What requirements each system needs?. For example the lifetime of the components, the slope of the PV's with respect to the ground, the height of the wind turbines with respect to the ocean level and other basic questions. These details are necessary in the simulation and a lot of users do not know about it.

One important aspect of HOMER is that it allows simulating all the combination of equipments and variables. The benefits of this software is that gives the opportunity to see how the outputs vary at every hour, it lets users enter multiple values in some inputs, and also enter more than one components size (the program choose the best one).

VI. SKILLS DEVELOPED BY THE STUDENTS

After interacting and learning to use HOMER software, undergraduate students and all users alike will be expected to gain resourceful non technical skills that will help them in their career and future studies. Some of the skills expected to learn during research are:

- Ability to apply economic analysis and provide feasible solutions to lower cost of energy for different establishments.
- Ability to design hybrid energy systems, components, and processes to meet the necessary energy demands.
- Ability to identify, formulate, and solve engineering problems using techniques learned in previous courses.
- Ability to learn about local codes and standards related to interconnection and net-metering.
- Apply logistics and make good decisions on energy security.
- Knowledge of how energy systems work and operate. Their purpose and what economic benefits they come with.

VII. UPRM'S CURRICULAR SEQUENCE ON ENERGY SYSTEMS AND HOMER

At UPRM (University of Puerto Rico Mayaguez) it has been developed a list of courses in the area of power systems that can include the program HOMER. Table 1 shows the UPRM's curricular sequence on energy systems where HOMER can be a useful tool as part of the class. An introduction of circuit analysis is necessarily to understand the electrical behavior of the devices that will be used for the simulated project. Additionally in a class of power system it could be done a simulation and analyze how much power is required by the system. Also in a class of power electronics can make a simulation and analyze the amount of energy that is going to be delivered to some devices. HOMER can be used in for undergraduate research and design projects that involve energy systems. The UPRM students have the opportunity to takes these courses and apply all the knowledge acquired by using HOMER.

VIII. CONCLUSION

Homer is a useful program that can really help undergraduate student in the area of designing of renewable energy systems. This is because it is a very easy program that anyone with basics knowledge in the area of energy system can use. The program demonstrate that with just a little tutorial on how to use the program any person, specially undergraduate students, are capable to design renewable energy systems without a bachelor's degree or a master degree. Instead it prepares students with useful tools to successfully start a master degree.

It is very important to encourage student to learn to use this kind of programs that works with renewable energy. Because by taking advantage of tools like this everyone can learn and adapt new solutions to fix the problems the world faces nowadays and have a better tomorrow. How we use energy today will determine the way we live in the future.

| Course | Course Name | Description |
|-----------|--|--|
| INEL 3105 | ELECTRICAL SYSTEM ANALYSIS I | Analysis of direct current and alternating current linear electric circuits; laws and concepts that characterize their behavior. |
| INEL 4103 | ELECTRICAL SYSTEMS ANALYSIS III | Analysis of Magnetic Circuits and Polyphase Balanced Systems; Transformers; Power Transmission Lines; Computer-aided Analysis of Their Systems. |
| INEL 4415 | POWER SYSTEM ANALYSIS | Formulation of Bus Admittance and Bus Impedance Matrices; Symmetrical Components; Symmetrical and Unsymmetrical Faults; Load Flow; Economic Operation of Power System. |
| INEL 4416 | POWER ELECTRONICS | Design of Circuits for Rectification, Inversion, Frequency Conversion, direct Current (d.c.) and Alternating Current (a.c.) Machines Control, and Other Non-motor Applications using Solid State Devices |
| INEL 4998 | UNDERGRAD - UATE RESEARCH | Participation, Under The Supervision of A Faculty Member Acting as An Investigator, In A Research Project. |
| INEL 5195 | DESIGN PROJECT IN ELECTRICAL ENGINEERING | Capstone design course in which students apply the fundamental knowledge in electrical engineering to solve engineering problems considering engineering standards and realistic design constraints. |

Table 1: Example of UPRM's Energy Systems Curricular Sequence

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Special Session: IEEE Real World Engineering Projects: Discovery-Based Curriculum Modules for First-Year Students

Stephen Williams, Anita Vasavada, Jacques Nicolas Beneat, Gregory Cappuccino, David Lin, Warren Rosen, Eric Carr, Kirk Reinkens, Mingrui Zhang, Francesco Amoroso

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Abstract – This special session is organized to provide an interactive forum for the introduction of a set of new curriculum modules developed under IEEE’s Real World Engineering Projects (RWEPP) program. The modules, which are representative of a larger collection of curriculum modules available to the public via an open-access RWEPP web portal, are designed for use in the first-year engineering and computer science classroom, and are hands-on, team-based projects that emphasize the societal impact of the work that engineers do.

After a brief introduction to the RWEPP program and the showcased curriculum modules, the authors of the modules will work one-on-one with the audience providing tutorials on the laboratory activities associated with their modules in a highly interactive, simultaneous mode. Audience members can learn in-depth about the modules that interest them most. Each project will have its own demonstration table, with posters of information and hands-on demonstrations and / or videos. This will allow for audience members to interact directly with the authors, and to try out the same sorts of activities that are proposed for the students.

Keywords – laboratory instruction, first-year students, curriculum development, engineering education.

SPECIAL SESSION AGENDA

The special session will begin with a 10 minute overview of the Real World Engineering Projects program, followed by a brief (10-minute) introduction to the projects and a short question and answer session. The bulk of the session (60 minutes) will be used for one-on-one, interactive, live project tutorials by the authors of the curriculum modules, set up “poster-session style”, i.e., with simultaneous, informal presentations by the authors. Each project will have its own demonstration table, with posters of information and hands-on demonstrations and/or videos. This will allow for audience members to interact directly

with the authors, and to try out the same sorts of activities that are proposed for the students. This will give audience members a strong sense of how the activities might work at their own institutions, and an opportunity to talk directly with the authors about their own experiences with the project in the classroom.

SESSION GOALS AND EXPECTED OUTCOMES

The IEEE RWEPP program’s ongoing goal is to develop an on-line, open-access library of high quality, hands-on, team-based curriculum modules for use in first-year college courses in electrical engineering (EE), computer engineering (CE), biomedical engineering (BE), electrical engineering technology (EET), and computer science (CS). These curriculum modules are designed to be used by faculty members around the world who teach first-year students in introductory laboratory courses. The modules are designed as stand-alone units each covering about two weeks of instruction, so that faculty can pick and choose the modules they like to build a course that meets their needs. The curriculum modules are specifically designed to be discovery-based, and to illustrate real-world contemporary problems whose engineering solutions benefit society.

The RWEPP approach to first-year instruction is expected to help with retention of students, by clearly demonstrating the relevance of fundamental engineering and science concepts to real-world, contemporary problems, and by showcasing the impact that engineering has on society. Students are guided in discovering the importance of a contemporary problem in a way that will excite their interest in creative solutions. The modules make use of activities that allow students to discover key concepts about engineering science and design in a hands-on way; they demonstrate how and why technical methods work, rather than simply providing a recipe for a solution. The societal impact focus of the modules is expected to help in the retention of all students, and particularly women, by providing the students with opportunities to understand how their own future work might help others.

The goal of this special session is to showcase new curriculum materials that have been developed for first-year

students under IEEE's Real World Engineering Projects (RWEPP) program. The curriculum modules being presented are representative of a larger set of modules available on-line via the RWEPP portal, www.realworldengineering.org. The expected outcomes of the session are that attendees:

- Will be encouraged to use the curriculum modules in their own classrooms.
- Will engage in discussion about the importance of relaying to their students the benefit to society of what engineers do.
- Will exchange information on learning methods that successfully engage first-year students and support recruitment and retention of those students.
- Will be made aware of future opportunities to contribute to IEEE Educational Activities Programs curriculum development efforts, particularly through grants from future rounds of the RWEPP program. This awareness will help the RWEPP "gain momentum" in building and strengthening its library.

HIGHLIGHTED RWEPP PROJECTS

Vehicle Passenger Safety: Exploring Whiplash Protection Systems

Anita Vasavada, Kirk Reinkens

Students will design and evaluate an active head restraint system.

- Learning about whiplash injury, and characterizing a physical model of the human head-neck system.
- Evaluating the physical model in the context of neck injury testing, and designing a head restraint which can limit head movements during a collision.
- Characterizing a motor and specifying commands which can move the head restraint appropriately when an impact occurs.
- Evaluating a sensor which will activate the motor before an impact occurs.
- Testing the ability of the entire active head restraint system to limit head motion during a simulated rear-end collision.

Design of a Guitar Tab Player in MATLAB

Jacques Beneat

In this project work with several MATLAB programs to look at the effects of frequency and modeling of signals. The project has two models. In the first module, the students use several MATLAB scripts to discover the effects of sampling, the frequency spectrum of signals, and the modeling of a harmonic signal such as that of a guitar string. In the second module, the students make use of the modeling efforts of the first module to implement a realistic guitar tab player.

Coping with the Emerging Energy Demand for Charging Plug-in Electric Vehicles

Gregory Cappuccino

In this hands-on project, student teams will be engaged to cope with the real-world problem arising from the increasing demand for charging Plug-in Electric Vehicles from the electrical energy distribution grid. By means of MATLAB simulations, each team will analyze the effect of multiple quasi-contemporary charging requests on the electrical grid, hence discovering how, as the number of users to be charged increases, either the grid collapses or the user requests may not be entirely fulfilled. The class will discover how smart energy dispatching strategies and smart battery charging methods may mitigate or completely overcome the discussed problems. The class will also be asked to reflect on how the traditional "dumb" grid infrastructure should be modified to allow each proposed solution to be really implemented, finding out the necessity of developing a smart grid capable of interacting with vehicles.

Remote Surgical Robotics: Control Systems and Human-Machine Interfacing

David Lin, Kirk Reinkens

This project focuses on optimizing a prototype remote surgical robot which has force-feedback capabilities. The objective is to detect the surface of a gelatin brain by tactile perception through the robot. Students explore the tradeoff between sensitivity and range while considering human factors as design constraints.

Microcontroller-based Smart House for Improved Energy Efficiency

Warren Rosen, Eric Carr

In this project the students will program a simple microcontroller to measure temperature and control functions such as heaters or coolers in a prebuilt smart house. The house is made of a foam shell electric heater, thermoelectric air conditioner and an attic fan with vent.

Image Processing Algorithms for Identifying Gulf Oil Spill

Mingrui Zhang

This project is to teach computer science students algorithm design as a problem-driven process. Students are asked to develop image processing algorithms to locate oil spills on satellite images and implement them in a Java-based software application. Working on their projects, students will learn to analyze the problem, inspect sample images and identify patterns, design algorithm(s) and validate algorithm(s). Ocean color satellite images are pre-processed and provided with this project.

Special Session:

Connecting with Community:

Empathy, Experience, and Engineering with Elders

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Abstract—A hands-on special session at the Frontiers in Education conference introduces an experiential exercise in empathy. Participants will use prostheses to simulate some of the physical disabilities that often accompany aging, then attempt everyday activities to better understand how engineered artifacts – and engineering design choices – can facilitate or hinder these tasks. The “empathy exercise” introduced here is suitable for inclusion in a wide range of engineering classrooms. It draws student attention to the importance of end user understanding and increases student understanding of the connection between engineering decisions and societal impact at a visceral level.

Keywords- *interdisciplinary; broad competencies; empathetic engineering*

I. SESSION GOALS

Engineering is ultimately about solving problems *for people*. Participants in this special session will both experience and potentially take home a specific active learning technique that helps students to bridge between the technical work of engineering and the human needs of its ultimate beneficiaries.

Participants should leave this session equipped to integrate a people-centric experiential class session into their (engineering design) classes and/or with new ideas and techniques for connecting their course content to the end users who are the ultimate beneficiaries of their students' work.

II. SESSION DESCRIPTION

This hands-on session will focus on a set of "empathy exercises" intended to bridge the too-common gap between engineering problem-solving skills and the needs of those whose problems are ostensibly being solved. How do design decisions that engineers make affect the lives of those who use their designs?

In this session, participants will

- experience some of the physical limitations associated with aging;
- explore the ways in which engineered artifacts can facilitate or complicate tasks; and
- gain a visceral understanding of the connections between engineering design and human needs.

The session will also provide opportunity for participants to discuss ways to incorporate this session or similar activities into their own classrooms.

During the session, participants will use a variety of props to simulate disabilities commonly associated with aging: reduced vision, mobility, dexterity, and auditory and tactile sensation. Equipped with age-simulation props, participants will attempt a range of activities of daily living and assess the impact of disability on the activities. They will explore how



Figure 1. A student and volunteer transfer pills into containers while simulating the restricted dexterity typical of arthritis.

This project received support from the Metrowest Health Foundation and from the Franklin W. Olin College of Engineering Innovation Fund.

existing tools either aid or complicate tasks, depending on the sensitivity of their design. (How do various vegetable peelers work when wearing gloves that simulate arthritis? How do cataracts impact the ability to read information on a pill bottle?)

Session participants will be asked to evaluate and reflect upon their experiences, much as our students and community volunteers do. Associated discussion will introduce the course and context in which the authors use this exercise, highlight our partnership with elder members of our community, draw explicit connections to engineering education, and aid participants in planning ways in which this exercise could be incorporated into their classrooms.

III. SESSION AGENDA

The session will open with a ten minute overview including a preview of core activities, background in which the facilitators use the material, and suggestions as to what to look for/think about during the experiential activity.

The experiential portion of the activity will occupy the central fifty minutes of the session. Room layout will be highly structured with multiple stations, each involving an impairment and a set of tasks, for participants to rotate among. At each station, sample tasks will allow directed but open-ended exploration.

Following this core activity, participants will spend up to thirty minutes in facilitated groups (with structured worksheets to stimulate discussion):

- (a) reflecting on experiences and learning
- (b) connecting this experience to home institution classes
- (c) planning take-home tasks and adaptations of this material

IV. ANTICIPATED AUDIENCE

This session is directed at faculty members who teach engineering classes that are in principle connected to end user needs, such as design, capstone or cornerstone curriculum, as well as first-year engineering survey classes. All disciplines are welcome and some examples will be chosen from the worlds of software, electronics, mechanics, and building/infrastructure design.

V. EXPECTED OUTCOMES/FUTURE WORK

This special session will have two primary outcomes:

- (1) Creation/adoption of user-centered empathy experiences in participant campuses. These activities will help students to connect engineering curriculum to the end users

who are the ultimate beneficiaries of their work. Instructions for replication of this activity will be provided and available for adaptation.

- (2) Feedback on the activity -- both during the session and



Figure 2. A community volunteer tries on a vision-restricting prosthetic.

from subsequent adopters -- will improve this material and increase its effectiveness and adoptability. The facilitators will continue to use this activity in our course, to develop it further, to package instructions for adoption elsewhere, and to support collaborative development of this material by others.

In addition, this special session will create a community that shares this experience, enhancing incentives to adopt in classrooms and creating new ways of adapting this and similar experiential learning activities.

VI. JUSTIFICATION AS A SPECIAL SESSION

This activity is fundamentally experiential and would make limited sense as a paper or panel. The key insight in this activity is gained by participating. Instructors will also benefit from seeing how their students might experience and learn. As an experience, it is novel and engaging for a wide and diverse range of participants.

ACKNOWLEDGMENT

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New Pedagogic Challenges in Engineering Education

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Abstract— Never has the speed of development in the area of engineering been as accelerated as it is today, as we observe the enormous and driven growth of the area of engineering. Today's tendencies require concerted new efforts in engineering education - or in other words, the importance of pedagogy in the field of engineering is growing enormously. These changes strongly demand new didactic and pedagogic paradigms. The International Society of Engineering Education (IGIP) offers to contribute to the relevance and pedagogical aspects related to developing educational concepts in engineering education. (Abstract)

Keywords- *Engineering Education, pedagogy, didactics, IGIP, challenges*

I. IGIP AND ENGINEERING EDUCATION

IGIP has almost a 40-year tradition of contributing to engineering education and its members and many activists have contributed to making IGIP a leading global engineering association. IGIP presently has a worldwide membership of about 1.750 members (individual, affiliate, institutional). More than 1.100 professionals all over the globe at this moment bear the title of "IGIP International Engineering Educator - ING.PAED.IGIP". IGIP also works in good partnerships with international associations as IFEEES, IEEE Education Society, SEFI, and IELA, to name just a few.

The aims of the International Society for Engineering Education - IGIP are:

- To improve teaching methods in technical subjects
- To develop practice-oriented curricula that correspond to the needs of students and employers
- To encourage the use of media in technical teaching
- To integrating languages and the humanities in engineering education
- To foster management training for engineers
- To promote environmental awareness
- To support the development of engineering education in developing countries

It is important to consider that humankind has never faced such a rapidly changing and dynamic global environment which demands so much of engineers as we are witnessing today.

And as our environment changes, it is imperative we better learn to adapt, which requires us to question and, when necessary, be open to changes regarding our:

- Educational systems
- Pedagogy
- Methods and processes

Never before have the challenges in education and pedagogy been as challenging as today. Never has so much been demanded of engineers. The work of ASEE, IGIP, IEEE ES, and other associations focuses on improving the quality of Engineering Education. But what is exactly is engineering?

"Engineering is the discipline, art and profession of acquiring and applying scientific, mathematical, economic, social and practical knowledge to design and build structures, machines, devices, systems, materials and processes that safely realize a solution to the needs of society." [1]

A short definition of engineering might be: "Exploiting basic principles of science to develop useful tools, objects and processes for society." This means that engineering is the link between science and society, which can include almost anything that people come into contact with or experience in real life. The concept of engineering existed long before recorded history and has evolved from fundamental inventions such as the lever, wheel, and pulley, to the complex examples of engineering we witness today. But today, there are two actual tendencies:

First, we can observe an enormous (and accelerated) growth of the area of engineering.

Besides the traditional fields of civil engineering, construction engineering, electrical engineering, etc. new engineering disciplines have been created and more are in the process of creation. Some examples of recently created areas of engineering include:

- Software Engineering
- Data engineering
- Medical Engineering
- Neuro Engineering
- Gene Engineering
- Social Requirement Engineering, etc.

And new tasks requiring new competencies within traditional engineering disciplines have grown in number and complexity:

- Online Engineering
- Remote Engineering
- Virtual Engineering
- Reverse Engineering

On the other hand, we can observe a terrific decrease of the life cycles of technical (or engineering) products (and processes or technologies too!).

For example, how many years did it take for the following products to reach a market audience of 50 million?

- Radio 38 years
- TV 13 years
- Internet 4 years
- iPod 3 years
- Facebook 2 years
- Tablet PC (iPad) 1+ years

The field of engineering has never suffered such reduced times to bring their innovations from concept to market. Competition in the field of technology is now measured in weeks.

Both of these realities require a concerted effort to evolve engineering education into what today's reality is demanding of practicing engineers. In other words, many traditional educational models and practices are no longer functional. For this reason, the importance of pedagogy is growing at an enormous pace. The need to innovate and apply new paradigms to the teaching-learning process is an absolute necessity.

II. NEW QUESTIONS OF TODAY'S AND FUTURE ENGINEERING EDUCATION

There are especially serious changes in the social position of learning:

- According to some estimates, more than 80% of all learning occurs on the job rather than in tertiary and post-tertiary education!

Learning in the future has to be an integrated part of the job! Moreover: Learners in the workplace are not only consumers of learning resources, but often also developers and resource providers. Learners are also teachers who participate in the development of content and often in its delivery as well. This new model provides new challenges related to the integration of learning and work. [5]

Data from Australian and Portuguese surveys show that engineers tend to spend the majority of their working week (around 60%) engaged in activities which involve interaction with others (meetings, supervision, writing reports, etc.) and only around 40% is devoted to technical engineering activity.

- There are also new organizational aspects in engineering education [6]:

On the one hand, engineering issues, either in industrial products or in engineering projects, are quickly becoming increasingly complicated and most of these issues cross disciplinary lines.

On the other hand, the working environment is becoming more and more internationalized due to the globalization of the world economy. Products are fabricated by worldwide cooperation and manufacturing resources are linked by international supply chains. Nowadays, engineers have to know how to work in multi-cultural environments with people from different countries.

This means the next generation of engineers will need to possess the ability to work seamlessly across cultures, have outstanding communication skills and be familiar with the principles of project management, logistics, and systems integration.

- To face current real-world challenges, higher engineering education has to find innovative ways to quickly respond to the new needs of engineering education, and at low costs.

This means it is necessary to improve the agility of engineering education in the future. One of the approaches in this direction is the creation of virtual educational units.

All these trends result in new questions and the resulting need to evolve educational practices, especially in Engineering Pedagogy. Some of these important questions to consider include:

- What learning approaches have to be used to effectively response to these changes?
- What are the pedagogies that provide the most effective learning experiences for engineering students of the 21st Century?
- What learning skills in engineering education need to be developed and how can engineering teachers succeed in guiding their students to achieve them?
- What pedagogical approaches have been found to support the different phases of the present life-long learning continuum, or is more research necessary?
- What are the approaches that enable competence in leadership skills in a multi-cultural working environment, and what is the best way for these competencies to be delivered?
- Ambient technology is becoming a reality. What does ambient learning in Engineering Education look like? How can it be designed, delivered and assessed?
- How can engineering education support individualized and personalized learning to compensate for individual differences (learning styles, learning strategies, learning preferences, field dependency, etc.)

These are some of the reasons why the relevance and importance of engineering pedagogy is growing so enormously.

III. IGIP'S INTERNATIONAL ENGINEERING EDUCATOR TITLE

This paper, up to now, has attempted to show that dramatic changes are necessary in engineering education and that these changes strongly demand a new look at the didactic and pedagogic concepts that presently form the basis of engineering education. IGIP offers a space for professionals to look into, debate, and put into practice different concepts related to engineering education.

IGIP has established a prototype curriculum for engineering pedagogy which is already used in several countries. In contrast to ABET, FEANI, or EUR-ACE, IGIP is not an accreditation body for engineering curricula. By passing the curriculum as proposed by IGIP in any accredited or other institution worldwide, IGIP states that a given engineering educator with an ING.PAED.IGIP title has all the competencies needed to teach to the highest standards with the best available teaching technologies. Interested engineers can continue their education in accordance with the IGIP Curriculum and obtain a diploma that will provide the knowledge and skills necessary for engineers to become better teachers. IGIP, worldwide, already has 46 approved educational centers and more than 1100 approved "International Engineering Educators" (ING.PAED.IGIP).

The IGIP model's point of departure is that individual engineering lecturers initiate and are responsible for teaching and learning concepts that train engineers and technicians. The quality and success of engineering studies are decisively influenced by teacher competencies in the area of pedagogy as pedagogical skills represent a network of knowledge and skills that transmit knowledge and experience, much like Web 3.0. For this reason, technology and educational practice must go hand in hand when we are dealing with the education of engineers.

Engineering educators expand their typical engineering subject competence by acquiring teaching and learning skills in theoretical and practical coursework corresponding to the objectives of the ING.PAED.IGIP model. Students taking engineering education training should acquire the necessary professional skills which technical teachers must have to be able to exercise their profession effectively and creatively.

The proven IGIP engineering education curriculum is based on the knowledge of traditional pedagogy in philosophy and the liberal arts, but with respect to the particular character of the technician and the analytical-methodological approach in the fields of engineering science.

After many years of experience in industry or research, engineers who are appointed as teachers at a technical school or university are influenced by their professional careers. Their way of thinking is determined by the precision of the technology they work with, by their work with quantifiable and measurable events and objects. The influence of their discipline and the "language" of engineers must be taken into account in

engineering pedagogy education, and they must penetrate the engineering education curriculum.

The ING.PAED.IGIP is a registered program which certifies a certain educational level for teachers, trainers or instructors. Any engineering educator who passes the curriculum at any IGIP accredited training Centre for International Engineering Education, and whose education, training, and professional experience meet IGIP standards, may apply to be registered as an "International Engineering Educator - ING.PAED.IGIP".

The qualification profile of a specialized engineering pedagogue is based on two pillars:

- Engineering qualifications which were earned through a recognized and/or accredited engineering study program plus relevant professional experience
- Educational qualifications in engineering pedagogy acquired in the course of a comprehensive educational program

The engineering pedagogy program is generally an independent course of studies taken after an engineering program. However, it can also form an integral part of engineering degree programs. Already existing educational programs for engineering pedagogues can be accredited by the IGIP. Importantly, to be accredited, they must meet the accreditation criteria defined by IGIP.

The goal of IGIP accreditation is to insure that graduates of the accredited engineering pedagogical programs are well prepared to perform their teaching duties in engineering subjects and meet the criteria required to become International Engineering Educators, ING.PAED.IGIP. Another goal is to promote quality assurance, quality improvement, and modernization of engineering pedagogy programs and to create public awareness of the high quality of the IGIP program for engineering pedagogues. Accreditation is a voluntary process which educational institutions must apply for through the responsible IGIP national monitoring committees.

The accreditation criteria defined by IGIP for a program for engineering educators are:

- Organization of the program
- Entrance requirements for the first year students
- Skills/abilities of the graduates
- Engineering pedagogical curriculum
- Lecturers and professors
- Institutional resources
- Quality control and feedback

IV. COMPETENCES IN ENGINEERING PEDAGOGY

An "ideal" teacher with a technical background should acquire the necessary professional competences of an engineering educator. These general professional competences consist of two main groups:

- Technical expertise
- Specific engineering pedagogical competencies.

Educational theory offers different lists of competences [7]. The IGIP concept of engineering educational competences is to be summarized as follows:

- Pedagogical, psychological and ethical competences
- Didactical skills and evaluative competences
- Organisational (managerial) competencies
- Oral and written communication skills and social competences
- Reflective and developmental competences

Other categorizations might operate with the terms “technical expertise”, “pedagogical competences”, and “human competences”. Some authors substitute the term “competences” by “virtues” [8].

Technical Competences

It is assumed that the candidate has acquired a high level of technical knowledge while studying engineering and has met the requirements as defined by the “Fédération Européenne d'Associations Nationales d'Ingénieurs – FEANI” for registration as a European Engineer – EUR ING. An engineering diploma and at least one year of professional experience in engineering are also required.

Pedagogical, Psychological and Ethical Competences

It is assumed that engineering pedagogues create a positive working and learning atmosphere, see the students as learning partners in a relationship characterized by mutual respect, effectively employ group-dynamics, and stimulate engaging interaction between themselves and students and among the students themselves, using a variety of strategies. Furthermore, engineering pedagogues use student input and provide students the space necessary to promote creativity, support students in developing their professional identity, stimulate “value-orientation” in the students and are aware of their own ethical point of view (within the field of conflict between humans, society, and the environment) which permits them to better conduct themselves as professionals in the different fields of engineering.

Didactical Skills and Subject Expertise

Engineering pedagogues use engineering pedagogy models of the teaching process to create their own lessons, develop their own personalized teaching style and strategies to promote the flow of information, and observe the components of the six-dimensional education space in their own teaching and relate these to the selected teaching method. They select eclectic teaching methods and strategies, e.g. laboratory didactics and project work, and follow up by rethinking and reevaluating their teaching methods and strategies with their colleagues and students. They set clear teaching goals, select suitable materials, and structure them appropriately. They find illustrative explanations and develop clear manner of communicating content and actions. They integrate new technologies and methodologies into their teaching practices. They are comfortable using what may be called the “classic” teaching media and effectively employ “new” teaching media (e.g. learning platforms, etc), taking into account the individual

differences and learning strategies of students in a more personalized learning process (e.g. intercultural differences). They make effective use of student experiences as teaching points, effectively building on these experiences and, therefore, stimulating students to translate personal experiences into practical working theories. They advise students on how to develop their portfolios and stimulate students to include their experiences into the learning process, all the while being responsible for their actions and self-assessing themselves as professional engineers.

Evaluative Competences

Engineering pedagogues develop instruments for (self-) assessment of professional engineering skills and evaluate their students using both quantitative and qualitative means to continually monitor, assess, and record student progress during the learning process.

Organizational / Managerial Competences

Technical teachers create an adequate physical and virtual learning environment, poses time management skills for their own work, observe relevant laws and are aware of educational policy, administer all relevant data adequately, and can work “on the fly” if necessary.

Communicative and Social Competences

Engineering pedagogues work as part of trans-disciplinary teams, making their own vision of teaching explicit and effectively relating it to the visions and concepts of their colleagues. They contribute to the development of guidelines and visions of their own profession and to the modernization process of teaching. They have or create relevant regional or (inter)national networks that contribute to knowledge in the field of engineering pedagogy and effectively communicate it to their peers. They also communicate satisfactorily both orally and in writing in a variety of contexts and are competent in scientific writing.

Reflective and Developmental Competences

Teachers with a technical background appreciate new developments (e.g. new technologies) and readily integrate them into their teaching, systematically rethinking their own teaching strategies and their teaching behaviors, making their own learning process transparent to students and colleagues. They are also willing and in the position to initiate IGIP accreditation and register as an “International Engineering Educator - ING.PAED.IGIP”.

The IGIP “Recommendations for Engineering Pedagogy Studies” (in short IGIP Curriculum) are described in detail in [10].

Interested institutions and engineers, teachers, and students are welcome to contact one of the 23 IGIP National Monitoring Committees or the IGIP headquarters in Austria.

CONCLUSIONS

Technical university teaching has often been perceived as a poor cousin to research. Few technical universities require any specific technical teacher education for their academic staff. Interestingly, this is the only level of learning where academic staff receives no teacher training. Yet teaching is an art that, at least to some degree, can be taught, if the institutions of higher learning support it as an important element. The International Society for Engineering Education (IGIP) is working to assure that graduates of accredited engineering pedagogical programs are well prepared to perform their teaching duties in engineering subjects and meet the criteria for IGIP registration as International Engineering Educators, ING.PAED.IGIP. IGIP's ultimate goal, however, is to promote quality assurance, quality improvement and modernize engineering pedagogy programs and educational practices. Its intention is also to create public awareness of the high quality of engineering pedagogue programs.

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Assessing the application of three theories of conceptual change to interdisciplinary data sets

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Abstract— The study of students' preconceptions and how they affect their learning in science, technology, engineering and mathematics (STEM) fields is of nationally recognized importance. There are, however, various and contradictory theoretical approaches to conceptual change, and none of them have been rigorously applied in the context of engineering education. This paper is part of a larger study drawing on existing sets of data from a wide range of engineering content areas to develop a theoretical explanation of conceptual change in engineering education. In the work reported here we re-analyze students' understanding of concepts about axially loaded members (from mechanics of materials) and Boolean logic (from digital logic). Previously published analyses of these data argue that the context of a problem or question effects students' reasoning about that concept. These contexts can range from the presence or absence of figures or diagrams to the social contexts of the problem. We explored three potential theoretical explanations for the context-sensitivity of student reasoning: (1) a perceptual cues theory, (2) a domain specificity theory, and (3) a language-based theory. It is argued that these competing theoretical explanations do not contradict each other as much as they overlap, and potentially productive syntheses of the theories are proposed as directions for future work.

Keywords- *conceptual change; Mechanics of Materials; Digital Logic*

I. INTRODUCTION

The study of students' preconceptions and how they affect their learning in science, technology, engineering and mathematics (STEM) fields is of nationally recognized importance [1]. Beyond the agreement to identify and address students' preconceptions, however, there is little consensus about the nature of preconceptions or even what is meant by the term "preconceptions." The progress of empirically based research in addressing these calls depends on a more rigorous description of what is meant by preconceptions, what is meant by learning, and how one interferes with the other.

Within conceptual change research, preconceptions are assumed to be functionally equivalent to accepted conceptions acquired through formal learning, but differ only in content [2, 3]. In this paper, we will distinguish between the acquisition of new knowledge (the creation of new knowledge structures) and conceptual change (changing the substance of preconceptions to accepted conceptions).

In some cases the benefits of new knowledge is obvious, or not strongly contradicted by preconceptions – students' life experiences rarely lead them to doubt that gravity causes an acceleration of 32.2 feet per second per second, for example, so this knowledge is easily acquired. Common life experiences do contradict, however, that an object in motion tends to stay in motion. Learning Newtonian physics therefore requires students to reevaluate life experiences and ways of thinking as well as acquire the individual bits of knowledge being proposed in class (e.g. the equations of kinematics). This type of learning is conceptual change and is typically much more difficult to achieve than acquiring facts like the acceleration due to gravity [4].

Despite overwhelming evidence as to the importance and frustrating lack of conceptual change in traditional education [5], a number of vitally important questions remain contentious and difficult to answer. Why is conceptual change difficult? What are the actual processes that underlie it, and most importantly, what can educators do to promote it in their classrooms? In the past few decades, several theories of conceptual change have been proposed, but none have been clearly superior in terms of their ability to explain observed phenomena or guide instructors in helping their students learn [4, 6]. The development of these theories is typically based on one or only a small number of science disciplines, and few of these published efforts have included engineering concepts or practices [for exceptions see 7, 8, 9]. The purpose of this paper is to contribute to the development of a theory of conceptual change in engineering.

II. BACKGROUND

The work reported in this paper is part of a larger effort to utilize existing data to develop and test a theory of conceptual change for engineering education. The data being used consists of more than 250 interviews with engineering students conducted over the past several years in the course of the coauthors' ongoing research programs. These interviews cover engineering topics that include fluid mechanics, geometric highway design, thermodynamics, and a variety of topics within both mechanics of materials and digital logic.

This paper is based on analyses of a subset of those data, specifically interviews about students' understanding of axially loaded members (40 interviews) and Boolean logic (16 interviews). We chose this subset because the methodologies and findings of the interviews addressed a similar fundamental problem, despite being developed separately. In particular, both studies emphasize the ways in which students' reasoning and conceptual understanding seemed to be context dependent – understandings change as the contexts of the interview were changed [10, 11]. For the purpose of our discussion, contexts can be different tasks, presentation styles, or social contexts.

The most prominent theories of conceptual change either do not directly address the context dependence of students' knowledge [12], or they attribute significantly different meanings to it [see for example 13, 14-16]. This question may be more important in the context of engineering education than in the broader field of conceptual change research, because engineers are expected to use the knowledge they gain during formal education through problem sets and examinations in radically different contexts in practice (e.g., design and documentation). Engineering educators in particular need to be concerned with any phenomena that seem to limit students' abilities to apply understandings in new contexts.

The purpose of this study was to develop and test theoretical explanations for why students' understanding of fundamental concepts in mechanics of materials and digital logic seem to be context dependent.

III. METHODS

A. Data Collection

As described above, the data used in this study were collected as parts of two separate studies. Results from these studies have been published previously [10, 11]. In both studies, one purpose of the interviews was to present slightly different versions of the same concepts in order to better understand how students' reasoning changed with context. In the interviews about axially loaded members, Brown and Montfort tested context dependence by presenting axially loaded members in multiple ways: two-dimensional schematic drawings, isometric sections, stress elements, and pictures of actual failed concrete cylinders. For the interviews about Boolean logic, Herman et al varied both the social contexts of the problems (e.g., people deciding on pizza toppings or following a recipe to make apple pie) and the specific tasks (e.g., to write a Boolean expression or fill in a truth table). Students were always asked about the same fundamental concepts. For axially loaded members, students were asked

about normal and shear stresses, forces and strains. For Boolean logic, students were asked to reason about common operators including if-then, if-and-only-if, OR, XOR and AND.

B. Analysis

For this paper, we report our reanalysis of the mechanics of materials and Boolean logic interviews. To focus the analysis, we chose to examine students' understanding of one set of concepts from each topic: if-then (implication) and if-and-only-if (bidirectional implication) from Boolean logic and shear force, stress, and strain from mechanics of materials. This narrowed focus allowed for richer descriptions and a more grounded coding of the data to facilitate theory development.

The interviews were primarily analyzed by researchers Dr. Herman and Dr. Montfort who have expertise in conceptual change research. Dr. Herman also provided expertise with digital logic concepts and Dr. Montfort provided expertise with mechanics of materials. Each researcher was a novice in the opposite topic. The primary analysis of each group of interviews was conducted by the novice in that topic. Dr. Montfort analyzed the Boolean-logic interviews that had been designed and conducted by Dr. Herman, while Dr. Herman analyzed the axially-loaded-member interviews which had been designed and previously analyzed by Dr. Montfort. After this preliminary, independent analysis, the researchers compared and discussed codings until agreement was reached.

This novice-led analysis familiarized the novice with the transcripts and technical content of the interviews, but more importantly, it exposed the "expert blindspots" [17] of the content expert. For example, in some cases student statements that had been coded as "incorrect" by the expert in the content area were recoded to be inconclusive due to leading or unclear wording of questions as identified by the novice in that area.

This first stage of analysis, particularly the adjustment of codes to account for blindspots, further emphasized the ways in which students' reasoning appeared to change in different contexts. We conducted a second stage of coding in which the researchers went back to the interviews outside their expertise and searched for patterns and themes [18] in students' reasoning across those questions that had been designed to probe the same concepts. In this use a "pattern" is a grouping of observations. For example, Dr. Montfort identified the pattern that students who referred to "zeros" and "ones" in solving Boolean logic word problems also tended to check their work and successfully identify errors.

The patterns identified were similarly discussed and verified by both researchers before moving to the third stage of analysis. In this stage, the two researchers proposed explanations for those patterns, and sought vignettes in both sets of interviews that supported and challenged those explanations.

We derived three explanations for the differences in student reasoning that we observed in the data. These explanations were developed iteratively through the analysis as opposed to being assumed prior to the analyses. These three explanations will be introduced in the context of the theoretical works that informed and inspired them and supported by vignettes from

the data. Although we acknowledge the foundational influence of existing theories of conceptual change on our explanations, we do not intend to be faithful to any existing theories. Rather, we will expand upon their implications in the context of engineering education.

In the reports to follow, students are identified by interview topic and a number: A1 and A2 represent two different students interviewed about axially loaded members, while B1 and B2 represent two different students interviewed about Boolean logic. Note that while each theory is supported by a single student example to allow for sufficient detail, all three theories were developed and validated across both datasets.

IV. PERCEPTUAL CUES

The perceptual cues explanation argues that students' use of knowledge is cued by physical perceptual features (e.g., visual or auditory) of the interview that prompt their use of knowledge or reasoning. Building on Minstrell's construct of facets [19] and diSessa's model of conceptual ecology [20], this explanation does not assume that students possess or use coherent domains of knowledge, but rather use pieces of knowledge as they seem relevant or related to the situation. Perceptions cue or activate individual cognitive entities (e.g. memories, facts, beliefs, equations) or strings of common thoughts (e.g. algorithms to solve common problems). In this model, conceptual change is the process of creating more consistent and useful strings of concepts and ensuring that they are cued by all pertinent contexts [21]. Evidence supporting this explanation would be instances where students' reasoning seems directly dependent on what they attend to in the problem set-up. Differences in reasoning would necessarily accompany differences in perception or attention.

A. Supporting Case

When presented with various representations of an axially loaded member and asked if shear stress was present, student A2 sometimes said yes, and sometimes no. Despite the frequency of these questions, and their reoccurrence within only a few minutes, A2 did not appear perturbed by the inconsistency.

A2 correctly identified and reasoned about shear stress when using Mohr's circle (a complex graphical analytical tool relating normal and shear stresses that many students struggle to understand), but she was less able than many students to identify the role of shear in the failure of a concrete cylinder under compression. Many students, even those who struggled to describe shear stress in axially loaded members throughout their interviews, correctly identified the 45° angle of failure (a useful perceptual cue for these students) and associated it with the maximum shear stresses under axial loading. When asked to describe the cause of failure given the same picture, however, A2 reasoned, "...it looks like it has a weakness at an angle in the member sort of like...with the grains this has a failure point but at an angle rather than something straight." When asked "what forces are present and how they are acting," A2 replied, "Well there is a compressive force. So you would have the compressive force acting. So you would have - I don't really understand what you are asking."

In this exchange, we hypothesize that her response to the interviewer's questions about the failed concrete cylinder was cued by the interviewer's description of a "concrete cylinder that failed in compression" and the testing machinery that provided that compression is clearly shown in the pictures. Understandably, then, A2's description of "what forces were present and how they were acting" began and ended with those compressive forces. Furthermore, the rough, pebbly appearance of the failure plane cued her knowledge of "grains" and "failure points," rather than the more abstracted analyses she preferred in earlier questions showing more simplified and idealized members.

Even in reference to the more simplified figures, however, A2's reasoning aligned with the problem features that were most salient to her. When presented with angled, diamond-shaped stress elements (as opposed to the more common square ones oriented parallel to the edges of the page), A2 naturally and easily discussed shear stress in reference to those elements, saying for example that there would be less stress when the elements were oriented that way "because of it being distributed over more surfaces." Reasoning based on the distribution of stress over the "surfaces" of a stress element in this way contradicts the ways stress elements are presented and used in courses, but *is* strongly supported by the visual cues presented in the problem.

A2's reliance on the perceived features of the problem extends beyond shear stress to reasoning about internal and external forces. She would reason using primarily external forces when the figures presented only members with external forces, and primarily internal reactions when those forces were drawn.

B. Challenges

As noted, certain perceptual cues did not always correlate with more difficult tasks. For example, some students were better able to discuss shear in the context of the concrete cylinder, but others were better able to discuss shear in the context of Mohr's circle. In hindsight and after extensive analysis, we can tell that A2 and students who had similar difficulties appeared to envision microscopic components (e.g. "with the grains" or "the fibers") when discussing the concrete cylinder, but these distinctions and patterns would be difficult to identify in the moment or to predict. Although the use of perceptual cues may provide a clean explanation (e.g., "students talk about what they see or hear"), it does not lend itself to predictive power of a students' reasoning ability in a specific context. We identified these themes only after analyzing the interviews several times prior to and during this study.

This theory generates some valuable questions. Why do students fixate on the things they do? Why is A2 so intuitively able to distinguish external and internal forces, but not able to distinguish forces and stresses?

V. DOMAIN-SPECIFICITY

Building on Vosniadou's "framework theories," [22] the domain-specificity explanation argues that students' reasoning and conceptual understanding is controlled by the domain in

which they situate their thinking. The domain of a question, as determined by the student, determines the concepts, procedures, and expectations that are available to be applied. Students identify the domain of a problem based on their perceptions of it. In this model, changes in students' reasoning in response to superficial changes in problem features are caused by shifts in the domain in which the student is acting.

A. Supporting Case

As an example, we will present student B7's apparent understanding of the operator *if-then* in Boolean logic. When first asked, "We're going to be talking about Boolean Algebra. Could you explain the phrase 'IF A THEN B'?" How would you describe that in common, everyday English, to a senior who is about to start CS?" he asked, "You mean programming, or more like the logic part?" In this statement, we can see that the student is negotiating which domain to use: the programming domain or the logic domain.

When told to just consider "the logic part," B7 responded with a statement that would be true in the programming domain, but not the logic domain: "Basically, if we have one condition, and we have that it's true, it follows, B. So, if expression A is valued to true, then it follows with B." When asked to write a Boolean expression to show what he meant, B7 wrote a statement in a form of computer programming pseudocode using the words "if" and "then." When asked to write it "with just symbols and variables instead of programming code," B7 wrote " $A \rightarrow B$." In attempting to encourage B7 to elaborate on what he had written, the interviewer suggested ways in which to translate the function into a Boolean expression such as "using a symbol like AND, or OR, and complements," and referring to the specific course that would have covered this material. B7 became frustrated as he was unable to express "IF A THEN B" in any other way:

B7: Well the thing is that, IF A THEN B, there's no AND's and no OR's. IF A; you just write "A." And then, "follows B."

Interviewer: Ok, ok, so what is the relationship between A and B, then?

B7: What?

Interviewer: What is the relationship between A and B, are they...?

B7: Well, B is what happens when A follows to true.

Later in the interview, B7 is asked to express the phrase "if a sandwich has turkey (t) then it must also have cheese (c)" as a Boolean expression (correctly written as $f(t,c) = t \wedge c$). He reasoned about the IF-THEN better than many students by noticing, "...it's not saying anything about C whether it has to have cheese[....] Basically what'd we'd be saying now is that we have turkey then there will be cheese, but not necessarily that if we have cheese then we have to have turkey." During this reasoning, however, B7 wrote " $c=t$ " as the Boolean expression reflecting his reasoning, which is what's known as an assignment operation in programming. When asked if " $c=t$ " is a "standard Boolean algebra expression" B7 argues that is by

explaining how the operation functions in programming: "C could be expressed as a function and it would be T. So yes."

B7's reasoning and conceptual understanding can best be explained by describing the domains within which he reasons. Initially, B7 is explicitly confused as to the domain of the interviews, confusing computer programming with the more general computer science, and not clearly understanding what the interviewer implies with the phrase "Boolean algebra." Although he tends to use programming terminology, B7 is sometimes clearly aware of the disconnect between the questions and his perceptions of the domain, as evidenced by his frustration with the first line of questioning.

We cannot simply say that B7 is thinking in the "wrong domain," however, because throughout the interview he confidently and adeptly uses many Boolean algebra concepts. Furthermore, B7 had internalized some of the nuances of *if-then*. For example, B7 manages to avoid a common mistake by immediately recognizing that if-then is one directional relationship between the presence of turkey and cheese. This apparent mastery of a difficult concept, however, is immediately juxtaposed by a comparably unusual lack of understanding of how to express the concept in Boolean algebra.

We propose that B7's conceptual difficulties with Boolean algebra are caused by his failure to create strongly defined and distinct domains. Throughout his interview, B7 tries to justify reasoning by appealing to different domains and unknowingly switching between domains. He argues that " $c=t$ " is standard Boolean expression because "C could be expressed as a function and it would be T." While this statement could be a Boolean expression, it unnecessarily appropriates a concept from the programming domain. In other words, B7 lacks the mechanisms to distinguish between two domains and assess the coherence and consistency of his reasoning from the perspective of a single domain. This missing mechanism is most obvious in the first exchange quoted where B7 and the interviewer are apparently unable to make themselves understood. They each understand the components and concepts being applied – *if-then*, A's and B's as variables that can be true or false – but they are speaking about different domains and thus lack the means to interpret each other's statements. The interviewer's repeated questions imply that B7's responses are incomplete or inappropriate, while B7's repetitions of the same phrases imply that he is unable to determine what is missing from his response; he lacks the framework, or domain, to adequately assess the appropriateness of his response.

B. Challenges

Although many students' general patterns of reasoning matched B7's and tended to correspond with questions concerning the domain (e.g. "in programming, or in logic?"), it is difficult to completely separate domain-specificity as the causal agent. Simply put, any differences in student reasoning occur in response to different questions and at different times, and could conceivably be affected by any changes in circumstances including temporary changes in affect, different physical environments, wording of questions or even non-

verbal cues from the interviewer. Even if the patterns of domain-confusion continue to co-occur with changes in student reasoning, it is unclear which causes the other. As described above, there is a feedback loop between the ways in which perceptions inform domains and domains inform perceptions. As students change their reasoning in response to different questions, is it because their perceptions are overly mediated by their domain, or because their domain is too limited by their perceptions?

VI. LANGUAGE-BASED

The language-based explanation moves outside the assumption that we can infer students' conceptual or cognitive processes, and instead focuses on the actual data being recorded: student and interviewer use of language. In this definition, language includes any form of verbal, written, or bodily form of expression including drawings, statements or gestures [23]. Instead of assuming that students' *reasoning* or *conceptual understanding* changes when the problem presentation changes, we instead focus on how their uses of language are different or consistent. The use of language includes both the communication of ideas from the participant to the interviewer and the interpretation of the interviewers' statements by the participant.

A. Supporting Case

As an example, we present evidence from student A4's interview about shear forces, stresses, and strains. Throughout A4's interview, he treats forces' and stresses' directions (i.e. in the vertical and horizontal directions or in the X- and Y-planes) as defining descriptions of their fundamental nature. For example, he defines normal forces as "forces on the X-plane." Similarly, he argues for the absence of shear stress in an axially-loaded member by reasoning that "there are no forces in the Y-plane, there are no vertical forces." It's important to note that A4 may not be merely skipping a step in describing a causal sequence, or inferring that "forces in the Y-plane" or "vertical forces" are indications of or causes of shear stress. As indicated by his use of terminology throughout the interview, he apparently treats the statement "there are no vertical forces" as synonymous with "there is no shear stress."

A4 would likely find this discursive tool to be useful in courses that build upon a mechanics foundation, because decomposition of forces into x- and y-components makes up a small but significant portion of the activities students engage in within the context of the course. In much of his coursework, A4 would not even need to be able to discursively distinguish between a force's direction and nature (i.e. normal or shear), because they so reliably correspond. It makes sense then, that he does not make these distinctions in the interview. Unfortunately, normal and shear are not synonyms for X and Y, so this discursive tool has its limits for allowing productive reasoning.

For example, A4 stated that shear stress was present in one axially loaded member, but absent in another when the only difference between the two members was the frame of reference: (in one case the x- and y-directions would align

with normal and shear stress and in the other case they would not). Despite being told it was the "same member," A4 made contradictory claims about it within a few seconds.

Interviewer: looking at that top member, are there shear forces present?

A4: No.

Interviewer: And describe your reasoning.

A4: There are no forces in the Y-plane, there are no vertical forces.

Interviewer: And so now, we are making a cut on the same member at cross section BB and just draw the resultant forces and describe what forces are present at cross section BB.

A4: It would be as it comes off perpendicular to BB which also will give it a shear. It should be down.

When discussing forces on the member with a hypothetical non-perpendicular cut in the second set of questions, A4 could discuss the decomposition of the forces into normal and shear components because the relative directions of the forces could be envisioned on a rotated XY axis, and there was therefore no need to distinguish between the direction and nature of the forces.

A4's discursive conflation of "shear" and "vertical" was apparent in his interpretations of questions, as well. Regardless of how a question was phrased, A4 used the terms "shear strain," "shear" and "strain" interchangeably to describe some deformations, again failing to make appropriate distinctions between normal and shear strains, or between strain and stress.

B. Challenges

A primary challenge for this explanation is whether we should distinguish between a students' ability to explain their reasoning and their ability to reason well. For example, a student may have limited ability to engage in discourse about their conceptual understanding in English, but may be able to discourse accurately about their conceptual understanding by making predictions, graphs, figures, or even equations. Does an inability to communicate conceptual understanding with one mode of communication imply that a student possesses detrimental preconceptions? How do we distinguish between different modes of communication and are some more valuable than others for conceptual formation?

VII. CONCLUSIONS

Although we pose these theories as three distinct theories, it may already be apparent that there is considerable overlap between these proposed explanations. Considering that each theory was derived from a different, supposedly contradictory, intellectual tradition, we believe that this observable overlap is a finding in itself. Their overlap identifies potentially fruitful areas for future research that build a synthesis of the three theories into a new and more flexible theory.

First, the importance of language holds paramount across all three explanations. Students' perceptions and domains are largely identified by the language they use. Again, this use of

the word “language” refers to all the students’ efforts at making and interpreting meaning including speaking, drawing, writing equations, and gesturing. Future research in conceptual change, and indeed future efforts to teach for conceptual change, could benefit from closer and more nuanced attention to students’, researchers’ and instructors’ use of language.

Second, the concepts that students struggled to apply in these interviews are often considered fundamental, and their misconceptions are probably directly contradicted in most relevant courses. Small changes in the ways in which problems are presented render many students unable to apply basic concepts, even minutes after they have displayed mastery of them in another context. This supports a well documented trend of low conceptual understanding among engineering students, but adds the potential explanatory factor of highly context-dependent abilities.

Third, all of these explanations go beyond the content itself to examine the contexts in which it is situated, which means the ways in which a subject is typically presented are as important as the subject itself. What is being emphasized, implied and assumed in the typical representations of digital logic or mechanics of materials? Who are the people using these subjects, and what problems are they actually solving with them? Even though they are largely implicit and tacit, these messages are communicated in the ways the subjects are taught.

Finally, we’d like to highlight the ways in which these theoretical differences are important to the practice of engineering education. It is acknowledged that students struggle to learn some aspects of Boolean algebra and axially loaded members, but the response to that problem depends on one’s understanding of the cognitive processes underlying it. If students’ understanding is limited by their perceptions, the emphasis should be on helping students expand their abilities to link perceptions to pertinent engineering fundamentals. If it is the domain-specificity of their understanding that is problematic, then explicit instruction about the boundaries, purposes and history of the subject should help. If it is rather a problem of language, then treating learning as language acquisition could facilitate conceptual change. Without an empirically based and tested theory of conceptual change in engineering education, it is difficult to even define the problem, let alone begin to solve it.

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As per an earlier study [9], since problem-solving activity was alternated with the easier activity of answering three Likert-scale questions, the efficiency with which students solved pre-test problems should have increased with alternation than without. But, the time spent per problem on the pre-test was not significantly different between the control and test groups [$F(1,254) = 2.368$, $p = 0.125$] (See Table VII). Then again, more recent literature on task switching finds that subjects take longer to perform alternating tasks than massed tasks, because of alternation or mixing cost (e.g., [10,11]). In this study, the effect of such alternation cost was not found to be significant either.

TABLE VII. TIME SPENT PER PRE-TEST PROBLEM: CONTROL VERSUS TEST GROUP

| | <i>Average (seconds)</i> | <i>N</i> |
|---------|--------------------------|----------|
| Control | 55.6843 | 145 |
| Test | 61.2365 | 110 |

C. Affective Learning

After eliminating the students who had scored 100% on the pre-test:

- There was no statistically significant difference in the prior self-confidence of the control and test groups [$F(1,229) = 0.083$, $p = 0.774$] (See Table VIII).

TABLE VIII. PRIOR SELF-CONFIDENCE: CONTROL VERSUS TEST GROUP

| | <i>Average</i> | <i>N</i> |
|---------|----------------|----------|
| Control | 2.7214 | 133 |
| Test | 2.7543 | 97 |

- There was no statistically significant difference in the post self-confidence of the control and test groups [$F(1,216) = 1.163$, $p = 0.282$] (See Table IX).

TABLE IX. POST SELF-CONFIDENCE : CONTROL VERSUS TEST GROUP

| | <i>Average</i> | <i>N</i> |
|---------|----------------|----------|
| Control | 2.0563 | 128 |
| Test | 2.182 | 89 |

- There was no statistically significant difference in the average feedback response of the control and test groups [$F(1,216) = 0.123$, $p = 0.726$] (See Table X).

TABLE X. AVERAGE FEEDBACK RESPONSE: CONTROL VERSUS TEST GROUP

| | <i>Average</i> | <i>N</i> |
|---------|----------------|----------|
| Control | 2.4164 | 128 |
| Test | 2.4498 | 89 |

So, in terms of *affective learning due to tutoring* - self-confidence and feedback about the tutor – the treatment did not result in any statistically significant difference between the control and test groups.

Earlier studies had shown that self-confidence of the students increased significantly from using the tutors (e.g., [12]). There was no significant difference in the improvement in the self-confidence between the control and test groups [$F(1,215) = 0.271$, $p = 0.603$] (See Table XI).

TABLE XI. PRE-POST CHANGE IN SELF-CONFIDENCE: CONTROL VERSUS TEST GROUP

| | <i>Average</i> | <i>N</i> |
|---------|----------------|----------|
| Control | -0.6472 | 127 |
| Test | -0.5873 | 89 |

Earlier studies had shown that female students were more likely to provide positive feedback about the tutor than male students [13]. When average feedback response was analyzed with treatment and sex as fixed factors, no main effect was found for treatment [$F(1,199) = 0.256$, $p = 0.613$] or sex [$F(1,199) = 2.45$, $p = 0.119$] and no significant interaction was found between the two [$F(1,199) = 0.278$, $p = 0.599$].

IV. DISCUSSION

Introduction of the alternate task did not result in any statistically significant difference in the scores of the control and test groups on the pre-test. It did not promote better cognitive learning or affective learning during tutoring. There could be a number of reasons for the negative results:

- Though alternation was found to be on the average more efficient than massing, differences were found among subjects in whether they could benefit from alternation, and these differences were ascribed to the subjects' ability to persevere, called perseveration [14]. So, in the current study, some students may have benefited from alternation whereas others may have been hindered by it, the cumulative effect being to cancel each other out.
- An earlier study had concluded that the effects of alternation are proportional to the dissimilarity of the alternating tasks [15]. The activity of the alternate task, i.e., answering Likert-scale questions was very dissimilar from the problem-solving activity of the main task. However, since the three Likert-scale questions were about the problem that the student had just solved, the mental task set of the alternate task may not have been dissimilar enough to accrue the benefits of alternation. Other studies suggest that the effects of alternation vary according to the types of tasks involved, e.g., mental versus motor (e.g., [16]). Both problem-solving and answering Likert-scale questions are mental tasks, which may be another reason why no benefits were found that could be ascribed to alternation.
- Earlier studies have shown that massing is more efficient than alternating (e.g., [17]) for complex tasks. The main task in this study was solving problems, which is a complex task involving multiple steps. So, as per the earlier study, alternating (test condition) should have been found to be less efficient than massing (control condition). But, no significant difference in the time spent per problem was found between the control and test groups.

- According to the research on task switching, alternation results in increased error rates as compared to massing because of switch costs (e.g., [6]). This might help explain why alternation did not produce better learning or test results in the current study. Then again, the current study contradicts task switching studies in that alternation did not impair learning or test results in any significant manner in spite of switch costs. This is all the more significant considering that the task in this study – problem-solving, is considerably more complicated than the simple stimulus-response tasks used in most task switching studies.

The current study differs from earlier studies on alternation in the following respects: it considered the task of solving problems, which consists of multiple steps, and is hence more complex than single-step stimulus-response tasks considered earlier; both the primary task and the alternation task were conducted entirely online; and the primary task was in the domain of computer programming. It is possible that under these conditions, the positive benefits of alternation cancel out the negative costs associated with task-switching. This hypothesis bears further experimentation.

ACKNOWLEDGMENT

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The Effect of Interleaving an Alternate Task During Tutoring and Testing

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Abstract—The effect of interleaving an alternate task during tutoring and testing was studied in the context of an online problem-solving software tutor. A controlled study was used and ANOVA was used for data analysis. It was found that introduction of the alternate task did not result in any difference in the scores of control and test groups during testing. It did not promote greater cognitive or affective learning during tutoring. Some possible reasons for the negative results are discussed.

Keywords—*alternating tasks; online learning; software tutor; computer programming*

I. INTRODUCTION

We have been developing software tutors to help students learn programming concepts by solving problems. These software tutors present a sequence of problems, have students solve them, and provide feedback from which students can learn. However, solving several problems back to back can be monotonous and exhausting. It seems intuitive that breaking up the problem-solving session and introducing alternate tasks in between could break the monotony and increase engagement. Did the alternate task, which was introduced to break up the monotony of problem-solving, help students learn better with our tutors? We conducted a controlled study to test this hypothesis.

The effect of alternating tasks has been studied under multiple terms – early studies were on *alternating tasks* (e.g., [1]); more recent studies have been on *spacing in learning* or *distributed practice* (e.g., [2]) and *task switching* (e.g., [3]). In an early study on alternating tasks, researchers compared an alternating protocol where video game-like tasks and word problem tasks were alternated, against a massed protocol in which the tasks were grouped together by type [4]. They found that alternating task protocol was more advantageous for learning and retention of both video games and word problems. Literature on spacing in learning, i.e., temporally separating learning sessions with possibly other activities in between, has shown that spacing is better for retention than massed learning wherein all the learning is done in one continuous session (e.g., [5]). Research on task switching (e.g., [3]) has looked into the factors that promote or inhibit performance when tasks are alternated. One of the key findings of this research is that alternation comes with a switch cost in both reaction time and error rate (e.g., [6]). Note that the advantage of alternation for

learning as found in research on alternating tasks is at odds with the increase in error rates due to alternation found in research on task switching. So, it is unclear from prior literature what we could expect to find on the effect of alternation on learning in the current study.

A large part of the earlier research on alternating tasks and task switching was conducted with well-defined stimulus-response tasks such as solving arithmetic problems, word problems and classification problems, also called single-step tasks [7]. In contrast, in the current study, the main task is solving problems, a task that involves multiple steps, and is hence, more complex than the stimulus-response tasks studied earlier. The problem-solving task and the alternate task were both carried out entirely online in the current study. The focus of the current study is on the effect of alternation on performance during tests and learning during tutoring – both cognitive and affective. Finally, the domain considered in this study is computer programming, which, to the best of our knowledge, has not been the subject of prior studies on alternation.

In the rest of this paper, we describe the software tutor and the protocol used for the study, followed by results of data analysis and discussion of the findings.

II. METHODS

For this study, an online software tutor was used, which deals with selection statements, which are a part of introductory computer programming. The software tutor presents problems and has the student solve them. Each problem contains a computer program that includes selection statements. The student is asked to predict all the outputs of the program, one output at a time, along with the line number of the code that generates each output. After the student submits the answer, the tutor provides two types of feedback - whether the answer is correct, and step-by-step explanation of the correct answer. Earlier evaluations have shown that the step-by-step explanation helps students learn [8]. The tutor on selection statements is part of a suite of software tutors called problets (www.problets.org).

When using the software tutor, students went through the following sequence of stages, all administered over the web, back to back and without any break:

1. **Registration** – students entered identifying information about themselves - their name, and demographic information;
2. **Pre-Survey** – students rated their knowledge about the various concepts covered by the software tutor on a 5-point Likert scale (1=Very well, 2=Well, 3=Average, 4=Not well, 5=Not at all). They responded to five different statements:

- How well do you know 'if' statements?
- How well do you know 'if-else' statements?
- How well do you know nested 'if' statements?
- How well do you know nested 'if-else' statements?
- How well do you know the boolean data type?

Their average response on these five questions was used as a measure of their prior self-confidence in the topic. Note that a numerical response of 1 corresponds to the greatest self-confidence and 5 corresponds to the lowest self-confidence.

3. **Problem-solving stage** - the software tutor presented problems to the students, had them solve the problems, and provided them feedback from which they could learn. This stage itself consisted of three segments:
 - **Pre-test** consisting of 12 problems, one per learning objective. If a student solved a problem correctly, the student was given credit for the corresponding learning objective. No feedback was provided to the student, and no more problems on the learning objective were presented to the student. On the other hand, if the student solved a problem incorrectly, feedback was presented to the student immediately after the student submitted his/her solution to the problem. Additional problems were presented on the learning objective during the subsequent segments of the stage.
 - **Adaptive practice** – during this segment, additional problems were presented to the student on only the learning objectives on which the student had made mistakes when solving problems during the pre-test. For each such learning objective, the student was presented multiple problems until the student had mastered the learning objective, i.e., solved at least 60% of the problems correctly.
 - **Post-test** - during this segment, the student was presented test problems on the learning objectives that the student had mastered during adaptive practice.

Note that if a student solved all the pre-test problems correctly, no practice or post-test problems were presented to the student. The entire problem-solving stage was limited to 30 minutes. So, the students who did not solve

all the problems correctly during the pre-test may still not have completed practice or post-test because they ran out of time. Finally, for a concept (learning objective) to be considered as *having been learned by the student*, the student must have solved the problem on that concept incorrectly during the pre-test, repeatedly solved problems during practice until the student had mastered it, and must have correctly solved the post-test problem on that concept.

4. **Post-Survey** – the software tutor administered the same instrument as on the pre-survey. The student's average response on the post-survey was used as a measure of her/his self-confidence in the topic after the problem-solving session.
5. **Feedback** – students rated the usability, ability to learn from, and usefulness of the software tutor by responding to 14 statements on a 5-point Likert scale (1=Strongly agree, 2=Agree, 3=Neutral, 4=Disagree, 5=Strongly disagree). Some of the 14 statements were "The feedback provided to my answers was useful", "The tutor helped me learn new material", and "This tutor should be made available to all the students". Note that a numerical response of 1 corresponds to the most positive and 5 corresponds to the most negative assessment of the software tutor.

In one early study of alternating tasks, when a task was alternated with an easier task, the efficiency of doing the first task was observed to increase, and when it was alternated with a more difficult task, the efficiency of doing the first task was observed to decrease [9]. Therefore, in the current study, an alternate task was used that is significantly easier than solving problems – one that involved answering three Likert-scale questions. During the problem-solving stage, the test group students were asked to answer three Likert-scale questions after solving each problem: the first to rate the level of difficulty of the problem; the second on whether the problem helped the student learn; and the last on whether the student wanted to solve additional problems of that type. Control group students on the other hand were not asked to answer these three questions – instead, they solved problems back to back. Since literature on task switching finds that alternating task protocol takes longer than massed or blocked protocol, the difference being referred to as alternation cost (e.g., [10]), the test group was allowed 33 minutes for the problem-solving stage whereas the control group was allowed 30 minutes. All the other stages of the tutor were configured identically for the control and test groups.

Registration and problem-solving stages were required of all the students. Pre-survey, post-survey and feedback stages were presented to all the students, but were optional, i.e., students could continue without responding to some or all the statements during these stages.

Data was collected in fall 2009 and spring 2010. 474 students from 18 institutions (both 2-year and 4-year) used the tutor during those two semesters. The institutions were randomly assigned to control or test group. The size N varied from one data analysis to the next due to several reasons: pre-survey, post-survey and feedback stages were optional; some students solved all the pre-test problems correctly during the

problem-solving stage; and some students ran out of time during the problem-solving stage. Therefore, in the next section, N has been included in the results of every analysis.

III. RESULTS

A. Average pretest score

The score on each pre-test problem was calculated as the ratio of the number of steps correctly identified and the total number of steps in the correct solution, resulting in a scale of 0 (incorrect) \rightarrow 1.0 (correct). Average pretest score was calculated as the average of the scores of all the problems attempted by a student. ANOVA analysis of the average pretest score from the two semesters combined showed no statistically significant difference between the control group (no alternate task after each problem) and the test group (with alternate task after each problem) [$F(1,473) = 0.670$, $p = 0.414$] (See Table I).

TABLE I. PRE-TEST SCORE: CONTROL VERSUS TEST GROUP

| | Average | N |
|---------|---------|-----|
| Control | 0.8984 | 261 |
| Test | 0.9093 | 213 |

Interestingly, when only fall 2009 data was considered, the control group scored significantly more than the test group [$F(1,219) = 4.49$, $p = 0.035$]. On the other hand, when only spring 2010 data was considered, the test group scored significantly more than the control group [$F(1,253) = 7.785$, $p = 0.006$] (See Table II).

TABLE II. PRE-TEST SCORE BY SEMESTER: CONTROL VERSUS TEST GROUP

| | | Average | N |
|-------------|---------|---------|-----|
| Fall 2009 | Control | 0.9153 | 121 |
| | Test | 0.8772 | 99 |
| Spring 2010 | Control | 0.8838 | 140 |
| | Test | 0.9373 | 114 |

So, when data from the two semesters were combined, significant and contradictory differences found in individual semesters were cancelled out.

In order to account for ceiling effect, students who had scored 100% on the pre-test were eliminated (116 students in the control group and 102 students in the test group). After this elimination, no statistically significant difference was found in the average pretest score between the control group and the test group [$F(1,255) = 0.207$, $p = 0.649$] (See Table III).

TABLE III. PRE-TEST SCORE AFTER ELIMINATING CEILING EFFECT: CONTROL VERSUS TEST GROUP

| | Average | N |
|---------|---------|-----|
| Control | 0.8171 | 145 |
| Test | 0.8260 | 111 |

There was no statistically significant difference between the control and test groups in fall 2009 [$F(1,126) = 1.329$, $p = 0.251$] or spring 2010 [$F(1, 128) = 2.115$, $p = 0.148$] (See Table IV).

TABLE IV. PRE-TEST SCORE BY SEMESTER AFTER ELIMINATING CEILING EFFECT: CONTROL VERSUS TEST GROUP

| | | Average | N |
|-------------|---------|---------|----|
| Fall 2009 | Control | 0.8373 | 63 |
| | Test | 0.81 | 64 |
| Spring 2010 | Control | 0.8016 | 82 |
| | Test | 0.8479 | 47 |

So, the statistically significant differences observed earlier between the control and test groups in individual semester data was due to the data being skewed by the students who had scored 100% on the pre-test – students who did not stand to learn from the software tutor. So, for all subsequent evaluations, only those students were considered who did not score 100% on the pre-test. For these students, the alternating task did not result in any statistically significant difference in the average test score between control and test groups.

B. Cognitive Learning

Analysis of cognitive learning applies only to the students who scored less than 100% on the pre-test since only these students were presented practice and post-test stages by the tutor. It was found that:

- During the adaptive practice stage, students in the test group solved more practice problems than those in the control group, but this difference was not statistically significant [$F(1,240) = 2.256$, $p = 0.134$] (See Table V).

TABLE V. PRACTICE PROBLEMS SOLVED: CONTROL VERSUS TEST GROUP

| | Average | N |
|---------|---------|-----|
| Control | 5.8921 | 139 |
| Test | 7.0784 | 102 |

- There was no statistically significant difference in the number of concepts learned between the control and test groups [$F(1,212) = 0.01$, $p = 0.921$] (See Table VI).

TABLE VI. CONCEPTS LEARNED: CONTROL VERSUS TEST GROUP

| | Average | N |
|---------|---------|-----|
| Control | 1.5968 | 124 |
| Test | 1.5843 | 89 |

So, in terms of cognitive learning due to tutoring – the number of concepts learned and the amount of practice needed to learn the concepts – the treatment did not result in any statistically significant difference between the control and test groups.

As per an earlier study [9], since problem-solving activity was alternated with the easier activity of answering three Likert-scale questions, the efficiency with which students solved pre-test problems should have increased with alternation than without. But, the time spent per problem on the pre-test was not significantly different between the control and test groups [$F(1,254) = 2.368$, $p = 0.125$] (See Table VII). Then again, more recent literature on task switching finds that subjects take longer to perform alternating tasks than massed tasks, because of alternation or mixing cost (e.g., [10,11]). In this study, the effect of such alternation cost was not found to be significant either.

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| | <i>Average (seconds)</i> | <i>N</i> |
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C. Affective Learning

After eliminating the students who had scored 100% on the pre-test:

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- There was no statistically significant difference in the post self-confidence of the control and test groups [$F(1,216) = 1.163$, $p = 0.282$] (See Table IX).

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| | <i>Average</i> | <i>N</i> |
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- There was no statistically significant difference in the average feedback response of the control and test groups [$F(1,216) = 0.123$, $p = 0.726$] (See Table X).

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So, in terms of *affective learning due to tutoring* - self-confidence and feedback about the tutor – the treatment did not result in any statistically significant difference between the control and test groups.

Earlier studies had shown that self-confidence of the students increased significantly from using the tutors (e.g., [12]). There was no significant difference in the improvement in the self-confidence between the control and test groups [$F(1,215) = 0.271$, $p = 0.603$] (See Table XI).

TABLE XI. PRE-POST CHANGE IN SELF-CONFIDENCE: CONTROL VERSUS TEST GROUP

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IV. DISCUSSION

Introduction of the alternate task did not result in any statistically significant difference in the scores of the control and test groups on the pre-test. It did not promote better cognitive learning or affective learning during tutoring. There could be a number of reasons for the negative results:

- Though alternation was found to be on the average more efficient than massing, differences were found among subjects in whether they could benefit from alternation, and these differences were ascribed to the subjects' ability to persevere, called perseveration [14]. So, in the current study, some students may have benefited from alternation whereas others may have been hindered by it, the cumulative effect being to cancel each other out.
- An earlier study had concluded that the effects of alternation are proportional to the dissimilarity of the alternating tasks [15]. The activity of the alternate task, i.e., answering Likert-scale questions was very dissimilar from the problem-solving activity of the main task. However, since the three Likert-scale questions were about the problem that the student had just solved, the mental task set of the alternate task may not have been dissimilar enough to accrue the benefits of alternation. Other studies suggest that the effects of alternation vary according to the types of tasks involved, e.g., mental versus motor (e.g., [16]). Both problem-solving and answering Likert-scale questions are mental tasks, which may be another reason why no benefits were found that could be ascribed to alternation.
- Earlier studies have shown that massing is more efficient than alternating (e.g., [17]) for complex tasks. The main task in this study was solving problems, which is a complex task involving multiple steps. So, as per the earlier study, alternating (test condition) should have been found to be less efficient than massing (control condition). But, no significant difference in the time spent per problem was found between the control and test groups.

- According to the research on task switching, alternation results in increased error rates as compared to massing because of switch costs (e.g., [6]). This might help explain why alternation did not produce better learning or test results in the current study. Then again, the current study contradicts task switching studies in that alternation did not impair learning or test results in any significant manner in spite of switch costs. This is all the more significant considering that the task in this study – problem-solving, is considerably more complicated than the simple stimulus-response tasks used in most task switching studies.

The current study differs from earlier studies on alternation in the following respects: it considered the task of solving problems, which consists of multiple steps, and is hence more complex than single-step stimulus-response tasks considered earlier; both the primary task and the alternation task were conducted entirely online; and the primary task was in the domain of computer programming. It is possible that under these conditions, the positive benefits of alternation cancel out the negative costs associated with task-switching. This hypothesis bears further experimentation.

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Work in Progress: Using Writing-to-Learn Methods to Improve Conceptual Knowledge in Engineering Statics

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Abstract—Writing assignments were implemented in a statics course to improve conceptual understanding. The assignments required students to explain in words their solution process for specific homework problems. Quantitative analyses of Statics Concept Inventory (SCI) and course exams data showed significant improvements on the SCI in the experimental section; however, scores on course exams did not significantly improve. Qualitative data indicate that students who were dissatisfied with the process problems cite unfair grading, rather than the work, as cause, highlighting a key area for enhanced collaboration between engineering and writing faculty. These results provide empirical validation for the use of writing-to-learn assignments and validated discipline-based assessment tools such as concept inventories as a means to engage content faculty in writing assignments that support conceptual learning.

Keywords- *statics; conceptual understanding; conceptual knowledge; procedural knowledge; writing-to-learn; writing*

I. INTRODUCTION

In addition to being an important foundational course for many engineering disciplines, statics is also a troublesome course for many students. The difficulty that students face can be seen in low grades and/or high withdrawal rates, but it may also be reflected through poor conceptual understanding, even among those who successfully pass the class [1].

In Spring 2011, the authors conducted a pilot study to assess the viability and utility of using short writing assignments as a way of increasing the conceptual understanding among students in statics [2]. The pilot study was in the form of a pseudo-experimental design involving a statics course taught at a large public university with a total course enrollment of approximately 300 students. The writing assignments, referred to as process problems, asked students in the experimental sections to explain in words the process that they used to solve a particular homework problem. The process problems were assigned and collected once weekly and graded by graduate teaching assistants; all other course assignments and assessments were the same in both sections.

Quantitative data in the form of student grades and pre/post scores on the Statics Concept Inventory [3] showed significant gains in conceptual understanding (i.e., scores on the SCI) by

students in the experimental section; however, procedural knowledge (i.e., scores on tests) did not significantly improve [2]. This paper focuses on qualitative data in the form of student interviews to explain how the written process problems may have impacted student conceptual understanding and/or performance in the course.

II. BACKGROUND LITERATURE

In the cognitive view of learning, the goal of formal education is viewed as a process by which novices in a field develop knowledge and transition toward more expert thinking. Experts, especially adaptive experts, are believed to possess high levels of both quality conceptual knowledge and quality procedural knowledge [4-6]. According to Rittle-Johnson and Alibali [7], conceptual knowledge is “explicit or implicit understanding of the principles that govern a domain and of the interrelations between pieces of knowledge in a domain”, whereas procedural knowledge can be thought of as “action sequences for solving problems” (p.175).

In the mathematics education community, an ongoing debate dubbed the “math wars” [8] has not reached widespread consensus regarding the primacy and relative importance of conceptual and procedural knowledge for knowledge development in novices. However, some evidence suggests that the two types of knowledge may be interlocked, requiring that they be developed simultaneously [9]. This may have important implications especially in statics, where students and instructors often tend to focus more on procedure and may fail to develop appropriate conceptual knowledge [1, 10].

We believe that writing-to-learn assignments may provide effective ways of developing conceptual knowledge in mechanics courses like statics. By having students explain their mathematical solutions, students can make links between problem-solving procedures and course concepts. Writing may also be used to promote reflection, which can result in metacognitive thinking and adaptive problem solving.

III. QUALITATIVE DATA COLLECTION METHOD

Interview participants were purposively selected from survey responses based on their course enrollment history and their current course section. Surveys were sent to all of the nearly 300 students in Statics; 136 responded, 41 agreed to be interviewed, and 13 were selected. Interviews were conducted toward the end of the semester with students in both the experimental and control sections by Venters and another Ph.D. student outside of the research team. The interview protocol was 30-45 minutes long, was semi-structured, and featured open-ended questions related to the students' experiences, study habits, and perceptions of the course and perceptions of the process problems. Finally, all interviews contained a think-aloud portion where students were given a statics problem and asked to share their thoughts as they viewed and attempted to complete the problem; follow-up questions meant to probe their explanations of their thought processes were asked after the think-aloud was complete.

IV. QUALITATIVE DATA RESULTS AND DISCUSSION

Analysis of the interview transcripts is currently ongoing, with coding labels developed through a grounded theory process in which themes are grouped and then related to theoretical concepts of conceptual and procedural knowledge.

General opinions of the process problems were mixed; some students in experimental sections did not feel that the problems were useful to them, though they did not feel that they hurt their understanding either. Rather, many students felt that their grades were negatively impacted by the problems and disliked them for that reason along with issues of time. Even among those that expressed dissatisfaction with the problems, many reported that they felt other students would benefit from doing such problems.

Students who did like the problems and felt that they had a positive impact on their understanding were students who tended to approach the course from a more conceptual view; such students mentioned that they often read for understanding and actively tried to connect homework problems to underlying theory. In some cases, students who had unsuccessfully completed the course previously discussed their change in studying habits from that of simply solving problems to learning the material on a deeper level. Further work needs to be done to determine the extent to which the process problems may have assisted in that change.

V. CONCLUSIONS

In conjunction, the qualitative and quantitative data help to explain why and how the process problems may have supported conceptual knowledge development among students in the experimental sections. While the exams given by the instructor consisted of traditional workout problems that emphasized procedural knowledge, the students who succeeded in the class and embraced the process problems demonstrated

more metacognitive awareness of problem-solving and the importance of understanding statics conceptually. This finding raises questions for future work about the interplay between conceptual and procedural knowledge.

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Using practice theory to investigate professional engineers' workplace learning

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Abstract—This paper reports on the first phase of an Australian inter-disciplinary partnership study concerned with professional learning of experienced engineers. It is a theoretically motivated, qualitative paper that aims to produce detailed descriptions of professional learning that arise within professional engineering work. The paper uses *practice theory* to conceptualise professional learning. By using 'practices' as the units of analysis, professional learning is understood as an integral part of everyday work practices that is embodied, relational and material rather than an individual attribute. The paper concludes by suggesting that practice theory may provide organisations with an alternative perspective of workplace learning, inviting them to reconsider how professional learning is acknowledged, rewarded and fostered in organisations.

Keywords - *continuing professional development; professional learning; practice theory; qualitative research*

I. INTRODUCTION

Engineers, like all professionals, face an ever-changing work environment that requires them also to continually respond to change. Such change arises from new knowledge, new ways of doing things, new organisations and organisational cultures and other imperatives from the social, economic and political environments in which they operate. It is not only new professionals who face these types of change, but also those well established in their careers. In most organisations Continuing Professional Development (CPD), or professional learning, is charged with the task of keeping professionals abreast of change. However, we contend that conventional approaches to looking at professional learning through skills and knowledge and the development of competencies are inadequate, and that new ways of conceptualizing research on professional learning are needed.

Current understandings of professional learning are beset by difficulties. Over recent decades, at the structural level, professional bodies have been influential in establishing Continuing Professional Development (CPD) programs to encourage the continuing professional learning of engineers. These CPD programs have turned from acts engaged in by professionals for their own satisfaction to a systematised and codified set of activities that have consequences for continued registration and, in many cases, the right to practise their

profession. Responsibility for engineers' professional development has been gradually subject to more rigorous surveillance, and indeed, self-surveillance. Furthermore, because it is easier to measure attendance than almost anything else, CPD is often synonymous with participation in courses or seminars. This is counterproductive as it moves from focusing on the outcome of CPD (development) to the input (the activity). Further still, 'career episodes' used to demonstrate competence to professional associations are reliant on skills in portraying what they do in written forms, that may have little to do with competence in engineers' substantive roles [1].

Our research partner, a large Australian engineering company, echoes our dissatisfaction but acknowledges an interdependent relationship between professionals, employers and professional associations. It too is interested in generating dynamic accounts of experienced engineers' learning that will have consequences for how learning is acknowledged and rewarded, and ultimately how work might be organised in ways that foster professional learning.

A further, more philosophical, difficulty with contemporary understandings of professional learning is that it is seen invariably as something that *individuals* do. When they learn they *gain* knowledge as a 'thing' that they thereby possess to *apply* as needed at some later date. The metaphors 'acquiring' and 'transferring' learning are used without realising that they are metaphors and not descriptions of concrete reality [2]. These metaphors disconnect learning from the actual practices and contexts in which learning is developed and used, and they ignore the social dimension of learning. Our assumption is that these traditional metaphors need to be replaced with more generative ones that represent the social and situated nature of professional learning and can lead to fresh understandings of CPD. The main metaphors invoked by newer learning theories are *participation*, *construction* and *becoming* [1].

Heeding such dissatisfactions, as well as noting alternative theorisations and what they can illuminate, we have adopted practice theory. A practice approach embraces ideas of *participation* (in practices), *construction* (of knowledges) and *becoming* (professionals) and is not reliant upon metaphors of acquisition and transfer. Focusing on participation in practices also allows us to see learning as a social act in context. An understanding of practice theory in professional learning shifts

the focus from the acquisition and transfer of predetermined skills or knowledges to the *generation* or construction of them by individuals as they engage with others in the ‘bundles of practices’ [3] that make up their work. Finally, the idea of *becoming* professional recognises the enduring nature of learning and professional work. These theorisations of learning sit well with the practice approach we advocate for here.

This paper begins by discussing the practice approach adopted. It then frames an investigation of engineering practices that aims to elicit learning through notions of practice. Next it identifies the challenges of the practice approach and how it can lead to a more satisfying view of CPD that better reflects professional learning. Taking into account our initial qualitative data, it presents some initial conceptualizations of engineering practice and concludes with some remarks about the potential of the study for fruitful future research.

We are not the first to look at engineering and related professions with a practice lens. Bjørkeng, Clegg and Pitsis undertook a longitudinal study of a leadership team to provide an account of the unfolding of a practice [4]. Gherardi and Nicolini provide an account of the circulation of safety knowledges within an organisation in the building industry - developing comprehensive conceptualizations of practice in the process [5]. Suchman employs a practice-orientated approach to investigate bridge building in order to contribute to understandings of organisational knowledge and acting [6]. Each of these studies provides a helpful example of the utility of practice theorizations in empirical studies. However, while they contribute to management and organisational learning, the research reported here is specifically focused on learning and in particular the continual professional learning of experienced engineers. In this way this we position the study alongside empirical studies in health professions, community services and other fields, that have taken up theorizations of practice, learning and change [7].

II. BACKGROUND

The reported research comes from a partnership project that is investigating professional learning in one of Australia’s largest engineering organisations. The interdisciplinary team consists of researchers from two faculties at the University of Technology, Sydney — Arts and Social Sciences, and Engineering and Information Technology. The Organisational Development Program Manager from the partnering organisation is also a member of the research team.

The organisation’s remit includes work in the areas of social infrastructure and building, civil engineering, water and environment, rail, aviation, tunneling, mining, communication and energy. It employs engineers with a variety of specialties and various years of experience. It invests considerable time and money in comprehensive graduate programs for new engineers. For its experienced engineers, professional learning is recognised and rewarded against a capability framework via performance management processes.

A. Aim

The broad aim of this research is to explore continuing professional learning of experienced engineers. A more particular aim is to identify practices that underpin quality continuing professional learning by experienced engineers within the context of their typical working life.

B. Rationale

This research addresses an important problem for engineering organisations: understanding how and what experienced professional engineers learn. Our focus on experienced engineers recognises that while there are many graduate programs in place specifically for new professionals, there is a dearth of research focused on the more experienced professional. The traditional approach to professional education leaves both employers of engineers and accrediting bodies (e.g. Engineers Australia) with several different, but related, challenges to recognising and developing the capability of engineers. First, for employers like our partner organisation, there is the problem of knowing what their employees know and can do, and how they can recognise and deploy expertise effectively. Second, there is the problem of providing effective training and development opportunities for staff. This includes the challenge for employers of knowing when to provide a training response to a particular issue, and when (and how) to foster learning through work allocation or other indirect processes. Added to this, more empirical evidence is needed to indicate what might be the scope and quality of everyday professional learning, and what mechanisms can be established to account for it.

C. Methodology

The research is a theoretically motivated, qualitative study that focuses on producing detailed descriptions of various types of learning, for both groups and individuals that arise within professional engineering work. The research involves the development of a richly informative account of professional learning that will be sufficiently detailed to support in-depth analysis and theory development.

In order to distil focus for this ‘rich account’, the project comprises several phases of data collection. The first, and the one we report on here, is the *identification* phase where we analysed a range of documents, held focus groups with experienced engineers and followed up with by semi-structured interviews with focus group participants. Our purpose was to create an initial list of practices that constitute the work of experienced engineers. In the second phase we are seeking *elaboration* on the identified practices, as well as identifying any further practices that arise. To do this we are carrying out unstructured observations, as well as a second round of focus groups and semi-structured interviews. In the third phase we intend to *validate* our findings by having our descriptions of practices reviewed by members of the organisation and by looking for examples of identified practice in other sites. Again, we intend remaining open to the identification of further practices (which we will then subject to elaboration, validation and so on). In this way the methodology is both iterative and generative.

III. THEORIZATIONS OF PRACTICE

Learning in professional practice involves, *inter alia*, interactions with a variety of others in a wide range of contexts. Tangible issues commonly drive such interactions. Much of the learning arises from the exigencies of work and the challenges encountered there. What holds together all the sites, purposes and relationships is that they cohere around the notion of practice. It is what professionals practise that we take as the centrepiece of learning challenges: they undertake practice, they extend their practice, and they take up new practices. We also believe that they learn through their practice – and if this is the case, then already the *participation* metaphor appears to be more aligned to professional learning than *acquisition*.

Following what Schatzki and others term the ‘practice turn’ in contemporary theory [3], there are a variety of approaches on which to draw to enable a focus on practice to be conceptualised. From ideas commonly found in the organisational literature, Gheradi [8, 9] identified several streams of research in what she terms ‘practice-based studies’: cultural and aesthetic approaches, situated learning theory, activity theory, actor network theory, and workplace studies. These streams of research have in common a focus on practice as located, mediated and relational. Many of these theories move to a quite different kind of configuration from the conventional educator’s focus on the competences of individuals and the knowledge and skills they can acquire. Such theories allow for, or indeed insist on, a variety of relational features to be considered together. Practice is an integrating idea than links thinking with doing and people with contexts. It is useful to consider five interrelated elements of practice that may be seen across various bodies of work. First, that practice is more than the application of knowledge or product of learning but a complex process of knowing-in-practice [10]; Second, that practices are socio-material; Third, that they are embodied and relational; Fourth, that practices exist evolve in historical and social contexts; and, fifth, that practices are emergent [7].

Schatzki’s work is useful because of the idea that “bodies and activities are ‘constituted’ within practices” [11]. Practices provide units of analysis that bring together the practitioner, the material objects with which they work, their relations with others and the context in which they operate. A practice view seeks to avoid separating these as variables that might be separately manipulated apart from the whole practice. This is not to say that particular features of practices might not be foregrounded, but that they are never treated independently.

A second way Schatzki’s work is helpful is that there is an emphasis on “know-how, skills, tacit understanding, and dispositions” [11]. The focus is on what is directly connected to the ‘doings’ of a practice and the ‘sayings’ that are part of the practice. Here practice is inherently dialogical and activity-focused. The organisation of practices is social, being expressed in the connections of doings and sayings that compose them, as opposed to an individual’s doings and sayings. Doings are what people do with others and with

things, and these interact with what people say. Both doings and sayings are done with people’s bodies. However, while sayings do consist of speech, they are more than this. Sayings are differentiated from doings of practice in that a saying conveys meaning and has a semantic function whereas doings may not [12]. In this sense sayings are anything that is communicative.

Schatzki also emphasises action and structure. He defines practices as “structured spatio-temporal manifolds of action ... that have two basic components: action and structure” [13]. *Structural* elements include know-how concerning the actions or the ‘how to’ of practice; rules that specify guidance or instructions; teleo-affective structuring that explains the purposes or emotions that cause people to act towards possible ends and goals; and general understandings that may be relevant, for example, the nature of a particular kind of work. Practice *actions* are performances of people that are embedded with these structural elements. Practices thus entwine people, technologies, spaces, time and artifacts. Through these embedded structures and material arrangements, practices frame future action possibilities for both individuals and the organisation.

In short, a profession (engineering in this case) consists of a bundle of interrelated practices and material arrangements. While some practices may be dispersed (in that they can be seen in other professions) there are many that are germane to the profession. Each practice consists of activities, material ‘things’ and bodies and is purpose-focused. Within the profession there is a shared understanding of the practice. These practices are prefigured in that they have a history in the profession, yet each instantiation keeps alive the possibility for reconfiguration (i.e. change).

With this in mind a final, and perhaps more pragmatic, reason for employing a practice approach is that it offers our partner organisation a new way to think about professional learning. Aspects of practice theory may be represented to partners more straightforwardly than other conceptualisations as they can readily accept that work is made up of ‘bundles of practices’ and that it is from engaging with practices that both a need for learning as well as learning itself emerges.

IV. PRELIMINARY FINDINGS

The partner organisation’s remit of activities (its macro activities) such as project design, project and risk management, people management, design and operations, shape the activities of individual engineers (their micro activities). For instance engineers spoke about how they design/plan, diarise important events and information, seek out new information on the Internet or in documents from a range of sources, and identify important contacts for their networks – all with the purpose of carrying out project design, project and risk management, people management, design and operations.

However, it is in between these macro and micro activities, of organisation and individuals, where engineering *practices*

are revealed. These are neither organisational nor individual activities. Rather, they are *collective* practices that typically comprise an assemblage of people. Some examples of practices identified in the identification phase of the research include organisation include *toolbox talks*, *site walks* (sometimes called *pit tours*), and *design/end of month reviews*. We expand on the last two practices below.

A. Site walks

A common practice among the engineers we spoke with was the site walk (or pit tour in one instance). For example, professional engineers may undertake a site walk as part of the tender preparation phase of a project:

...most engineering jobs you can't price, unless you've seen the site. That's the most important thing. The plans only tell half the story to what's actually out there. Because the plans tell you what it's going to look like when it's finished. They don't tell you what it looks like when it starts... (Tim - Estimator)

For site engineers, the site walk is the routine way to start the day. The site engineer looks for anything that has changed overnight, e.g. excavation collapse/erosion, vandalism, protective covers dislodged by wind, rainwater damage or ponding, because the results of any of these may have to be rectified or 'made good' before any progress can be made:

We usually go for a site walk prior to the men[sic] starting the day. Go around, look for issues, especially with the weather... (Denis - Site Engineer)

A site walk might be undertaken to maintain communication with a client or as part of a project milestone meeting:

So the client and I, after the meeting, had a one-on-one walk through the job and we both expressed some concerns that we have with each others' team and made promises to each other to fix things... Then I went and walked the job again with the project manager and shared a little bit of the conversation that I'd had with my owner rep and the action items that I believed that came out of this meeting that should be addressed. (Gordon - Senior Division Manager)

B. Design/End of month Review

Another shared practice among the engineers we spoke with included is what they referred to as 'reviews'. These can take the form of 'end of month' reviews and 'design reviews'. Basically, the later are meetings between the major stakeholders. As one engineer told us:

There's quite a bit of governance work associated with a hundred million dollar job. You have to look - you have to approve payments. You have to review quality. You have to - you just got to keep up with it and since you're only down there - or I'm only down there twice a month - it's also just a very good time to make sure my client's happy. (Gordon)

Engineers with different job classifications attend design reviews at different stages of projects. For example an estimator attends the pre-construction review meetings, a project engineer may only attend review meetings that occur

during the construction stage of a project, and a site engineer may not attend a review meeting at all but will typically provide information for the project manager to take to the meeting.

So it goes through the team. So the services manager will do a review, the site manager, the engineer and then the project manager will do a final one. So we'll each sit down and do our own individual thing, get together and bounce ideas off each other, if need be - if we spot an issue. (Tim)

A related practice within this organisation was what we call the *pre-review* review (i.e. the meeting before the meeting):

So I went and met with my folks for about an hour and a half, said hello to all of them, how's things going?... Anything you want me to bring up in this meeting that I need to know about, or - probably the most important question I was asking them, is there anything that the client's going to bring up at this meeting that I don't know about, because if there is, tell me right now so I can prepare for that discussion (Gordon - Senior Division Manager)

V. DISCUSSION

A common feature of these practices is that they are strongly linked to the productive work of the engineers and almost always involve purposeful communication with a variety of others. Moreover, these others represent a range of roles within the project (e.g., clients, sub-contractors, designers, site managers, etc.). Each member brings to the instance of the collective practice particular expertise and knowledge. The practice's success is reliant on the professional diversity of group members, and the co-production of new knowledges is only possible because of each member's unique contribution.

Each of these practices shares some important features that link them to practice theories. First, all feature the *embodied* action of those involved, by this we mean that these specific engineering practices encapsulate what professional experienced engineers routinely do. For instance the 'end of month' and 'toolbox talks' are routinised organisational practices that occur in specific times and locations. Those involved bring knowledges, dispositions, working histories and their bodies. Each instantiation of the toolbox talk is shaped by the collective embodiment of its participants. The professional identities of participants is confirmed and reaffirmed within the practice, as does participants' sense of agency [14].

The practices identified here are *mediated by materiality*. Indeed, practice theory tells us that *all* human activity is undertaken in conjunction with things, and for engineers this could mean things like tools, raw materials, specifications, drawings, blackberries, mobiles, pens and diaries (to name just a few). However, less tangible things also mediate practices, for example, regulations, organisational procedures and individual and collective cultures and dispositions. All of these influence the practice in particular ways. While engineers seek to shape materials, materials hold potential to shape practice. For instance site walk participants react to a sloping soil surface in ways laypeople would not. For the layperson it

might appear as a simple pile of dirt, for the professional it can mean risk and/or the need for further action.

Such professional practices are also understood as *situated* practices, and there are many ways in which a practice is situated. It is situated in particular settings, in time, in language and in the dynamics of interactions [15]. For Kemmis, practice “has aspects that are ‘extra-individual’ in the sense that the actions and interactions that make up the practice are always shaped by mediating conditions that structure how it unfolds” [14]. These may include cultures, discourses, social and political structures, and the material conditions in which a practice is situated.

These practices are also *relational*. They occur in relation with others who practise, and in relation to the unique features a particular practitioner brings to a situation. Practice is thus embedded in sets of dynamic social interactions, connections, arrangements and relationships. Schatzki suggests that, “[o]ver any period of time, human practices link and form gigantic nets, just as arrangements are connected into immense material structure and practices and arrangements relate in myriad ways” [16].

Finally, a last commonality of these practices are that they are *emergent*. Practices exist, they evolve over time and over contexts; they change in the light of circumstances. New challenges require new ways of practising. Practices emerge in unanticipated and unpredictable ways, and in this the practitioners’ knowledge and skills are open to continual construction (and reconstruction) [17].

Learning and practice

The practices described above (along with others not described) are related to each other in the ‘bundle of practices and material arrangements’ that collectively constitute the work of professional engineers. People, artifacts, social groups and networks develop characteristics through relationships with other subjects, social groups or networks such that they are formed and structured socially [14, 18].

Practices change and evolve over time and learning is implicated in this complex processes. What Schatzki [13] calls the “practice memory of an organisation” has a powerful influence in pre-configuring practices and in defining whether ‘learning’ *per se* is or is not a legitimate activity. Particular kinds of learning practices may or may not be sustained and perpetuated in any given organisational context. This raises the issue of learning-conducive work. There is good reason to think that some workplaces are far more generative of learning than others [19]. Some forms and contexts of work, even when the same qualifications are required of practitioners, are far more demanding and lead to considerably more learning than others. After all, as far as the organisation is concerned, why would it want or need to foster more learning than is needed for the purposes of production?

So what might this mean for employers and accrediting bodies that use traditional mechanisms that capture, acknowledge and ultimately reward CPD this are reliant on static notions of learning where skills and knowledge are

acquired, transferred and/or operationalized? Preliminary findings of this practice-focused account of professional learning demonstrate dynamic and situated practices being *constructed*. Through *participation* in practices, new knowledges are being constructed, and the engineers (while already professionals), are also *becoming* professional. Indeed, this preliminary account of practices suggests that practice is not only the site of learning but learning itself.

While learning itself may be a further practice that can be examined, it might not present itself as such in many situations. It is eclipsed or occluded by practices that are of greater importance in professional work, namely, the performance of work to satisfy employers, clients and ones peers. When ‘learning’ is required, most professionals can readily construct a learning discourse, but this can tend to privilege a restricted range of activities and ways of thinking about work [20].

Yet learning is integral to the practices described above. For example, consider Tim’s comment of ‘*bouncing ideas of each other*’. It is reasonable to assume that he, and others, developed new understandings as a result of this practice. Likewise, Gordon’s comment about finding out any potential issues in the pre-review in order to prepare for the review can be construed as learning.

However, learning is not necessarily how practitioners conceptualise what they do when they practise. They see themselves as tackling a problem or meeting a challenge or exploring an issue, without using the language of learning. In one of our previous studies of workplace learning, the lack of an explicit learning discourse alongside what we identified as multiple acts of learning was notable in several of the work groups we studied [21].

Learning therefore may not be seen as a practice that exists separate from other practices. For many purposes it might not be useful to single it out for attention. Tensions arise between naming and codifying ‘learning’ that may be of value to individuals for professional registration purposes, and acknowledging learning as an integral part of work and thus a normal everyday activity that would be distorted by formalization [22]. The more integral learning is to the practice of work, the more problematic it is to treat it independently of work for official recognition.

VI. CLOSING REMARKS

We conclude this paper by saying that it appears that significant continuing professional development (i.e. professional learning) results from engaging in the collective practices that constitute professional work. We suspect that the knowledges/skills co-produced within these practices are also reflected in the micro and macro activities: the professional development of individual engineers and the development of the organisation.

In regard to the approach we have taken, there is more to be said about the benefits, issues and difficulties of interdisciplinary research. However, we save this discussion for another paper.

This paper argued for a practice approach to investigating professional learning of experienced engineers. It framed an investigation of experienced engineers' work within notions of practice [3]. Through presenting qualitative data and conceptualizations of engineering practice the paper points to the challenges and opportunities that this approach could lead to in regard to alternate understandings of CPD. Further research is needed to investigate the organisations' and accrediting bodies' capacity to acknowledge and reward professional learning in light of the practices we have identified so far. However, we maintain that the practice approach offers a fruitful lens for such research.

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Work in Progress: In their own words - how “changemakers” talk about change

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Abstract – We present preliminary work on “change knowledge” through a study investigating what exemplar “changemakers” understand about the process of undergraduate STEM education transformation.

Keywords – transforming STEM education; change knowledge; change agents; radically transparent research

I. INTRODUCTION

This work in progress underscores a collective view that undergraduate engineering education in the United States is a complex system in need of transformation in order to meet the rapidly changing realities of our global existence [1-3]. Prior attempts to change undergraduate STEM education have had only temporary local impact [4], a low success rate but comparable to change attempts in higher education as a whole [5-6].

Fullan, Cuttress, and Kilcher [7] claim this may due to a lack of “change knowledge,” a missing ingredient in understanding why good ideas or policies fail to get implemented or that are successful in one situation but not in another. Here, change knowledge refers to a person’s assumptions and values about the system in which they work, such as their views about the nature of engineering and the aims and process of engineering education, and hypotheses on how to work within that system to avoid barriers and ultimately enable a desired transformation. If a person applies the change knowledge they have, we call them a “changemaker”. The concept of change knowledge (1) is situated in engineering education systems research [8], (2) moves the lens from investigating the artifact being changed to the human agent that initiates a change, (3) parallels the concept of “pedagogical content knowledge” [9] because it refers to the tacit dimensions of contextualized knowledge that support effective practice, and (4) supports theories of transformative learning [10-11] that are characteristic of biographies of engineering education change agents [12-13].

Research also indicates that traditional dissemination approaches such as peer-reviewed and archival publications are not effective mechanisms for transforming educational practice [14-15]. Some argue that these focus on the “telling” and not the “doing”, making it difficult to develop a rich understanding of

research that may be transferred to other contexts [16]. In this paper, we share preliminary findings from a study that asks exemplar “changemakers” to talk about their experiences of “doing” socially beneficial change in STEM education – their motivations and inspirations, assumptions about how transformational change occurs, and experiences as “changemakers”.

II. BACKGROUND & PROCEDURES

Eight “changemakers”, STEM change agents whose impact exceeded institutional, regional, and national boundaries were interviewed. Subjects were selected through a combination of convenience and snowball sampling for variety in terms of context (academia, government, and industry) and change goals (policy, curriculum, instructional and assessment approaches). The semi-structured narrative-style interview protocol had four questions: (1) *what do you see as your greatest accomplishment?* (2) *what caused you to come to that point of view?* (3) *what caused or inspired you to pursue this [presumed change]?* and (4) *what do you think of this diagram* (a causal loop diagram as an artifact to elicit personal theories of change), *what causal links look relevant, and what do you think is missing?* Interviews lasted 45 to 90 minutes and were transcribed.

Analysis is following an inductive thematic process where patterns and themes of analysis are emerging out of the data rather than imposed prior to data collection [17]. We are using the constant comparison technique where inductive category coding is combined with simultaneously comparing observations across cases [18]. Sensitizing concepts from existing theoretical frameworks are guiding collaborative perspective taking – moving back and forth between logical constructions and the actual data in a search for meaningful patterns.

III. PRELIMINARY FINDINGS: CHANGE KNOWLEDGE

The following examples illustrate aspects of change knowledge emerging from the data.

Changemakers have a comprehensive vision regarding the system they seek to change and specifically identify transforming the way people think, as compared to what people do, as critical for success. They have developed an awareness of the fears people associate with letting go of practices that have worked well in the past,

and are able to help overcome these fears by guiding them through a sensemaking process. By naming a new participant's existing practices in a way that links to the change vision, they shift the framing of the change initiative from "letting go of prior ways of thinking" into a trajectory that participants are already aligned with.

Changemakers describe their accomplishments with humility, citing the collaborative process of change over the leadership of an individual. Changemakers focus on relationship building over information dissemination. They talk about a "different kind of leadership" that focuses on facilitating ways to find a shared vision, being able to "see the way" and help others "see the way".

Changemakers aren't interested in fighting. They recognize they have limited time and resources, and don't want to spend those resources on places and people who will be unwilling to change. They develop an ability to assess the opportunity cost of a situation and walk away if it's too high, and try to find opportunities within the existing infrastructure.

Changemakers appear to be strongly motivated by personal, often emotional, life experiences that anchor their efforts for socially beneficial change. For example, Mr. Am, frustrated by the tragedies of cancer patients, promoted the idea of sustainable chemistry to minimize the use and generation of hazardous substances; Mr. S, who described his childhood of doing hands-on jobs with real instruments, shared his experiences with how he prepares holistic and self-directed learners.

IV. FUTURE WORK

Early findings suggest dimensions of change knowledge that speak to motivations, identity formation, and assumptions about educational transformation as involving systems thinking and attending to the human dimensions of change as a social and developmental process. We are still analyzing the data and our experiences have inspired the pilot of a novel approach to change, "radically transparent research"[19], a notion inspired by the real-time transparency practices of open source communities, transformative action research [20], and ways to integrate educational research and practice. It involves inviting the broader community to observe and contribute to the process of discourse analysis and collaborative sensemaking [21], and has potential as its own change initiative, aimed at revealing, challenging, and transforming perspectives on educational change.

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Feedback Effects: Comparing the Change Resulting from Peer and TA Feedback to Student Solutions of Model-Eliciting Activities

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Abstract—Since 2002, students in a first-year engineering course at Purdue University have participated in several Model-Eliciting Activities (MEAs). MEAs are realistic, open-ended, client-driven engineering problems designed to foster students' mathematical modeling abilities. The primary artifact produced by each team is a memo to the client describing a procedure for solving the engineering problem. Since 2007, three cycles of feedback and revision have been used in the course, with students receiving reviews from peers and teaching assistants (TAs) throughout the process. Prior to 2009, students received the first round of feedback from TAs, and the second from peers. After 2009, this order was reversed, and students received the first round of feedback from peers, and the second from TAs. This paper investigates whether the amount of change differed based on whether reviews were provided by TAs or by peers.

Using the Levenshtein distance [1], the amount of change between consecutive drafts was calculated for four offerings of two different MEAs. Each MEA was offered with both the pre- and post-2009 sequencing, allowing a clear comparison of sequencing methods. Results from this study indicate that on the first revision, the amount of change resulting from TA reviews was indistinguishable from that resulting from peer reviews. However, on the second revision, the amount of change resulting from TA reviews was significantly different (greater) than the change resulting from peer reviews. Overall, the amount of change resulting from feedback was greater when peer reviews were provided first, and TA reviews were provided second. These results suggest that review expertise is more critical in the later stages of the process of solving an MEA.

I. LITERATURE REVIEW

The review process is widely employed in academic publishing, and to a lesser extent, in classrooms. It is most often utilized to improve the quality of written work, as in essays or papers. There are two primary dimensions typically used in analyzing review: a) changes produced in artifacts, and b) author and reviewer opinions of the process. In discussing both of these, two secondary dimensions of the review process are also important: c) the expertise of the reviewer (real or perceived), and d) the power relationship of the reviewer to the author.

This paper is concerned with the application of the review process in a first-year engineering course at Purdue University involving Model-Eliciting Activities (MEAs). MEAs are realistic, open-ended, client-driven engineering problems designed to foster students' mathematical modeling abilities. A detailed description of MEAs and their development can be found

in [2], [3], [4], [5], [6]. The primary artifact produced by each team is a memo to the client describing a procedure for solving the engineering problem. MEAs are based on the models and modeling perspective first developed by Lesh et al. [7], [8]. This paper builds on previous work regarding the review process as applied to MEAs. An overview of these works is shown in Table I.

Peer and TA reviews were conducted according to guidelines contained in the MEA rubric [9]. Reviewers provided qualitative review comments and assigned the memo draft quantitative scores along multiple dimensions. It is clear from prior research involving MEAs that in at least some cases these reviews lead to improvement. This was shown by Verleger and Diefes-Dux [10], who selected a single, "exemplary" case where changes in drafts of student work could be directly attributed to reviewer comments. The challenge is to understand the extent to which review comments yield meaningful change in the author's work, and the conditions necessary that lead to this type of change. As mentioned previously, one important dimension in understanding these conditions is to examine reactions to the review process from authors and reviewers. Diefes-Dux and Verleger [11] surveyed approximately 1200 students, and compiled the results of their experiences in providing reviews to other students, and in receiving feedback from reviews provided by both peers and TAs. Cardella et al. [12] interviewed TAs involved in providing reviews to students, and documented detailed reactions from two TAs regarding the experience of both providing reviews, and the effectiveness of the training designed to prepare them for this process.

The second important aspect in studying the review process is to examine the actual effectiveness of the reviews. A first step in this process would naturally be to examine the quantitative review marks received by students for each draft of their work. However, Verleger et al. [13] showed that while expert scores held relatively high correlation with other expert scores, TA review scores have a correlation of only 0.1 with expert scores. In light of this, it is not reasonable to expect peer review scores to have a high correlation with expert scores. In short, review scores from TAs or peers are not reliable measures of MEA solution quality.

An alternative approach is to examine different versions

Table I
OVERVIEW OF THE RESEARCH ON THE MEA REVIEW PROCESS.

| Ref. | Primary Author | Pub. Date | Semester of Study | MEA Studied | N* | Dimensions of Study† | Notes |
|------|----------------|-----------|-------------------|----------------|---------------|----------------------|--|
| [11] | Diefes-Dux | 2009 | Fall 2008 | PPC, JIT, STM | ~1200 I | b | Student reactions to providing and receiving reviews. |
| [12] | Cardella | 2009 | Fall 2008 | - | 2 TAs | b | TA reactions to providing reviews. |
| [15] | Cardella | 2011 | Fall 2008 | PPC, JIT, STM | ~1200 I | b, d | Multidimensional analysis of review process. |
| [10] | Verleger | 2008 | Fall 2007 | Nano-Roughness | 1 T | a, b | Examined single piece of work that changed in response to review comments. |
| [13] | Verleger | 2010 | Fall 2008 | PPC | 584 I = 147 T | a | Showed that rubric scores are unreliable measure of MEA memo quality. |
| [14] | Carnes | 2010 | Spr 2009 | JIT | 50 T | a | TA feedback leads to more substantive changes than peer feedback. |
| [16] | Bishop | 2011 | Fall 2008 | PPC, JIT, STM | | a,c | Used Levenshtein distance to examine change. |

* I = Individuals, T = Teams, TAs = Teaching Assistants.

† a = changes produced in artifacts, b = author and reviewer opinions, c = reviewer expertise, d = reviewer-author power relationship.

of actual artifacts produced throughout the review process. Carnes, Cardella, and Diefes-Dux [14] randomly sampled 50 drafts of student work from a single 2009 MEA, and examined the changes in detail. They observed that TA feedback appeared to be more detailed, and tended to lead to more substantive changes in subsequent drafts of student work. There is also an ongoing effort to take a multidimensional approach to study the review process artifacts produced by the review process [15].

Notwithstanding these efforts, there are several limitations of the studies previously mentioned. First, many of the studies had a relatively small sample size. Second, most of the studies cited looked only at a single MEA, and did not consider possible differences in effects between MEAs. Third, the order of feedback (Peer/TA or TA/Peer) is a confounding factor that has also not been accounted for.

It is important to acknowledge that the specific courses, semesters of study, and the artifacts used to derive the results presented in this work represent some of the very same artifacts used in other publications [10], [11], [12], [13], [14], [15], [16]. Despite this overlap, the analysis here takes a much broader look at these MEAs, includes information from a larger number of the different MEAs performed, and leads to novel insights not represented in previously published work. Thus, while the present work is novel, it is also essential that this paper be interpreted in the context of the previous work on MEAs at Purdue University as previously cited.

II. PURPOSE OF RESEARCH

The purpose of this research is to compare the impact of reviews from two different sources on student solutions of Model-Eliciting Activities (MEAs). This will be measured by computing the quantitative change between drafts using the Levenshtein distance. The major hypothesis tested in this research is that feedback from reviews provided by TAs will lead to more change than feedback from reviews provided by peers. This prediction is consistent with the idea that TAs have higher ability and are capable of producing higher quality reviews. It also presumes that higher quality reviews will lead to more change in student work. Further, this prediction is

Table II
NUMBER OF STUDENT TEAMS PARTICIPATING IN MEAS FALL 2007-2009

| Semester | MEA | R1 | R2 | $N_{S,M}$ | $N_{M,R}$ | N_M | N_R |
|-----------|-----|------|------|-----------|-----------|-------|---------|
| Spr 2008 | PPC | TA | Peer | 82 | 372 | | |
| Fall 2008 | PPC | TA | Peer | 290 | | 557 | 1067 |
| Spr 2009 | PPC | Peer | TA | 142 | 185 | (PPC) | (TA/Pr) |
| Fall 2009 | PPC | Peer | TA | 43 | | | |
| Fall 2007 | JIT | TA | Peer | 402 | 695 | | |
| Fall 2008 | JIT | TA | Peer | 293 | | 880 | 370 |
| Spr 2009 | JIT | Peer | TA | 140 | 185 | (JIT) | (Pr/TA) |
| Fall 2009 | JIT | Peer | TA | 45 | | | |

$N_{S,M}$ = number of teams, grouped by semester and MEA.

$N_{M,R}$ = number of teams grouped by MEA and review source.

N_M = number of teams grouped by MEA.

N_R = number of student teams grouped by review source.

consistent with the finding of Carnes, Cardella, and Diefes-Dux [14] that feedback from TAs leads to more substantive changes in student work. In light of this, it is important to examine whether the expected general trend (that TA reviews lead to more change than peer reviews) holds for different MEAs.

III. METHOD

A. Course & Participants

This study examined data collected between the Fall 2007 and Fall 2009 semesters in a required introductory course in problem-solving and computer tools at Purdue University. Several sections, each consisting of approximately 120 students, were taught each semester. A single section of the course consists of two paired 110-minute components: a lecture component taught by engineering faculty members, and a lab component led by graduate student TAs.

Enrollment for this course was approximately 200-1200 students per semester. As students worked cooperatively to produce each memo draft, the number of drafts for each revision of student work is equal to the number of student teams participating. The number of student teams for each semester included in this study is shown in Table II.

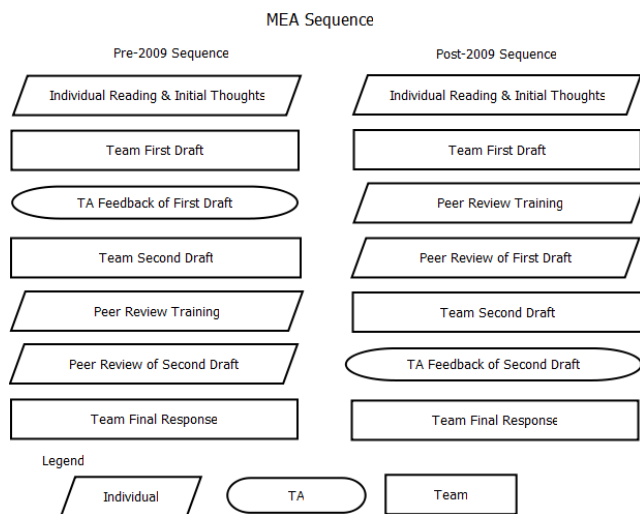


Figure 1. MEA Activity Sequence

B. MEA Order

Two MEAs were selected for examination in this study, the Purdue paper airplane challenge (PPC) MEA, and the just in time manufacturing (JIT) MEA. During the 2007-2009 semesters under consideration, three MEAs were administered each semester. When included, the PPC MEA was always appeared first in this sequence, and the JIT MEA always appeared second. Each MEA lasted 3-4 weeks.

C. Review Sequence

Since 2007, three cycles of feedback and revision have been used in the course, with students receiving feedback from peers and TAs throughout the process. Prior to 2009, students received the first round of feedback from TAs, and the second round of feedback from peers. After 2009, this order was reversed, and students received the first round of feedback from peers, and the second from TAs. The sequence of activities for these two periods as described is depicted graphically in Figure 1.

D. TA Training & TA Review Process

Before the beginning of each fall semester, graduate teaching assistants (TAs) attended a required 8-hour training, split across two days. TA training activities included instruction on MEA theory, solving an MEA, scoring seven MEAs, and scoring calibration activities. Calibration activities included a comparison of their own reviews to those provided by experts who had examined the same work, and group discussion of these differences. Emphasis was placed on appropriate use of the tools available to facilitate MEA scoring, including the MEA scoring rubric (discussed in [9]) and the instructor's MEA assessment and evaluation package.

Each semester, one TA was responsible for evaluating MEA solutions for 16-18 student teams for three separate MEAs. TAs used an abbreviated version of the MEA scoring rubric. The rubric is presented and discussed in full detail by Diefes-Dux, Zawojewski, and Hjalmarnson [9], but a brief description

is included here. The MEA scoring rubric consists of three dimensions: Mathematical Model, Re-usability/Modifiability, and Audience (Share-ability). Each dimension is scored independently, with each requiring both a quantitative score and qualitative comments regarding the team's procedure as applied to the particular dimension. Reviews typically required TAs to spend 30-60 minutes to evaluate each team draft. Reflections from two TAs of the training and review process are discussed by Cardella et al. [12].

E. Peer Review Training & Peer Review Process

Before reviewing their peers' work, students went through a review training process, as shown in Figure 1. This review training was similar in nature, but much shorter and less involved than the TA training. For this process, individual students used the Full MEA Rubric to evaluate a randomly selected prototypical student solution from a pool of sample solutions. Just as in the TA training, after students submitted their evaluation of the prototypical work, they were shown their review next to an expert review of the same memo. Students were asked to reflect on how they could improve their ability to review an MEA, and to apply these lessons in reviewing the work of their peers.

Students individually used the MEA rubric to evaluate the work of another student team. This review process was double-blind, so that neither reviewers nor the teams whose work was being reviewed knew the identity of the other. Since individuals evaluated team work, teams typically received multiple reviews of their solution from their peers, but only one when the TA acted as reviewer.

F. Measurement of Change

The measurement procedures used in this study are based on the principle of edit distance introduced by Levenshtein [1] and Damerau [17]. Edit distances thus defined can be used to compare the similarity of two strings or phrases with each other. These distances are used in a variety of applications ranging from DNA analysis to plagiarism detection. The Levenshtein distance is given by $D(X, Y)$, and computes the minimum number of substitutions, additions, and/or deletions required to transform string X into string Y . Basic units used in Levenshtein distance computations may be characters, letters, words, phrases, or any unit considered to be fundamental. We chose to use words as the fundamental unit in our Levenshtein distance calculations. Our procedure processed each draft of student work, first removing white space, then storing each word as a separate unit in a string of words that make up the draft. Like words, punctuation was treated as a separate unit.

Levenshtein distances are often normalized for a variety of reasons [18], [19]. In an attempt to represent the percent change between drafts of student work, we normalize the results by dividing the Levenshtein distance by the length of the first of the two drafts being compared. For example, in computing the normalized Levenshtein distance between drafts 2 and 3, we normalize this distance by the length of draft 2.

This is given by $C(X, Y) = D(X, Y)/|X|$, where X is draft 2, Y is draft 3, and $|\cdot|$ denotes the length of the draft.

G. Analysis Procedure

Preliminary analysis revealed that the assumptions of normality and constant error variance were not met by the raw values for the percent change response variables. For this reason, median values are reported for distance and change. Before continuing with the analysis, appropriate transformations were found using the Box-Cox method in SAS, and the recommended transformations were performed. The percent change from draft 1 to draft 3 required a log transformation, and the percent change between subsequent drafts (1-2 and 2-3) required a power transformation with an exponent of $\lambda = 0.32$. Since there were some zero-values for percent change between subsequent drafts (1-2 and 2-3), 1% was added to all scores for these drafts before transformation to make the transformation and subsequent analysis possible. This was not necessary for the draft 1-3 change. All statistical tests conducted were performed using the transformed response variables.

Drafts with a total number of words less than 30 were excluded from the analysis as these were clearly not valid products representing actual student work. No other criterion was used for data exclusion.

The data used in this analysis is summarized in Tables III, IV, and V. The analysis examined the [transformed] percent change between student drafts as a function of MEA and feedback source. The three response variables used were the [transformed] percent change from draft 1-2, shown in Table III; the [transformed] percent change from draft 2-3, shown in Table IV; and the [transformed] percent change from draft 1-3, shown in Table V. Note that original response variables in Tables III, IV, and V are given by $C(X, Y)$, $C(Y, Z)$, and $C(X, Z)$, respectively. These represent percent change between drafts. Similarly, transformed response variables are given by $C(X, Y)^{0.32}$, $C(Y, Z)^{0.32}$, and $\ln(C(X, Z))$. These represent transformations of the percent change between drafts.

IV. RESULTS

A. MANOVA Results

First, the data from all three response variables was analyzed using the multivariate analysis of variance (MANOVA) procedure in the SAS statistical package. The review order (TA/Peer or Peer/TA), and the MEA (PPC or JIT) each served as fixed two-level between-subjects factors. [Transformed] change between drafts served as a three-level within-subject response variable. This implies a 2x2 factorial design, with three response variables. A single MANOVA was used because it is more statistically powerful in testing our hypothesis, and because it allows us to compare all outputs on both MEAs considering review order with a single test.

The main hypothesis under study was to test whether the main effect of review source (TA or peer) had a significant effect on the change produced. The prediction was that it would, and this prediction was confirmed. Specifically (using

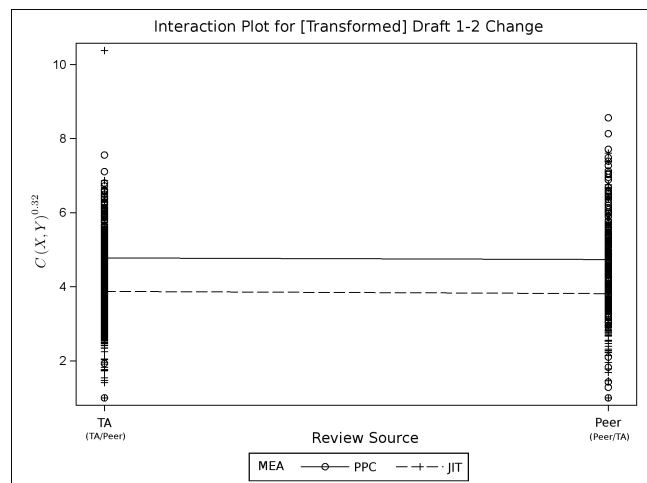


Figure 2. Interaction Plot for [Transformed] Draft1-2 Change

the Wilks lambda criteria), review source: $F(3, 1431) = 88.56$, $p < 0.0001$ was a significant main effect. Additionally, MEA was a significant main effect: $F(3, 1431) = 95.33$, $p < .0001$. The interaction effect MEA*review source was also significant: $F(3, 1431) = 7.94$, $p < 0.0001$, indicating that the effect of the review source depends on MEA. Interpretation of these effects is more clear in the context of the follow-up ANOVA tests.

Three separate 2x2 factorial ANOVAs were conducted to follow up on the initial findings from the MANOVA test. This was to determine the specific factors that account for the significance in the MANOVA. First, we examine the results of the change between drafts 1-2, then the results of the change between drafts 2-3, and finally, the overall change results between drafts 1-3. As before, review order (TA/Peer or Peer/TA), and the MEA (PPC or JIT) each served as fixed two-level between-subjects factors for all three ANOVAs. Type III Sum of Squares were used.

B. Draft 1-2 ANOVA Results

The data summarized in Table III was analyzed using a 2x2 factorial ANOVA procedure in the SAS statistical package. This ANOVA examines the results from the [transformed] change in the team-produced memo to reviews received between drafts 1 and 2. The interaction plot for this ANOVA is shown in Figure 2. The interaction effect of MEA*review source was not significant. Specifically, $F(1, 1433) = 0.85$, $p = 0.3572$. The main effect of MEA was significant. Specifically, $F(1, 1433) = 261.55$, $p < 0.0001$. The average [transformed] change between drafts 1-2 higher for the PPC MEA than for the JIT MEA. The main effect of review source was not significant. Specifically, $F(1, 1433) = 0.03$, $p = 0.8563$. This is contrary to the prediction that TA review feedback would lead to more change than peer review feedback, which was the primary focus of this analysis. Thus, for the change between drafts 1 and 2, there is no distinguishable difference in the amount of change resulting from TA and peer reviews. These results are supported by

Table III
CHANGE BETWEEN DRAFTS 1 AND 2 OF STUDENT TEAM MEA SOLUTIONS AS A FUNCTION OF MEA AND REVIEW SOURCE.

| Semester | MEA | R1 | R2 | N | median $D(X, Y)$ | median $C(X, Y)$ | mean $C(X, Y)^{0.32}$ | std. dev. $C(X, Y)^{0.32}$ |
|-----------------------|-----|------|------|-----|---------------------|---------------------|--------------------------|-------------------------------|
| Spr 2008 & Fall 2008 | PPC | TA | Peer | 372 | 688 | 133.1 | 4.78 | 0.789 |
| Spr 2009 & Fall 2009 | PPC | Peer | TA | 185 | 660 | 134.5 | 4.74 | 1.366 |
| Fall 2007 & Fall 2008 | JIT | TA | Peer | 695 | 296 | 66.9 | 3.87 | 0.798 |
| Spr 2009 & Fall 2009 | JIT | Peer | TA | 185 | 249 | 58.3 | 3.81 | 1.084 |

Table IV
CHANGE BETWEEN DRAFTS 2 AND 3 OF STUDENT TEAM MEA SOLUTIONS AS A FUNCTION OF MEA AND REVIEW SOURCE.

| Semester | MEA | R1 | R2 | N | median $D(Y, Z)$ | median $C(Y, Z)$ | mean $C(Y, Z)^{0.32}$ | std. dev. $C(Y, Z)^{0.32}$ |
|-----------------------|-----|------|------|-----|---------------------|---------------------|--------------------------|-------------------------------|
| Spr 2008 & Fall 2008 | PPC | TA | Peer | 372 | 493 | 50.3 | 3.45 | 0.825 |
| Spr 2009 & Fall 2009 | PPC | Peer | TA | 185 | 633 | 67.7 | 3.88 | 0.863 |
| Fall 2007 & Fall 2008 | JIT | TA | Peer | 695 | 173 | 29.8 | 3.02 | 0.726 |
| Spr 2009 & Fall 2009 | JIT | Peer | TA | 185 | 405 | 65.1 | 3.89 | 0.713 |

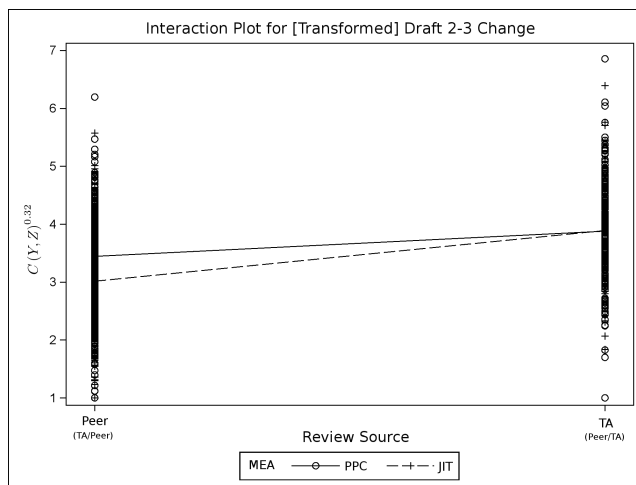


Figure 3. Interaction Plot for [Transformed] Draft 2-3 Change

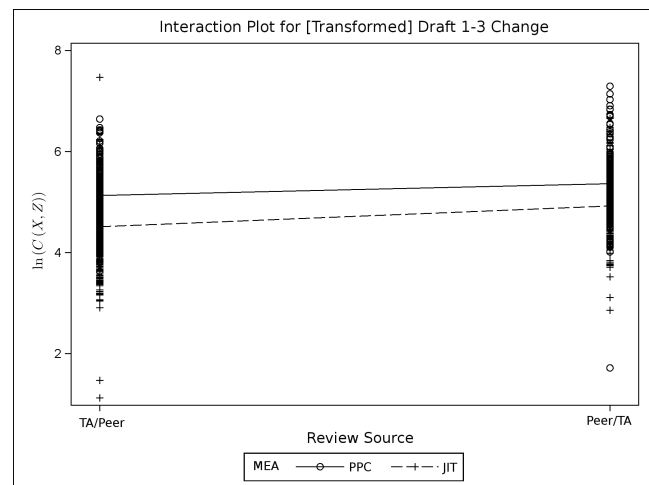


Figure 4. Interaction Plot for [Transformed] Draft 1-3 Change

a post-hoc means comparison using Tukey groupings that showed two distinguishable groups for the four LSMEANS, with group membership defined by MEA.

C. Draft 2-3 ANOVA Results

The data summarized in Table IV was analyzed using a 2x2 factorial ANOVA procedure in the SAS statistical package. This ANOVA examined the results from the [transformed] change in response to reviews received between drafts 2 and 3. The interaction plot for this ANOVA is shown in Figure 3. The interaction effect of MEA*review source was significant. Specifically, $F(1, 1433) = 22.19, p < 0.0001$. The main effect of MEA was also significant. Specifically, $F(1, 1433) = 19.68, p < 0.0001$. Post-hoc means comparisons using Tukey groupings show that the average [transformed] change between drafts 2-3 was higher for the PPC MEA than for the JIT MEA when peer reviews are followed by TA reviews, but the adjusted mean was not significantly different when TA reviews were received after peer reviews. However, this result is not particularly important, since differences are between MEAs are expected, but not the focus of any important research

question.

The main effect of review source was also significant. Specifically, $F(1, 1433) = 193.51, p < 0.0001$. This result is important, as the prediction was made that TA review feedback would lead to more change than peer review feedback, which agrees with the results of this analysis. Thus, for the change between drafts 2 and 3, the difference in the amount of change resulting from TA and peer reviews was significant, with more change resulting from peer reviews. These results are supported by a post-hoc means comparison using Tukey groupings previously mentioned that showed the adjusted LSMEANS form distinguishable groups for differences in review source.

D. Draft 1-3 ANOVA Results

The data summarized in Table V was analyzed using a 2x2 factorial ANOVA procedure in the SAS statistical package. The interaction plot corresponding to this ANOVA is shown in Figure 4. All three effects (both main effects and the interaction effect) tested in this ANOVA were significant. Specifically, the main effect of review source was significant with $F(1, 1433) = 88.39, p < 0.0001$; the main effect of

Table V
CHANGE BETWEEN DRAFTS 1 AND 3 OF STUDENT TEAM MEA SOLUTIONS AS A FUNCTION OF MEA AND REVIEW SOURCE.

| Semester | MEA | R1 | R2 | N | median $D(X, Z)$ | median $C(X, Z)$ | mean $\ln(C(X, Z))$ | std. dev. $\ln(C(X, Z))$ |
|-----------------------|-----|------|------|-----|---------------------|---------------------|------------------------|-----------------------------|
| Spr 2008 & Fall 2008 | PPC | TA | Peer | 372 | 889.5 | 168.7 | 5.13 | 0.465 |
| Spr 2009 & Fall 2009 | PPC | Peer | TA | 185 | 978 | 214.5 | 5.37 | 0.666 |
| Fall 2007 & Fall 2008 | JIT | TA | Peer | 695 | 409 | 88.6 | 4.51 | 0.563 |
| Spr 2009 & Fall 2009 | JIT | Peer | TA | 185 | 566 | 131.6 | 4.92 | 0.608 |

MEA was significant with $F(1, 1433) = 240.68$, $p < 0.0001$; and the interaction effect of MEA*review source was significant with $F(1, 1433) = 6.41$, $p < 0.02$. In interpreting these results, it is important to keep in mind the relationship between the three dependent variables. Specifically, the change from draft 1-3 is directly composed of the change from drafts 1-2 and the change from drafts 2-3. Thus, the change between drafts 1-3 represents an overall effect, made up of the change between subsequent drafts.

The significant main effect for review source indicates that the greater change in response to TA feedback, as compared to peer feedback from drafts 2-3, was sufficient to produce a significant effect in the overall measure of change between drafts 1-3. This indicates that the overall change between the initial and final drafts is greater when TAs give feedback on the second, rather than first draft. A post-hoc means comparison for this data using the Tukey method revealed four distinct groupings for the adjusted means.

V. DISCUSSION

The research hypothesis for this study was that student teams solving an MEA would change their solutions more in response to reviews provided by TAs than by peers. The results from this analysis did not support this hypothesis for reviews received between drafts 1 and 2. However, the hypothesis was supported when examining change in response to feedback received between drafts 2 and 3. If we assume that greater change between drafts is better, these results suggest that the review source is more critical in the later stages of the revision process in which teams produce solutions to MEAs. The significant interaction term found in the preceding analysis, combined with the means comparisons suggests that the magnitude of this effect depends on MEA, but the overall trend is the same for both MEAs.

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The Effect of Feedback on Modeling in an Authentic Process Development Project

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Abstract— Developing and using models is an important skill employed by practicing engineers that is difficult to cultivate in students. One way to help students develop modeling capability is through feedback. Feedback has been shown to be effective in helping students close the gap between actual and desired performance. This case study investigates the effect of feedback on student teams' use of models in a three-week, open-ended, process development project in which students conducted experiments using a virtual laboratory. Feedback took place during meetings with an expert coach, termed coaching sessions. Coaching sessions of four teams were found to include a substantial amount of model-related feedback. In addition, an in-depth exploration of a single team provides insight into the impact of both directive and facilitative feedback on student modeling behavior.

Keywords—*feedback; model development; virtual laboratory; engineering education; qualitative research*

I. INTRODUCTION

While studies on the actual activities of practicing engineers are sparse, the development and usage of models is believed to be an important skill when completing open-ended, ill-structured projects. For example, studies have found that practicing engineers develop and use models to better understand and predict the behavior of phenomena [1], [2]. The perception of engineering educators and students reflects this finding by emphasizing that problem-solving is central to engineering and modeling is a key part of problem solving [3]. While modeling is an important element in engineering practice, it is difficult to develop in students. One way to help students develop modeling capability is to provide them with timely feedback. Feedback has been shown to be one of the most important tools used by instructors to help students close the gap between actual and desired performance [4].

This paper reports findings from a study of feedback in the Virtual Chemical Vapor Deposition (CVD) Laboratory Project. This authentic, industrially situated project requires student teams to optimize an industrial process within economic constraints. It has been shown to engage student teams in iterative experimental design, analysis and interpretation, and redesign [5]. Throughout the project, teams have opportunities to receive feedback on their strategy, experimental design, and performance. We believe the iterative process, combined with the feedback they receive, helps teams develop and enhance

pertinent models to use in their solution process. In this study we begin to understand how feedback given to student teams in this project helps them develop and use models. Specifically, we ask the following research questions:

- 1) To what degree does feedback given to students in the Virtual CVD Laboratory Project directly pertain to modeling? What aspects of this feedback are directive or facilitative?
- 2) What is the effect of this feedback on student teams' subsequent use of models?

II. THEORETICAL FRAMEWORK

A. Modeling

While many definitions of a model have been proposed, for brevity we limit our discussion to the definition adopted from Schwarz et al., who define a model as “a representation that abstracts and simplifies a system by focusing on key features to explain and predict scientific phenomena” [6, p663]. We focus on the qualitative and quantitative, syntactic mathematical models that students develop and use to explain and predict the CVD reactor behavior. Modeling theories describing science, mathematics and engineering professionals in practice contend that models are constructed from prior knowledge and newly gathered information and that they are refined in an iterative cycle of creation, use, evaluation, and revision. One study examined the evolution of models of chemical engineering undergraduates placed in the role of plant operators, as they performed troubleshooting in a simulated chemical plant [7]. In another study, protocol analysis was used to examine how instructional design experts used prior knowledge and experience to solve ill-structured problems [8]. This study investigates student model development and usage with respect to feedback.

B. Feedback

Feedback can be broadly defined as “information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one's performance or understanding” [4, p81]. Based on an assessment of hundreds of meta-analyses from 180,000 studies, Hattie concluded that “the most powerful single moderator that enhances achievement is feedback” [9, p13]. While feedback has been shown to strongly influence student performance and learning, explicit research on the effect of feedback in engineering education is sparse. Findings

from studies of first-year engineering students [10], [11] show that feedback is positively related to learning gains. These results are consistent with studies in other disciplines [12].

In general, there is limited agreement on what characterizes “effective” feedback, especially in ill-structured, open-ended projects. Hattie and Timperley [4] suggest that feedback is more effective when the feedback is related to the achievement of and progress towards specific goals and that less complex feedback may be more effective than more complex feedback. They also suggest that feedback focused on the individual rather than the task and goal is not effective. Elaborated feedback, feedback in which an explanation is provided rather than a simple “right” or “wrong,” may be more effective than a simple mark or grade. Shute contributed a literature review on formative feedback which supports these suggestions and provides tabulated lists of “things to do,” “things to avoid,” timing related issues, and learner characteristics to consider when providing feedback [13]. Feedback has previously been grouped as either reinforcing feedback or corrective feedback [14]. Reinforcing feedback, which we call affirmative feedback [15], acknowledges a correct response and may include praise. Corrective feedback has been described by Black and Wiliam to have two main functions: (1) to direct, and (2) to facilitate. Directive feedback tells the recipient what must be corrected whereas facilitative feedback, which may be more effective, provides suggestions to guide the recipient toward his/her own revisions [16]. In this study we classify episodes of discourse that contain feedback using one of these three descriptions: affirmative, directive, or facilitative. We then extend our group's use of episodes as a discourse analysis framework [19], described in the methods section of this paper, to investigate directive and facilitative feedback, and its impact on modeling, in the industrially situated Virtual CVD Laboratory Project.

III. PROJECT DESCRIPTION

The Virtual CVD Laboratory Project provides opportunities for student teams to develop and refine solutions to an authentic engineering task through experimentation, analysis, and iteration. For this project, students were placed in the role of semiconductor process engineers. Student teams were tasked with the objective of optimizing an industrially sized virtual CVD reactor, which deposits thin films on polished silicon wafers. Performance metrics include high film uniformity at the target thickness, high utilization of an expensive and hazardous reactant, and minimization of development and

manufacturing costs. If one performance metric is optimized, it is generally at the cost of another. To achieve their objective, teams must find suitable reactor input variable values (temperatures along the reactor, flow rates for two reactants, pressure, and reaction time). Their final “recipe,” one of the final deliverables, consists of a set of values for these input variables that yields the best results with respect to the performance metrics. To optimize the reactor, they must integrate prior knowledge from previous courses. The desired learning objectives for the project include both development of professional skills (e.g., working in teams, communication) and integration of core engineering science concepts (e.g., material balances, reaction kinetics, diffusion).

A typical student team devotes 15 - 25 hours to this complex, three-week project. Key project milestones and corresponding opportunities for feedback are summarized in Table 1. The feedback analyzed in this paper occurred during two 20-30 minute meetings, referred to as coaching sessions and shaded in blue in Table 1, between the student teams and a faculty member, who we call the coach. During the coaching sessions the coach acts as a mentor or boss would in industry. In the design coaching session, students must deliver a memorandum that details values for their first run variables, a strategy for subsequent runs and experimental data evaluation, and an entire project budget (in virtual dollars). In the update coaching session students must deliver another memorandum with an update on their progress. The coach asks questions to guide students to further develop their experimental strategy, models, and understanding of core content and concepts, initial variable values, and budget. Feedback is tailored to engage students in identifying gaps in their current design and directing attention to methods for addressing those gaps.

IV. METHODOLOGY

A. Participants & Setting

The twelve student participants were drawn from two cohorts in the final year of an undergraduate chemical, biological or environmental engineering program at a large public university. The project described in this paper took place as the second of three laboratory projects in a capstone laboratory course. Students were organized into teams of three and maintained their team composition throughout the course. One coach provided feedback to all student teams. This coach has coached over 60 teams in the same capstone course over

TABLE I. TIMELINE AND OPPORTUNITIES FOR FEEDBACK IN THE VIRTUAL CVD LABORATORY PROJECT

| Timeline | Key Project Information & Milestones | Student-Coach Opportunity for Feedback |
|----------------|---|--|
| Project Begins | <ul style="list-style-type: none"> Project goals are introduced Criteria for success are indicated Issued laboratory notebook | Instructor (coach) delivers introductory presentation on integrated circuit manufacturing, some engineering science background, and the Virtual CVD software interface. Also presented are project objectives and deliverables. Feedback is limited to questions and in-class interaction. |
| ~End of Week 1 | <ul style="list-style-type: none"> Design coaching session <ul style="list-style-type: none"> Variable values for first run Experimental strategy Budget | Feedback occurs during a 20-minute coaching session. The coach and student teams ask questions of each other and discuss. If initial variable values, strategy, and budget are acceptable, student teams are granted access the Virtual CVD laboratory. |
| ~End of Week 2 | <ul style="list-style-type: none"> Update coaching session <ul style="list-style-type: none"> Progress to date | Another opportunity for feedback is this second 20-minute meeting between student teams and coach. Discussion includes progress to date, issues, and path forward. |
| ~End of Week 3 | <ul style="list-style-type: none"> Final recipe Final report Final oral presentation Laboratory notebook | Teams give a 10-15 min oral presentation to the coach, other instructors, and other students. Next students entertain a 10-15 minute question and answer session that affords additional feedback. Final project feedback consists of grades and written comments on final deliverables. |

several years and has many years of thin films processing experience. The coach has also published research papers and developed courses on the subject. This study is part of a larger study on student learning in virtual laboratories.

B. Data Collection & Analysis

Data sources include think-aloud protocol, student work products, and the Virtual CVD database logs. The think-aloud protocol [18], consists of transcribed audio recordings of the four student teams (Team A, Team B, Team C, and Team D) as they worked throughout the entire project. Student work products include the following items: laboratory notebooks in which students were instructed to detail their thoughts, calculations, and work throughout the project; all memos; final reports; final presentations; and electronic files, such as spreadsheets in which students developed mathematical models. Virtual CVD database logs record the chosen variables, measurements, and timing of all experimental runs.

Episodes analysis was performed on transcripts of the design coaching session for all four teams in order to investigate the first research question. In episodes analysis, feedback in the coaching sessions is characterized by parsing transcripts into a series of episodes. Each episode in this work has a central theme that has been found to fit into one of three general categories [19], a clear beginning and end, and contains up to four stages: surveying, probing, guiding and confirmation. Some smaller episodes have also been found to be nested within larger episodes, i.e., one themed discussion takes place in the context of a larger themed discussion. Episodes were classified as either model-related or not model-related. Model-related episodes were classified as either affirmative or corrective, with corrective episodes designated as either directive or facilitative. Episodes were designated as directive if the coach explicitly requested action and facilitative if guiding took place without an explicit request for action.

To explore the impact of feedback on student modeling behavior, we chose to examine one team in depth. Because Team A had the highest number of episodes that included corrective feedback on modeling, this team was chosen for a more detailed analysis. In addition to the design coaching session, episodes analysis was also performed on the update coaching session for this team. This team's entire transcript consisted of nearly 67,000 words in 226 pages. We used an iterative approach to relate the feedback in the coaching sessions to the team's modeling activity throughout this extensive project. First, two techniques were considered simultaneously: episodes analysis, described above, and Model Maps. A Model Map, described in [20], presents a chronological, visual inventory of the solution path that a team followed. A Model Map is created through analyzing work products and think-aloud protocol transcripts. The Model Map used in this study identified transcript page numbers corresponding to each instance of modeling activity. Initial analysis was performed by comparing the model-related episodes with Team A's Model Map, focusing on modeling activity after the coaching session, in order to identify commonalities. Commonalities were further investigated by carefully examining the corresponding sections of the transcripts. A list of keywords was developed from both the

coaching session episodes and the other sections of the transcripts that were identified by Model Maps. Keywords were then used to search the entire transcript for evidence of feedback related to modeling activity.

V. RESULTS & DISCUSSION

A. Feedback Related to Modeling: A Survey of Four Teams

Examination of the first coaching session for each of four teams suggests that some episode themes are present in most design coaching sessions (e.g., citing or evaluating sources, and performing a material balance), which is consistent with previous findings [17]. While some themes are common, each coaching session is unique and carefully tailored to each team's particular strategy. It was also clear that the design coaching session often involves episodes and feedback on themes that do not pertain to modeling, such as social dynamics, instructional design, input parameters, core content and concepts, and professional skills. In this study we focus on only the model-related episodes. To examine the degree to which feedback given to students in this project pertains to modeling (Research Question 1), episodes were grouped. Initially episodes were assessed as either model-related or not model-related. Next, the subset of model-related episodes was further divided into three groups: facilitative, directive, and affirmative. The results of this grouping are illustrated in Figure 1. Teams on average had 23 total episodes. An average of 10 of these related to modeling. The distribution of the type of feedback given in these model-related episodes varied from team to team. The model-related feedback that Team A received was fairly balanced between facilitative and directive and only included two affirmative episodes. Team B had come to the meeting with common model-related episode themes adequately addressed. This preparation appears to have prepared them well for the coaching session, since with regards to model-related episodes, minimal corrective feedback was given and no directive feedback was given. By contrast, Team C had come to the meeting late, and appearing unprepared. There was even an episode near the beginning of the meeting in which the coach asked the team if they wanted to postpone the meeting until the team was more prepared. They declined. In their coaching session, they had a few long, model-related episodes and, likely due to their lack of preparedness, many shorter episodes that focused more heavily on professional skills. The model-related episodes of Team D were distributed pretty evenly between the three types of feedback investigated here.

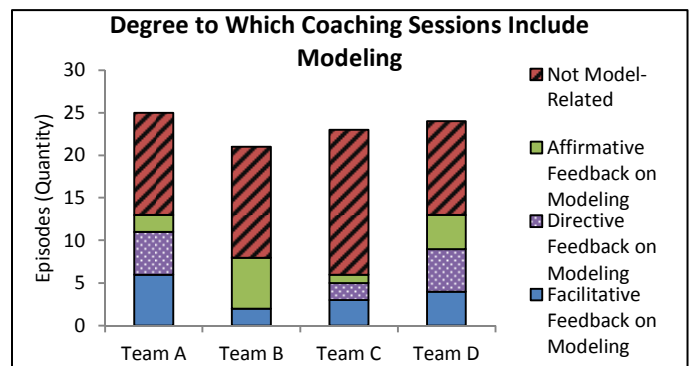


Figure 1: Episode grouping for four teams.

Considering all four teams, it is evident that different types of model-related feedback are given in these coaching sessions to varying degrees depending heavily on the teams.

B. Impact of Feedback on Modeling: A Detailed Description of Team A

In the design coaching session of Team A, two of the model-related episodes were primarily affirmations, either acknowledging or confirming student responses with no guiding or correction. Five model-related episodes contained primarily directive feedback. These five directive episodes had a central, unifying topic: choosing a method to determine flow rate values. Two were substantially longer than the other three. They guided students to realize that material balance was an appropriate method to find initial flow rate values and ended with a statement in which the coach directed the students to do so. The other three directive episodes were very brief and occurred later in the coaching session, simply reiterating the directive statement given earlier. Six episodes in the design coaching session contained primarily facilitative feedback. One was nested within the context of the two larger directive episodes discussed above. The other five facilitative episodes were centered on the topic of the impact of pressure. Within the context of pressure there are two sub-episodes: one is themed around diffusion, the other has a reaction kinetics theme. The reaction kinetics episode provides the context for a sub-episode relating the impact of reaction kinetics to industrial practice.

The update coaching session was much shorter than the design coaching session, containing approximately half as many words and only eleven episodes. In the update coaching session, all corrective feedback was facilitative, with no explicit request for action from the coach. This coaching session contained a brief episode on maintaining their laboratory notebook, multiple episodes on modeling and their experimental strategy, and concluded with discussion about the final deliverables. Two episodes were model-related, facilitative episodes corresponding to the central topics of determining activation energy and identifying the distribution of wafers in the reactor. The four central topics are elaborated upon in the following sections.

1) *Choosing A Method to Determine Flow Rate Values – Directive Feedback:* For the design coaching session, students are required to choose flow rate values for their initial run(s). Use of a material balance has previously been identified as a common method suggested by the coach to estimate or verify flow rate values in the design coaching sessions [17].

After identifying commonalities between episodes and Model Maps, and creating a list of keywords (i.e., material, mass, balance, flow, rate), the entire transcript of this team was explored in depth to look for indications of their activities prior to feedback and to examine their activities after feedback. At a team meeting the day before their design coaching session, the students expressed uncertainty in their values for flow rates. They proceeded to review literature and base one of their flow rate values on a journal article, while fixing the ratio between the two flow rate values. During a flow rate episode in the design coaching session, the coach probed the students regarding how they had selected their flow rates. They referenced a journal paper. However, the students had not

accounted for the difference in size between the reactor in the paper and the reactor in the project. The coach guided them with leading questions towards using a material balance to assess the reasonableness of their values. The students confirmed that they were able to do so. Near the end of the material balance episode the coach gave a directive statement: *"I really think that you need to do a material balance to see if that is a reasonable number."*

The students agreed. The students and coach discussed what values were needed for the calculation, specifically density, and how to acquire those values. The episode then ended. The coach reiterated the directive statement in three very brief episodes later in the design coaching session. After the coach directed the students to perform a material balance, this directive feedback was almost immediately taken up by the students; it was required before they could proceed with the project. In their team meeting directly following the design coaching session, students reflected as follows:

S1: *So, I don't know why we didn't think of this, mass balance.*

S3: *I know right?*

S3 immediately performed the calculation. Later in the meeting, another student did the calculation independently, so that they could be confident in their values. After calculating, the students expressed appreciation for the result:

S3: *Okay awesome stuff. When we get these numbers it's going to rock. I'm happy that we got these. For one I am really confused that we didn't figure this first. For two I am happy that we don't have this haphazard number no more. All the other ones are based off of things we looked up and yesterday we were just like sccms that's a good number. And we got pretty close considering we kind of guessed*

S1: *Oh no, it wasn't a randomly picked number*

S3: *Yeah it wasn't completely random but it still wasn't exactly for our process*

S1: *But it does show the fact that we were so close because if you don't account for the excess it is even closer right? It does show that these references that we are looking at have somewhat of an idea on what they're doing. I guess they are about the same size reactor*

The team was required to revise their memorandum before receiving approval to begin experimentation. They presented a revised memorandum to the coach just over an hour after the first meeting concluded. The coach checked the directive items and gave authorization. Later in the project this team used the concept of a material balance in another way; they incorporated it into their mathematical reactor model to calculate the depletion of reactant gas as it flows through the reactor.

2) *The Impact of Pressure – Complex, Facilitative Feedback:* The impact of pressure, as a central topic, was investigated similarly, with the following keywords: pressure, diffusion, and concentration. Like flow rate values, students must also choose an initial value for pressure before they can proceed with their experiments.

Analysis of the think-aloud transcript before the design coaching session revealed that students had surveyed a variety of references to find an initial value for pressure. They had also identified models of diffusion. In these early meetings the team focused on diffusion as a key to achieve one of their performance metrics, uniform film thickness. They even stated that the system was diffusion controlled and expressed a desire to develop models of diffusion. While preparing for the design coaching session, they emphasized that they wanted to convey to the coach that they have put effort into investigating diffusion, illustrated by the following excerpt:

S1: I don't know. But when we talk to him we can say that we had that, I don't know, but I want him to know we've been thinking a lot about diffusion

While pressure was not included in many of their diffusion discussions, the students explicitly related two aspects of diffusion directly to pressure. Discussions of these two aspects resulted in incorrect conclusions regarding both. Later, as the team wrote their initial memorandum they noted that they wanted to keep pressure low and that their initial pressure value was based on estimation.

During the design coaching session there was a group of facilitative episodes on this topic. An episode themed around pressure provided the context for two sub-episodes, one with the theme of diffusion and the other with the theme of reaction kinetics. A smaller episode, themed around situating the project in industry, was contained within the reaction kinetics episode. The coach began the pressure episode by directly asking the students how they determined the starting value for the pressure variable. The students cited a literature reference, and stated that they didn't think the pressure was as important as the other variables. Within the context of pressure, the team and coach discussed diffusion. During this sub-episode on diffusion, students stated that pressure should be low. The coach then asked why it would be problematic to use an incredibly low value for pressure. This prompted a discussion about the two aspects the students had previously considered, incorrectly, relating pressure and diffusion. It appears the team had a misunderstanding or incomplete understanding about the role of diffusion and the impact of pressure on the performance metrics. The team was guided to conclude that diffusion is not the only way pressure affects their performance metrics, which led to the second sub-episode.

This second sub-episode, on the concept of reaction kinetics, began with revisiting a previous question; the coach asked what other thoughts the students had about why the pressure should not be set too low. Students related pressure loosely to reaction rate. The coach focused discussion with a leading question regarding the contribution of pressure to reaction rates. The students were then guided to recognize that pressure plays a role in the concentration which in turn has an impact on the reaction rate. Within the reaction kinetics episode is another sub-episode which situated the project in the industrial context and linked the concept of reaction kinetics to its impact on high-volume manufacturing. At the end of this group of episodes, students acknowledged that if the reaction rate is slow, product will be made at a slower rate, which may pose a problem in high volume manufacturing.

Following the coaching session, the team discussed their previous understanding of pressure as it relates to diffusion and stated that they needed more information to better understand how diffusion relates to pressure. As they progressed through the project, it is clear from their discourse that they still lack a firm conceptual basis for determining pressure values. They continued to primarily reference diffusion when discussing pressure until one student, S3, created a mathematical model. Approximately one week after the design coaching session, S3 came to a team meeting with a mathematical model of the entire reactor. S3 then began to emphasize the impact of pressure on concentration and reaction kinetics, the same emphasis the coach had given in the design coaching session. This sentiment was reiterated several times throughout the meeting both in the context of trying to convey the information to the other two team members as well as trying to phrase it properly for inclusion in their update memorandum. However, S1 and S2 appear to maintain their understanding that pressure only impacts diffusion. The very last reference to the impact of pressure occurred in the team's last meeting; again S1 and S2 referenced decreasing pressure to increase diffusion, with no mention of reaction kinetics or reaction rate.

3) Determining Activation Energy –Facilitative Feedback: In this example, we show how feedback resulted in a change in a mathematical model parameter value. Prior to the second coaching session, S1 and S3 had a debate in which they discussed two options to acquire a value for one of their model parameters, activation energy: S1 wanted to calculate it from their experimental data, while S3 wanted to get it from a literature search. They chose to search for it because S3 commented that the team should keep things simple. This statement appears to reference an episode in the design coaching session on team dynamics in which the coach noted that S1 had a tendency to make things complex. S3 was also the student who was performing the bulk of the mathematical modeling and would be directly integrating the value into the model. S3 spent time independently finding model parameters, and expressed that activation energy had take “*a really long time*” to find. The keywords used to explore this topic include: activation, energy, Ea, reaction, and rate.

In the update coaching session, while discussing the team's experimental strategy, an episode directly addressed activation energy. The episode started with a student expressing uncertainty in their mathematical model parameters. The coach asked what value they used for activation energy and further probed to identify the source of their activation energy. After discovering that they had found the value at a website, the coach guided the students towards the other option they had previously debated, calculating a value from their experimental data. After this feedback, the students explicitly performed experimental runs in order to determine the activation energy experimentally with S3, the student previously opposed to this option, taking the lead and personally performing the calculations to experimentally determine the activation energy.

4) Identifying the Distribution of Wafers in the Reactor - Student-Initiated, Facilitative Feedback: Our final example is of straight-forward, student-initiated feedback. To explore this topic, keywords include: wafer, and zone. In this case, students noted a need to know the distribution of wafers in the reactor

while working on their mathematical model. The reactor has 5, independently controlled temperature zones in which the wafers are distributed. In a team meeting, prior to the update coaching session, students said “*we really need to know how many wafers are in each zone.*” They even cited that lack of information on the topic was impeding their modeling progress. They made an estimate about the distribution of wafers based on an image of the reactor; however, they also decided to ask the coach during the update coaching session. In the update coaching session, they asked and the coach provided them with the information. After the update coaching session, they immediately integrated it into their mathematical model. While this feedback was briefer than others, the students clearly had a need for the information and initiated the discussion. They were ready to receive the information and apparently perceived it as something that would help them towards their end goal.

VI. CONCLUSIONS & FUTURE WORK

Feedback on modeling is present to varying degrees in all coaching sessions that were examined. When exploring one team in depth, coaching was found to have a significant impact on the progress of the team. The first two general topics brought up concepts that hadn’t been fully explored by the team previously. One included primarily directive feedback, to which the students responded with the requested action, and later incorporated the same concept in a very different way into their project. The second included primarily facilitative feedback. The topic of the impact of pressure was complex and appears to have been incorporated by each student differently. The student who had created the mathematical model integrated it fully. The concept was required in order to develop the mathematical model. The remaining two students appear to have maintained their prior understanding more than integrating the feedback from the coach. It is possible, that because they were less involved in the creation of the mathematical model, that they did not need to further investigate the topic to proceed with the project and they did not have to reconcile what they understood with the complex interactions in the mathematical model. The final two topics were facilitative and had both been discussed explicitly by the team prior to the coaching session in which they received feedback. Feedback regarding both of these topics was fully integrated into the model development of the team.

While not discussed in depth in this paper, it appears that episodes focused on team dynamics and other themes not specifically model-related, may have had an influence on the team’s modeling activity. This warrants further investigation. In addition, modeling activity is not the only aspect of engineering practice that is elicited in this project. It has been argued that professional skills are an aspect of engineering practice that are underrepresented in engineering education and engineering education research [2]. With a similar approach to that used in this paper, we plan to investigate the development of professional skills in relation to feedback.

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The Effect of Student Learning Styles on the Learning Gains Achieved When Interactive Simulations Are Coupled with Real-Time Formative Assessment via Pen-Enabled Mobile Technology

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Abstract— This paper describes results from a project in an undergraduate engineering physics course that coupled classroom use of interactive computer simulations with the collection of real-time formative assessment using pen-enabled mobile technology. Interactive simulations (free or textbook-based) are widely used across the undergraduate engineering curriculum to help actively engaged students increase their understanding of abstract concepts or phenomena which are not directly or easily observable. However, there are indications in the literature that we do not yet know the pedagogical best practices associated with their use to maximize learning. This project couples student use of interactive simulations with the gathering of real-time formative assessment via pen-enabled mobile technology (in this case, Tablet PCs). The research question addressed in this paper is: are learning gains achieved with this coupled model greater for certain types of learners in the undergraduate engineering classroom? To answer this, we correlate learning gains with various learning styles, as identified using the Index of Learning Styles (ILS) developed by Felder and Soloman. These insights will be useful for others who use interactive computer simulations in their instruction and other adopters of this pedagogical model; the insights may have broader implications about modification of instruction to address various learning styles.

Keywords—learning styles, interactive simulations, real-time formative assessment, active learning, InkSurvey

I. INTRODUCTION

Explorations of new pedagogical models have many facets and produce rich insights into how engineering education can be enhanced and invigorated. In a two-semester study, we have been investigating the effectiveness of coupling two paradigms based on active learning strategies and constructivist learning theory: using computer simulations and gathering real-time formative assessment. To accomplish this, each student used a single, pen-enabled mobile device. Elsewhere, we describe emerging evidence of the effectiveness of this coupling in undergraduate engineering physics [1] and chemical engineering [2] courses.

However, the intriguing tangential question we consider here is: are the learning gains achieved when this model is implemented greater for engineering students of particular learning styles? It could be hypothesized, for example, that this learning activity, based on a visually-rich experience and hands-on manipulation of variables, is more clearly aligned with some learning style preferences and therefore might be more successful for certain students (*e.g.*, visual, sensing, and active learners) than others.

II. BRIEF DESCRIPTION OF THE COUPLED MODEL

The coupling of interactive simulations with real-time formative assessment will hereafter be referred to as “the Coupled Model.” In this case, the coupling was implemented using one Tablet PC per student, but other types of increasingly available and increasingly affordable pen-enabled mobile devices could accomplish this as well. Thus the coupled model is economically feasible using devices provided by the institution or the students themselves.

Many engineering educators use interactive simulations (*a.k.a.* “sims,” “applets,” etc.) to help actively engaged students better understand abstract concepts or phenomena which are not directly or easily observable. There are abundant free, high-quality, web-based simulations available online, even for advanced engineering topics, and others are available in association with engineering textbooks. However, as we examine pedagogical best practices for implementing the use of these to enhance learning, shortcomings have been identified with teacher manipulation of the simulations [3], with independent student exploration of the simulations [4], and with more precise (“cookbook”) direction of student exploration [5]. It seems that students need skillful guidance from the instructor as they use interactive simulations to discover insights, and careful monitoring as they draw conclusions about new principles and abstract concepts they investigate.

Both of these needs can be met by gathering real-time formative assessment. This cornerstone of constructivist learning is most effective when students respond to open-format (vs. multiple choice) questions, as higher levels of thinking can better be probed and richer insights into student thinking can be achieved. The questions asked for this assessment provide a vehicle for actively engaging students with the course content in the context of the interactive simulation, optimizing use of class time, and increasing student metacognition. Perhaps most importantly in the Coupled Model, these questions can guide learning through timely scaffolded questioning and feedback, helping students to attain a more mature understanding of difficult concepts.

Previously, gathering real-time formative assessment to open-format questions on a time scale that made it meaningful was a daunting task [6]. Socrates did it successfully with a small group of students, but most contemporary engineering instructors do not have that luxury. However, we have developed and maintain *InkSurvey*. This free, web-based software allows students equipped with pen-enabled mobile technology to use digital ink to respond with words, diagrams, graphs, equations, proofs, etc. to open-format questions posed by the instructor. The instructor, receiving these responses instantaneously, has unprecedented real-time insight into student thinking and can reinforce correct understandings and modify misconceptions on the most immediate of time scales. There is other software, both free and commercially available, that will facilitate this, but we chose *InkSurvey* since it is designed specifically for this purpose and has been used successfully in classes with enrollments exceeding 60 students. An additional feature of this use of technology is that a single device in the hands of the student can be used for both the interactive simulation and the construction of the response; this adds to its pedagogical appeal [7].

III. LEARNING STYLES

Over the past few decades, the study of human learning styles has emerged as a well-established field within the discipline of cognitive psychology. Although many different assessments of student learning styles have been used effectively in investigating how engineering concepts and skills are learned [e.g., 8-10], we utilize the widely accepted [11] Index of Learning Styles (ILS) developed by Felder and Soloman [12, 13]. This instrument's roots are in engineering education and it is available for free online [14]. This inventory and the awareness of various student learning styles that it stimulated impacted engineering education. Indeed, by 2000, leaders in engineering education considered identifying and teaching for various learning styles to be of great importance in improving the classroom environment in undergraduate engineering classes [15].

Based on responses to 44 items in the ILS questionnaire (each one forcing the students to choose between two alternatives), every student's learning style can be placed somewhere along each of four continua. These reflect the preferred way the student perceives information (sensory vs. intuitive learning style), how sensory information is most effectively perceived (visual vs. verbal learning style), how the

student processes information (active vs. reflective learning style), and how the student progresses toward understanding (sequential vs. global learning style).

Previous studies indicate that certain learning activities are more effective for engineering students with particular learning styles. For example, when a process control course in electrical engineering was redesigned to introduce active, collaborative learning and to increase student exposure to real-life problems, including the use of advanced computer simulations, researchers found significantly greater learning gains were achieved by students with "active" and "global" learning styles [16].

IV. PROCEDURE

The goal of the course targeted for this study, "Advanced Physics Laboratory I," is to introduce students to the process of modeling in engineering and science. This is illustrated predominately using wave phenomena but also requires coverage of fundamental statistical content. The latter is introduced in the first three weeks of the course via a one week laboratory exercise along with reading, and homework assignments from the text [17]. Much of the content delivery in class is associated with computer simulations coupled with real-time formative assessment (Coupled Model).

The students enrolled in the two sections are engineering physics juniors having 3 semesters each of physics and calculus, along with courses in differential equations, linear algebra, thermodynamics, analog electronics, and a summer session in vacuum systems, optics, machine shop, computer interfacing, and electronics.

The research presented here is focused on how student understanding of content, using the Coupled Model, is influenced by learning style. For measuring learning gains, a pre-test at the beginning of the semester and a summative evaluation at the end of the semester were administered, thus determining learning of content presented via the coupled model.

Simulations involving phasors in circuits, Fourier analysis, and diffraction, along with two others in statistics, were used. The procedure for measuring learning in the phasor circuits simulation is illustrated next. Details for the others will appear in another publication.

Learning objective: to understand how phasors are used in applying Kirchhoff's voltage law to a circuit by summing time-varying sinusoidal voltages of the same frequency across the circuit elements.

Pre-test Question: "How are phasors used in circuit analysis?"

Students were asked to play before class with the simulation found here:

http://vnatsci.ltu.edu/s_schneider/physicslets/main/phasor1.shtml .

Post-play *InkSurvey* question used in class: "What does this simulation illustrate?"

Scaffolding InkSurvey question used in class: “What did you observe in the circuit simulation relative to your understanding of the phasors?”

Summative assessment question: “Explain how phasors are used in the analysis of circuits.”

Student responses were then evaluated based on their demonstration of understanding that Kirchhoff's law is satisfied at each instant of time, using the rubric in Table I.

TABLE I. SCORING RUBRIC FOR PHASOR CIRCUITS SIMULATION

| Unsatisfactory | Satisfactory | Excellent |
|------------------------------------|--|--|
| No discussion of this relationship | Discusses Kirchhoff's law in a static phasor diagram | Relates Kirchhoff's law via a phasor diagram for different times |
| Score=0 | Score=1 | Score=2 |

V. RESULTS

A. Student Misconceptions Revealed by InkSurvey

As noted above, all students were asked to run the simulation and to explain (via *InkSurvey*) what they learned from the interactive simulation relative to their understanding of circuits. Typically, students did not notice that at each point in time on the animation, the voltage across the source equals the sum of the voltages across the inductor and resistor. The instructor, reading the earliest submissions on *InkSurvey*, appropriately coaxed them to think about Kirchhoff's law and how that relates to the simulation.

Students revised scaffolding *InkSurvey* submissions as necessary.

B. Analysis of data

All assessments were identically scaled with an appropriate rubric. Next, learning gains were calculated as average normalized gains, specifically the difference between summative and pre-test assessments divided by the difference between a perfect score and the pre-test assessment. The class average learning gain for each simulation is presented in Table II. Data from students who did not attend the coupled model class session were removed from this analysis. The p values for paired two tailed t-test results with unequal variance, all less than 0.001, showed significant learning gains which were most likely not due to chance. The same conclusion (every $p < 0.001$) was reached using the Kolmogorov-Smirnov test.

To determine the effect of learning styles (dependent variable) on learning gains (independent variable) achieved using the coupled model, we measured learning styles using the ILS learning style inventory [14]. These styles are categorized in complementary pairs. A score is given for each element of the pair. For example, the instrument measures active and reflective styles (ACT-REF) each on a scale of 0-11. The other measures are sensing and intuitive (SEN-INT), visual and verbal (VIS-VRB), and sequential and global (SEQ-GLO) learning styles. Figure 1 shows the learning styles distribution for the class, offered in two sections, with a total of 41 students.

A negative scale is introduced here to more easily graph the results. Data indicating a score on the first characteristic in the learning pair is shown as negative with a more negative value indicating a stronger learning style for the first member of the pair while the positive axis records the other aspect of the learning style pair.

TABLE II. LEARNING GAINS AND CORRELATION COEFFICIENTS FOR LEARNING STYLES AND LEARNING GAINS ACHIEVED, FOR FIVE SIMULATIONS. LEARNING GAIN FOR EACH SIMULATION IS CLASS AVERAGE (SEE TEXT). TABLE SUMMARIZES PEARSON R VALUE AND ACCEPTABLE RANGE FOR 95% CONFIDENCE.

| Simulation | N | Ave.gain | ACT-REF | SEN-INT | VIS-VRB | SEQ-GLO |
|----------------------|----|----------|---------------|---------------|---------------|---------------|
| 1. Circuits | 41 | 63% | 0.02 | 0.02 | -0.04 | -0.12 |
| 95% confidence range | | | -0.28 to 0.32 | -0.28 to 0.32 | -0.34 to 0.26 | -0.41 to 0.19 |
| 2. Fourier | 41 | 67% | 0.03 | -0.004 | -0.06 | -0.05 |
| 95% confidence range | | | -0.27 to 0.33 | -0.30 to 0.30 | -0.35 to 0.25 | -0.35 to 0.25 |
| 3. Diffraction | 30 | 60% | 0.03 | 0.01 | 0.10 | -0.15 |
| 95% confidence range | | | -0.32 to 0.37 | -0.34 to 0.36 | -0.26 to 0.43 | -0.47 to 0.21 |
| 4. Std Dev Mean | 40 | 75% | 0.25 | 0.04 | .14 | -0.11 |
| 95% confidence range | | | -0.06 to 0.51 | -0.27 to 0.34 | -0.17 to 0.43 | -0.40 to 0.20 |
| 5. Least Squares | 33 | 61% | -0.13 | -0.28 | 0.03 | 0.06 |
| 95% confidence range | | | -0.44 to 0.21 | -0.56 to 0.06 | -0.30 to 0.36 | -0.28 to 0.39 |

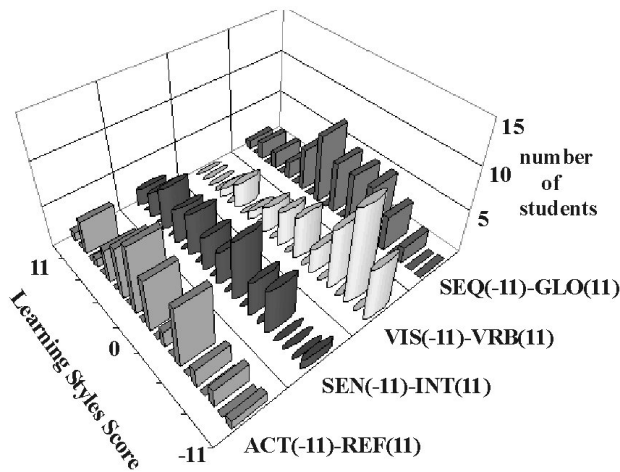


Figure 1. Learning Styles vs. Number of Students

For example, in the VIS-VRB pair, “visual” is the first term so a score further along the negative axis indicates more of a visual learning style, while further along the positive axis indicates more of a verbal style.

The independent variable, learning gain, was then correlated using a Pearson r value with each dependent variable corresponding to a particular ILS learning style and shown in Table II. The significance of each correlation coefficient is reported in Table II as a range within which the population correlation coefficient lies with 95% confidence [18].

Reliability and construct validity of the ILS learning styles measurement has been documented [11, 19, 20]. To test reliability of the learning gains measurement in this study, nine assessments (both pre-test and summative evaluations) were measured by four different raters. The inter-rater reliability was calculated based on the work of Ebel [21] using web-based software [22]. The resulting nine reliability estimates were then averaged to yield a value 0.82 with a standard deviation 0.12. The reliability estimate ranges between zero and one with the larger value indicating more reliability between raters.

C. Discussion

Although the original hypothesis at the root of this study was that the coupling of interactive computer simulations and real-time formative assessment would better meet the learning styles of some students than others, this is not supported by the learning gains data. As shown in Table II, this coupling resulted in significant learning gains for all categories of student learning styles; there is no statistically significant correlation between student learning style and the effectiveness of this pedagogical method in producing learning gains in this population of engineering physics students.

It is interesting to note that the three simulations on which students achieved the greatest learning gains (circuits, Fourier, and standard deviation mean) were also the three simulations with the greatest number of students present in class. We do not know the reasons for diminished attendance on certain

dates, but speculate that the student population present on any given day is not entirely random. This may account for the observed differences in learning gains achieved; however, the data suggest it is not a function of student learning styles.

The distribution of the learning styles of the engineering physics students included in this study did not closely mirror that previously reported in the literature for electrical [16, 23], chemical [24], bioengineering and mechanical [25], general [26] engineering undergraduate students, and others. Although all of these groups shared a preponderance of visual and sequential learning styles, the engineering physics students in this study had a greater population of students with reflective and intuitive learning styles than those consistently reported elsewhere for groups of engineering undergraduates. Nevertheless, even though the experimental group may not precisely reflect the learning styles of other known populations of engineering students, they represent a broad distribution of learning styles, as appropriate for this study.

It is greatly encouraging that this pedagogical model (coupling interactive computer simulations and real-time formative assessment) is not preferentially advantageous to any particular learning style, but rather is broadly effective across all learning styles.

VI. CONCLUSIONS

When interactive computer simulations were coupled with real-time formative assessment collected with *InkSurvey*, students achieved large and statistically significant learning gains on all five examples. These learning gains, however, are shown to have low correlation with student learning styles. The sample population used in this study has been measured to contain a broad distribution of learning styles. The reliability of the instrument to measure student learning styles has been documented, and the inter-rater reliability on measurement of student learning gains is very strong. We therefore interpret the low correlation between learning gains and learning style to indicate that the Coupled Model is effective in enhancing learning, independent of student learning style, in an engineering classroom.

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Automatic Classification of Question Difficulty Level: Teachers' Estimation vs. Students' Perception

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Abstract—The accurate estimation of the difficulty level of the questions posed to students is essential to help them to learn more effectively and efficiently. However, it is agreed that teachers usually fail to identify the correct difficulty level of the questions, according to the answers and final scores obtained by their students. Thus, this paper examines the ability of teachers for categorizing questions by difficulty level, comparing it with the students' perception and the measures obtained by an expert system of question automatic classification. The results show that students perceive questions more difficult than teachers, except for the harder ones. In addition, teachers are only lightly more accurate (closer to the expert system), in spite of the general students' tendency to overestimate the difficulty level of less difficult questions. Although no general conclusions can be obtained about behavior and accuracy of teachers and students when they analyze the difficulty of learning material, the provided analysis could be very valuable for teachers in order to detect unclear problem statements and students' misconceptions.

Keywords—educational technology; automatic question classification; expert systems; teachers' estimation; students' perception

I. INTRODUCTION

It is very common that teachers have to estimate the difficulty level of learning material (questions, items, problems...) when they design and define assessment processes for their students. However, several studies indicate that teachers usually fail to identify the correct difficulty level of the questions, according to the answers and performance of their students [1]-[5]. Besides, if the aim of adapting assessment to students according to their knowledge level is to increase their motivation and efficiency, it is important to take into account their difficulty level perception. However, there are not many studies where the perception and estimation of difficulty level done by students and teachers are compared and analyzed in an objective way. Moreover, as it will be shown in next section, there are not definitive conclusions about the accuracy of the teachers' and students' estimations, since, beyond subjective impressions, it can depend on several factors like the type and representation format of the problem or the specific context. Thus, a more objective estimator, that specifically addresses the context under study, could be a powerful tool in such adaptive learning environments.

In order to support teachers in the difficult task of categorizing questions according to their difficulty level, an automatic classification expert system that objectively estimates the difficulty level of the questions posed through a competitive e-learning tool called QUESTOURnament has been designed. In some competitive environments like QUESTOURnament, temporal variables can play a role comparable to scoring, which is the only factor traditionally considered in automatic classification systems. The intelligent system, which is implemented by using genetic algorithms and fuzzy logic, estimates the difficulty of questions from the students' behavior when answering them in the competition and from the initial classification of these questions made by the teacher.

This paper analyzes how learning actors estimate the difficulty of the questions posed in a real undergraduate engineering course in which QUESTOURnament and this expert system have been used. Students had to answer to a number of questions posed by the teachers through the QUESTOURnament system. For each of the questions, teachers as well as students had to indicate its estimated difficulty level. Later, the expert system was used in order to measure the difficulty level in an objective way.

The rest of the paper is organized as follows. Firstly different related studies from the literature are presented and the motivations for this study are discussed. Secondly, the expert system is briefly presented. Section IV describes the experiment and data collection. These data and the objective estimations achieved by the expert system are then used in order to compare students' and teachers' behavior and accuracy when estimating the difficulty level of the questions, obtaining the results and conclusions presented in the last two parts of the present paper.

II. BACKGROUND

Different studies [4], [6], [7] show that students learn more effectively and are more motivated if posed exercises are arranged according to their difficulty level; since too difficult or too easy questions can frustrate and decrease students' motivation. However, estimating the difficulty level of questions is not an easy job. Moreover, the different studies found in the literature show contradictory results when analyzing teachers' estimations. In fact, although most of the

authors state that generally students' performance tends to be overestimated by teachers [3], [8], [9], Evans and Byrd [10] suggest that teachers perceive a difficulty level of learning material greater than students.

There are several studies analyzing the performance of teachers when they estimate the difficulty of learning material, finding that the estimation accuracy sometimes depends on the own difficulty level of the learning material. For example, Mattar [11] states that teachers are less successful at rating very difficult or very easy items. In this respect, Watering and Rijt [5] indicate that teachers tend to overestimate the difficulty of easy items and underestimate the difficulty of hard items. However, Impara and Plake [3] do not think that teachers systematically behave like this. Moreover, according to the results in [12], teachers usually classify better the difficulty level of the hardest items.

It is therefore not possible to obtain a general conclusion about the accuracy of the teachers' estimations, since the results of different studies are incongruous. In addition, even within a same context teachers can perform differently. For example, during the experience described in [12], ten teachers had to order eleven items according to their relative difficulty and the results indicate that the teachers' accuracy about the difficulty level was different between them. A similar procedure was followed in [1], in which several teachers and students evaluated the difficulty of 14 mathematical tasks by ordering them. The results show that the classifications done by teachers and students are different and that the difficulty level depends on the type and representation format of the problem.

In spite of the difficulty of this task, students sometimes are better than teachers estimating the difficulty of the learning material. Results in [5] suggest that students estimate better the items difficulty level than teachers, while [13] also finds that students perform better on judging the difficulty of items than domain experts. Results shown by Lee and Heyworth [4] indicate high correlation between the item difficulty ratios, the teachers' estimations and the students' perceptions of problem difficulty level; although students' predictions were also more accurate than teachers' estimations.

The previously mentioned studies use different methods to evaluate and compare the performance of teachers and students when classifying learning material by difficulty. For example, [13] analyses six different difficulty level estimation methods, included the students' and experts' opinion, in order to review the accuracy of these methods as compared to a large scale IRT-based calibration.

In this research, due to the open and competitive nature of QUESTOURnament, no traditional or more common methods, such as IRT (Item Response Theory), can be used to objectively calibrate the difficulty of the questions [14]. A hybrid expert system based on genetic algorithms and fuzzy logic that estimates the real difficulty of the questions posed through the tool QUESTOURnament has been designed. The estimations and perceptions of difficulty level done by teachers and students are compared and tested against this expert system, which is briefly described in the next section.

III. EXPERT SYSTEM FOR AUTOMATIC CLASSIFICATION OF QUESTION DIFFICULTY

A genetic fuzzy expert system has been designed to dynamically adapt the difficulty level of the questions posed through the QUESTOURnament system. QUESTOURnament is a competitive e-learning tool integrated into Moodle that allows teachers to organize contests, in which students must answer several questions (called challenges within the system) within a limited time. Students compete with each other in order to obtain higher scores and be at the top-ranking. This system has been successfully used in different courses [15], [16], although a component of stress, due to its competitive nature, appears almost always as main drawback.

The main aim of the expert system is to objectively estimate the difficulty level of challenges in order to be able to define a contest by groups in which students with similar skills compete together by answering questions of a difficulty appropriate to them. In this way, the stress produced in the worst classified students could be reduced and their motivation would keep higher as they would have more chances to win.

In order to implement the expert system, genetic algorithms and fuzzy logic have been used, since other common techniques, such as the previously mentioned IRT, are not valid for the contexts of use of QUESTOURnament, due to its versatility and open character [14]. The system, described in detail in [14], identifies the characteristics of the questions for each difficulty level from the actual behavior of students and adjusts the new difficulty level of each question (see Fig. 1).

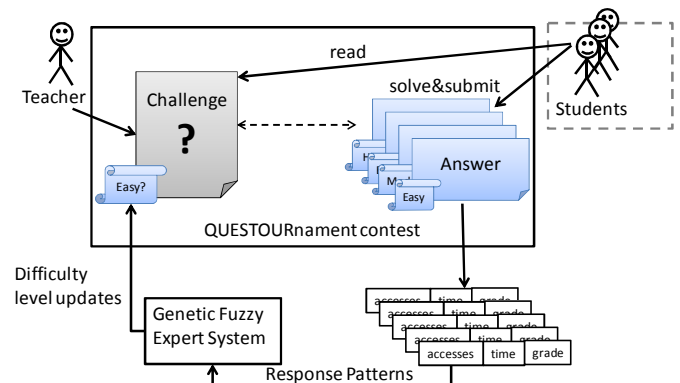


Figure 1. Diagram of the expert system for automatic classification of question difficulty

The expert system estimates the difficulty of challenges according to three levels (easy, moderate and hard) from the students' response patterns and from the initial classification of these questions made by the teacher [17].

More specifically, from Moodle and QUESTOURnament logs, three parameters are considered in the response patterns: time in minutes from the last reading of the question until the submission of the answer, grade obtained for that answer and number of accesses or readings before submitting the answer (*time*, *grade* and *accesses*, respectively). All these data make up a set of usage patterns that feed the expert system. It works iteratively and by difficulty level. In the first iteration, the questions are divided into the three difficulty levels initially defined by the teacher. Then, in next iterations, the new

classification automatically obtained in the previous iteration is used. This process is repeated until a stable situation is achieved.

For each difficulty level (easy, moderate and hard), the system uses the patterns of all the questions belonging to that level and obtains a set of fuzzy rules and membership functions of the three input variables (*time*, *grade* and *accesses*), which are used for reclassifying the questions. In the fuzzy model the membership functions of the output variable, the *difficulty*, always take the form shown in Fig. 2.

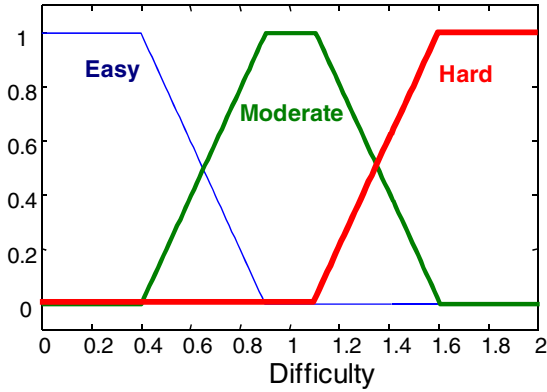


Figure 2. Membership functions of the output variable *difficulty*

Therefore, the system combines the students' behavior and the teachers' perception in order to objectively estimate the real difficulty level of each challenge. Background and motivation to design this new intelligent system, as well as a complete detailed description of it and its validation against a group of experts, can be found in references [14] and [17].

The system can be used in any engineering educational context, since it has not been designed for any specific subject. In fact, with the current version of QUESTOURnament, the challenges can be any type of questions available in Moodle question bank (essay, true-false, multiple choice...), although open answer questions was the only type available in version 1.0 of QUESTOURnament, which was the one used in the experiment described below.

IV. EXPERIMENT

A. Data Collection

The version 1.0 of the competitive e-learning tool QUESTOURnament was used in an undergraduate course of Diploma in Telecommunications Engineering given at the University of Valladolid (Spain). Thirty-eight students had to compete answering twelve challenges on IP addressing and routing. The challenges were essay or open answer questions. Assessment criteria were clearly stated and published for each individual challenge. Students had to indicate their perception of difficulty after solving each question and while they submitted the answer and participated in the competition.

The system also asked teachers to classify the challenges according to their difficulty level. Four teachers with more of ten years of experience participated in the experiment. Teachers selected one difficulty level for each challenge

according to their standard previous experience and without taking the competitive context into account.

B. Methodology

As aforementioned, when the students answered a question, they had to indicate their perception of difficulty according to a set of three values: 0, 1 and 2 (easy, moderate and hard, respectively). From these data, the average difficulty, as perceived by students, of the *j*th challenge d_j has been calculated, as in (1).

$$d_j = \frac{1}{N_j} \sum_{i=1}^3 n_{ij} \cdot D_i \quad (1)$$

where n_{ij} represents the number of learners that give feedback responses belonging to the *i*th difficult level for the *j*th challenge, N_j is the total number of learners that rate the *j*th challenge, and D_i is the challenge difficulty level quantified as 0, 1 and 2.

On the other hand, teachers were also asked to indicate their difficulty level estimation, according to the same set of values: 0, 1 and 2. The average difficulty estimated by teachers has been calculated by using the same procedure shown in (1).

Last, in order to compare teachers' and students' accuracy, the hybrid expert system that objectively measures the difficulty of the challenges has been used. Although the expert system works with three difficulty levels, it can obtain crisp numeric values that belong to two fuzzy sets in a considerable degree (for example, those values of difficulty around 0.6 belong to the easy as well as to the moderate fuzzy sets in a similar degree, as shown in Fig.2). Therefore, for a better analysis five levels have been used in this study, including those fuzzy areas found between two levels: *easy*, *between easy and moderate*, *moderate*, *between moderate and hard*, *hard*.

Finally, the membership functions shown in Fig. 2 have also been used to interpret and translate the numeric values obtained from students' and teachers' input into the corresponding linguistic values.

C. Detailed Study Objectives

This study aims at comparing the students' and teachers' perception of the difficulty level of the challenges posed in QUESTOURnament. On the basis of the literature as well as the own experience, it could be stated that students usually tend to classify questions harder than teachers. Besides, taking into account the specific competitive context of QUESTOURnament, it could be expected that teachers perform worse than students, since teachers estimate the difficulty in general terms, without considering the competitive nature of QUESTOURnament, whereas students do it immersed in the competition (as the expert system does too).

Therefore, this study tries to analyze the following two affirmations:

- The difficulty level perception reported by students will be higher than the difficulty level estimation done by teachers.

- The students' difficulty level perception against the expert system will be better than the teachers' difficulty level estimation against the expert system.

V. RESULTS AND DISCUSSION

For each of the twelve challenges posed, Table I shows the classification given by the expert system as well as the difficulty level estimated and perceived both by teachers and by students. For the expert system, the numeric value indicated between parentheses corresponds to the crisp numeric output. For the students and teachers, it corresponds to the average numeric value calculated as indicated in (1).

From data of Table I, it can be observed that students perceive challenges more difficult than teachers, except for the hardest ones. Besides, it is remarkable that none of the challenges are considered totally easy by students. Those challenges considered easier by the system are estimated as easy by the teachers but not by the students. When analyzing this, it should be contemplated that the system estimates the difficult level of questions having into account the real behavior of students when answering challenges. Therefore, students are answering correctly these questions, although they do not perceive them as easy. It should be noticed that teachers participating in this experiment tried to objectively estimate the difficulty of questions while this fact cannot be confirmed for every student. Students are inexperienced in this task and moreover they sometimes are not objective when indicating their perception. For example, the competitive nature of the context may influence the response of some students.

Therefore, for easy and moderate challenges, it seems to be true that the difficulty level perceived by students is higher than the difficulty level estimated by teachers. This same behavior cannot be confirmed for harder questions. This result did not agree on the one obtained by Evans and Byrd [10] who

suggest that teachers perceive a difficulty level of learning material greater than the indicated by students. On the other hand, the affirmation of that students' performance is overestimated by teachers cannot be confirmed as, although students perceive challenges more difficult than teachers, the output of the expert system is informing that many students are properly solving those challenges that are easy for the teachers.

The most difficult challenges according to the expert system (those classified as *between moderate and hard* or *hard*) obtain a high value in both students' and teachers' estimations, except for challenge 2, which is considered of moderate difficulty by teachers. This shows that more difficult items seem to be better classified than easy or moderate ones. In general terms, the hard questions were correctly classified by both the teachers and the students. However, the students had a tendency to overestimate the difficulty level of easy or moderate questions. Due to this behavior of students, they do not seem to be better classifiers of the challenges in this experiment than teachers, contradicting the affirmation suggested in previous section.

Finally, what it seems true is that this type of analysis can be very valuable for teachers. Data shown in table I can help them to detect special cases that should be analyzed. For example, for challenge 8 divergent classification results can be found for each of the actors; whereas the teachers consider that the question is easy, the students think that it is hard. However, the system objectively values its difficulty at the middle of the scale. Cases like this may be due to an unclear problem statement that could have confused students, thus teachers should revise the wording of that challenge. It could be also due to some important misconception not detected before. Therefore, teachers could have a powerful tool for detecting general students' misconceptions and problems formulated wrongly.

TABLE I. DIFFERENT MEASURES OF THE DIFFICULTY LEVEL: EXPERT SYSTEM, STUDENTS AND TEACHERS

| Id | Expert System | Students' Perception | Teachers' Estimation |
|----|-------------------------------------|-------------------------------------|----------------------|
| 1 | Moderate (1.08) | Moderate (0.79) | Moderate (1.00) |
| 2 | Between moderate and hard (1.51) | Between moderate and hard (1.33) | Moderate (1.00) |
| 3 | Easy (0.38) | Between easy and moderate (0.7) | Easy (0.00) |
| 4 | Between easy and moderate (0.52) | Between moderate and hard (1.28) | Easy (0.25) |
| 5 | Moderate (1.07) | Between moderate and hard (1.30) | Moderate (1.00) |
| 6 | Between moderate and hard (1.48) | Between moderate and hard (1.39) | Hard (1.75) |
| 7 | Easy (0.37) | Between easy and moderate (0.61) | Easy (0.00) |
| 8 | Moderate (1.08) | Hard (1.59) | Easy (0.25) |
| 9 | Hard (1.68) | Hard (1.70) | Hard (2.00) |
| 10 | Between moderate and hard (1.32) | Hard (1.57) | Hard (1.75) |
| 11 | Hard (1.62) | Between moderate and hard (1.46) | Hard (2.00) |
| 12 | Between moderate and hard (1.55) | Between moderate and hard (1.43) | Hard (2.00) |

VI. CONCLUSIONS

Research shows the problems that teachers have to correctly estimate the difficulty level of questions. Moreover, from literature no conclusions can be obtained about behavior and accuracy of teachers and students when they analyze the difficulty of learning material. The results of the experiment described in this paper do not provide light to the problem. Results are consistent with Impara and Plake [3] when they say that teachers do not systematically behave overestimating and underestimating the difficulty of easy and difficult questions, respectively, as it is affirmed in [5]. Besides, results do not confirm those obtained in [5], [13], [4], according to which teachers do less accurate predictions than students do, in spite of their expertise.

Results obtained in this type of studies seem to depend on different factors that should be analyzed: type and representation format of problems [1], context of the experiment, subjective reasons in the students, etc. This analysis could help researchers to understand how the difficulty of learning material could be better estimated by the learning actors as well as by automatic systems. Due to the complexity of the problem, automatic systems, such as the one described in this paper, adjusting the difficulty level of questions according to the actual students' response (which is conditioned by the specific context), are a very useful support tool for teachers and a key component for truly adaptive e-learning environments.

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Student Self-Efficacy in Introductory Project-Based Learning Courses

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Abstract—The purpose of this study is to determine how introductory Project-Based Learning (PjBL) courses affect the self-efficacy of first-year engineering students. Grounded theory is used to analyze twelve interviews with first-year students about their experiences in two PjBL courses, *Engineering Design* and *Physics Laboratory*. Data indicate that students' self-efficacy within each course is correlated with the extent to which their course goal perceptions align with those intended by faculty. In *Engineering Design*, students' recognition of the faculty's intended course goals corresponds to higher levels of self-efficacy. Conversely, in *Physics Laboratory*, students' low self-efficacy is correlated with a large gap between their perceived and faculty intended course goals. Analysis further reveals that this difference in course goal perceptions may stem from the variations in the courses' contingent scaffolding. Finally, our findings suggest that students' self-efficacy may be further supported by dynamic course scaffolding that allows for an increase in students' autonomy throughout a course.

Keywords — *First-Year Engineering Curriculum, Project-Based Learning, Self-Efficacy, Course Scaffolding*

I. INTRODUCTION

Project-based Learning (PjBL) is commonly defined as a pedagogical practice or an educational experience centered around one or more long-term student-directed projects [1-4]. These projects tend to model “real-world” work situations, with a focus on group work and hands-on experiences. Unlike traditional courses, in which faculty role is largely limited to imparting knowledge on students, instructors in PjBL environments serve as mentors, offering students significant autonomy [1-4]. In engineering settings, PjBL courses are likely to focus on knowledge application as opposed to knowledge acquisition. It has been argued that this emphasis on application is necessary for the engineering profession in which changing technology and industry demands render both technical and meta-skills more valuable than specialized content knowledge [4].

In the past two decades, a number of technical institutions have incorporated PjBL as a central curricular component, often featuring it in introductory courses [5-7]. As a result, many studies to date have focused on the effectiveness of PjBL, particularly as it pertains to the first-year engineering curricula [4-8]. Yet within the body of this work, little to no research has addressed the issue of how and to which extent PjBL affects students' self-efficacy, particularly in first-year courses. Our study addresses this gap by investigating introductory PjBL courses through a self-efficacy lens [9-12].

Introduced and popularized by Albert Bandura within a larger framework of social cognitive theory, self-efficacy refers to a personal belief in one's ability to perform a specific task or achieve a desired outcome [13]. A specified context and achievement level are what differentiate self-efficacy beliefs from more general self-confidence beliefs. For example, “I'm good at math” is a statement of confidence, whereas “I believe I can solve first-order differential equations without help” is a statement of self-efficacy. High self-efficacy beliefs have been shown to be positively correlated with student interest, achievement, and persistence in engineering courses [10-12, 14-15]. Conversely, low retention in engineering has been attributed to low self-efficacy beliefs [9-12].

To describe the development of these beliefs, Bandura defined four self-efficacy sources: (1) *Mastery Experiences* are past events strongly associated with either successes or failures in performing similar tasks. Experiences with positive outcomes are likely to result in higher self-efficacy, while experiences with negative outcomes are associated with lowered self-efficacy; (2) *Vicarious Experiences* are events in which individuals compare themselves to others with regard to their task outcome; (3) *Social Persuasions* are verbal judgments about others, often relating to stereotypes or biases; and (4) *Physiological States* are physical and emotional responses – such as anxiety or stress – encountered while attempting a task.

Current literature suggests that mastery experiences are the most prevalent sources of self-efficacy in educational settings [16]. Vicarious experiences can be influential when one has little experience in a subject domain, but they are not as influential as mastery experiences. Social persuasions and physiological states occur least often, though social persuasions are found more frequently in male-dominated academic settings [17-18].

Our study utilizes Bandura's framework while adding to the current body of knowledge in the context of first-year engineering courses by asking the following questions: 1) *How do PjBL courses affect first-year students' self-efficacy?* 2) *What factors of PjBL course implementation are most relevant to establishing students' self-efficacy beliefs?*

To answer these questions, we investigate two PjBL classrooms, *Engineering Design* and *Physics Laboratory*.

II. METHODOLOGY

A. Study site

This study is part of a larger multi-site, mixed-methods research focused on first-year engineering students' experiences in PjBL courses. In this paper, we focus on one of the study sites: a small technical undergraduate institution which features PjBL throughout its curriculum. In particular, we investigate two introductory PjBL courses: *Engineering Design* and *Physics Laboratory*.

B. Student interviews and analysis

Twelve second-semester first-year students, six women and six men, participated in semi-structured open-ended interviews about their experiences in physics and engineering courses. The interviews took place midway through the semester when the students were enrolled in the courses. Students were selected using "purposive" sampling [19-20] to ensure participation in the same physics and engineering courses, as well as to ensure an inclusion of students at varying performance levels. Grounded theory was employed to analyze students' interviews [21] and pseudonyms were used to preserve students' confidentiality. Codes and memos were used to organize the data into matrices and emergent themes were identified. In what follows, representative quotes are chosen to demonstrate general themes and emerging trends.

C. Course descriptions

Though from different academic disciplines, the two courses under investigation, *Engineering Design* and *Physics Laboratory*, share remarkable similarities with respect to overall goals, as well as use of projects, teamwork, and hands-on activities, while utilizing faculty in mentorship roles. As such, both courses can be described as PjBL environments.

Engineering Design introduces students to a design process through three long-term group projects. Throughout the semester, these projects increase in length, duration, complexity, and student autonomy, while faculty support is simultaneously reduced. This is achieved through a set of intermediate deliverables which decrease in frequency and procedural/organizational specificity as the course progresses. The course also features weekly instructor-student meetings that further allow faculty to guide student teams.

Physics Laboratory is offered as a co-requisite to a lecture-based course in introductory Newtonian Mechanics. According to the course syllabus, the goal of the *Physics Laboratory* is to expose students to an evidence-based open-ended experimental process with a large emphasis on student-driven learning while faculty guidance is minimized. Students work with partners of their choosing on weekly table-top experiments. Provided with an initial open-ended problem statement, students are expected to design, build, and perform an experiment, followed by analysis that usually extends beyond the classroom. Technical writing is reinforced through weekly "tech report" summaries.

III. RESULTS AND DISCUSSION

Our data suggest two emerging trends: (1) *Engineering Design's* course implementation allows for much higher self-efficacy in comparison to *Physics Laboratory*; and (2) *Engineering Design's* course scaffolding leads to more positive mastery experiences than those in *Physics Laboratory*.

Although occasionally experiencing frustration with the design process and the overall course, students in *Engineering Design* demonstrate positive affect and convey high self-efficacy. Many students find that the design process is straightforward and easy to follow, resulting in course enjoyment and confidence in their engineering abilities. For example, when asked to describe his overall feelings about the course, Cody responds with: "The best thing about [*Engineering Design*] is that we're not doing anything extremely difficult conceptually yet. It's not scary. It's really enjoyable" (Cody, April 9th).

As a result of the course many students report an increase in their interest in engineering. Combined with enjoyment and confidence, this enhanced interest facilitates positive self-efficacy development. Some students suggest that the course contributes to their identity as engineers: "[*Engineering Design* is] really useful ... it's made me *want* to be an engineer... now I'm really happy that there's a class that I like and I can see myself doing a job in" (Carolina, April 6th).

In comparison, many students express frustration in *Physics Laboratory* that is augmented by a lack of confidence in their abilities to complete the work. Many students express a lack of understanding of the lab goals and approaches necessary to perform them: "I didn't really understand what was going on... and I was just really frustrated because... I don't know what I'm doing. I'm just doing something and I don't like to just do something... I want to know what's happening" (Isabella, April 11th).

A majority of the interviewed students echo these feelings of frustration and confusion. When asked about her overall experience in *Physics Laboratory*, Loretta comments: "I'm not that interested in physics. I knew that [since] I came here, [and *Physics Laboratory* made me realize that I] actually wasn't good at it..." (Loretta, April 10th). Loretta's quote demonstrates the powerful negative impact that *Physics Laboratory* has on many students' interest, confidence, and self-efficacy beliefs. Many other students echo this sentiment with explaining that this course lowers their overall interest in physics as a field.

Our findings indicate that the students' self-efficacy beliefs in the two courses stem, for the most part, from mastery experiences. In fact, we find that vicarious experiences, social persuasions, and physiological states have little to no effect on self-efficacy belief formation. Students associate *Engineering Design* with positive mastery experiences; they find that the course teaches valuable engineering design skills, and often describe a sense of accomplishment associated with project completion. Betty

expresses this sense of positive mastery when she describes her feelings about her work in the course: "... I've actually built this with my own hands, with the help of some other people. I've made this work, I've worked out the kinks in it. I feel that this is really the highball experience..." (Betty, April 6th). Positive mastery experiences may be attributed to completion of projects with tangible and often successful results. These mastery experiences provide students with a sense of ownership over the design process, which further contributes to the overall positive outlook on the course and engineering as a field.

Conversely, students report having negative mastery experiences in *Physics Laboratory*, which appear to stem from repeatedly poor project outcomes. Carolina explains: "I put a lot of time into making my technical reports for that class and, no matter what I do, I always get really bad data... it just seems like I put a lot of time in there and I don't think it's actually helping me understand" (Carolina, April 6th). This perceived project failure appears to contribute significantly to students' lowered self-efficacy, especially because such negative experiences often occur repeatedly.

These quotes, and many similar ones from other students, suggest that there are key differences between *Engineering Design* and *Physics Laboratory* that, at least in part, lead to significant differences in students' self-efficacy. In the next sections, we examine the correlation between self-efficacy and the alignment of students' perceptions with faculty intended course goals. We will then investigate the effect that course scaffolding has on this course goal alignment.

A. The effect of student course goal perceptions

One noticeable difference between *Engineering Design* and *Physics Laboratory* is students' perceptions of course goals. Specifically, our data indicate that students' perceptions of course goals are more aligned with faculty's intentions in *Engineering Design* than in *Physics Laboratory*. This alignment in *Engineering Design* is highly correlated with students reported positive mastery experiences which generate high self-efficacy. Conversely, in *Physics Laboratory*, misalignment of students' course goal perceptions correlates with the lack of positive mastery experiences, establishing low self-efficacy beliefs in the course.

According to the course syllabus, the primary goal of *Engineering Design* is to teach students a design process. All of the interviewed students recognize this as the course's main focus. For example, when asked what *Engineering Design* is about, Betty responds with: "[The professors] pointed out that the design process of engineering could be structured" (Betty, April 6th). What is particularly interesting about Betty's quote is that she emphasizes the professors' role in focusing the course on design as a process, suggesting explicit nature of faculty intentions. Furthermore, students recognize the value of this course goal in their academic and professional careers: "I guess what I've learned a lot about is... how the design process works and why we have a design process" (Kyle, April 10th). These representative quotes embody the high level of purpose that students attribute to the class, allowing them to

continue building upon positive mastery experiences towards high self-efficacy and agency [22].

This alignment of students' course goal perceptions with faculty intentions plays a key role in developing mastery experiences. In fact, it is because students expect to learn the design process and their expectations align with the course experience, positive mastery experiences become possible: "I think the project has really helped... [Before this class] I guess I never really understood what went into the design process" (Carl, April 8th). Of note is that even in the presence of difficulties, students maintain positive mastery experiences. Patty comments that she isn't sure how her final prototype will turn out; however, when asked about this potential failure, she responds: "I feel there is a process I'm following..., so I still feel in control" (Patty, April 8th). It is this high self-efficacy and a sense of "being in control" that allow Patty and other students interviewed to develop a sense of agency and maintain an interest in *Engineering Design* and the field of engineering as a whole.

On the other hand, in *Physics Laboratory*, very few students recognize the faculty's intended course goals. According to the course syllabus, *Physics Laboratory* seeks to teach students the basics of the experimental process. However, when asked to describe the purpose of the course, students' responses vary widely. Only a few students recognize the faculty's intentions. For example, Cody explains: "[Lab is an] introduction to taking data and keeping a lab notebook and writing out tech papers" (Cody, April 9th). However, the perceptions of other students differ. For instance, Carolina believes that the main purpose of *Physics Laboratory* is to supplement knowledge from her physics lectures: "I think the point of [the] lab is... to help you understand [physics concepts] better..." (Carolina, April 6th). Other students, such as Patty, believe that the course is about proving known physics results: "[In] *Physics Lab* you're trying to prove that [physics laws] actually work... like one of the labs was proving Newton's mechanics" (Patty, April 8th).

These varied perceptions of course goals, many of which don't align with faculty's intentions, appear to contribute significantly to the students' inability to achieve positive mastery experiences in *Physics Laboratory*. The course is designed to teach students the basics of the experimental process; it is not designed to teach new physics concepts or to have students "prove" physics laws. Nevertheless, students expect these outcomes and feel incompetent when these perceived goals do not live up to their experiences. For example, Loretta, who believes that she should be focusing on collecting "good" data, comments on a negative mastery experience: "We took the data, and that went really well, and I was like 'Oh, this isn't going to take much work. I have nice data, I have almost everything done,' and it turned out that I couldn't even get a curve for the data, and that really messed me up. I didn't even want to look at it" (Loretta, April 10th). Because Loretta's expectations for the course are limited to successful data collection, her inability to do so results in a negative mastery experience and lowered self-efficacy. Though it is possible that she still is familiarizing herself with

the experimental process, in fact achieving the intended course goals, her misaligned perceptions and expectations further lead to a lowered sense of agency in the course and potentially the overall field of physics.

B. The role of scaffolding on course-goal perception

In this section, we investigate possible reasons that underlie the differences in students' perceptions of course goals in *Engineering Design* and *Physics Laboratory*, which, as discussed in previous section, lead to differences in students' self-efficacy. This is of particular interest given that the two courses have similar foci, i.e., they intend to develop an understanding of engineering design or experimental design as a process. One possible explanation emerging from our analysis points to the differences between the levels of faculty-supported scaffolding provided for students in the two courses.

In educational literature, scaffolding is defined as temporary support structures used by faculty to aid students with the completion of a task [23]. This construct is often confused with the idea of a supportive or structured classroom environment. To differentiate scaffolding from other educational supports, Van de Pol (2010) in his meta-analysis of studies on scaffolding outlines the following three requirements. Firstly and most importantly, scaffolding must be a *positive and interactive process* with both teacher and student as participants. If students do not recognize the support structures provided by the instructor, they cannot be classified as scaffolding. This relates to the second requirement, which is *contingency* or calibrated support. The amount of teacher support must be dynamic – stronger when a student is working in an unfamiliar domain and weaker when a student gains competency. Finally, scaffolding requires *fading support and a transfer of responsibility* over time. Initial support is required to allow the student to become comfortable with the material, but Van de Pol (2010) claims that a student must become autonomous and self-regulated in order to gain true mastery [23].

We argue in this section that the *contingency* and *interactive* components of scaffolding are necessary to align student course goal perceptions with the faculty's intended goals, ultimately resulting in higher self-efficacy. In the next section, we then further propose that the *fading support and transfer of responsibility* also play a role in building students' self-efficacy beliefs.

Faculty provide scaffolding in *Engineering Design* by requiring students to submit a set of *intermediate deliverables* during the first two projects. These intermediate deliverables are a series of assignments that aid students in the design process, such as a written list of functional objectives, a work-breakdown chart, a set of design alternative sketches, etc. For example, Gloria describes her experience with the second project: “[The professors] taught us... all the little engineering tools that we’re supposed to use... and then gave us a problem statement, and told us to revise it, and [then we started to] work with due dates for every little part” (Gloria, April 9th). Because these intermediate deliverables outline the steps of the design process, it becomes apparent to Gloria that the

course is about learning design as a process. Almost every student comments on these intermediate deliverables, alluding to the important role they play in establishing the purpose of the course.

For most students, the structure provided by the intermediate deliverables is sufficient to properly align their course goal perception with those intended by faculty. However, some students require extra support to fully understand the course's purpose. These students are further supported by the *Engineering Design* faculty who, in their mentorship role, provide additional contingency structures. For example, during the second project Cody and his team rushed through many design steps, focusing more on the end product than learning of the process. Cody describes his experience and faculty intervention (i.e., contingency) as follows: “Well, on the last project our team didn’t really do as much [about] the metrics... and we were kind of excited to get on the building of it, so we kind of got slapped on the wrist for that” (Cody, April 9th). Though Cody's description of the faculty response is somewhat negative, he comments later in the interview that the purpose of the course is to learn the design process, suggesting the intervention's success. Thus, the individualized support provided by faculty, combined with the structure of the intermediate project deliverables, ensures that every student in *Engineering Design* recognizes the course's main focus.

In comparison, students in *Physics Lab* perceive a complete lack of scaffolding. Here they are given no intermediate deliverables, guidelines, or coaching, bringing about feelings of frustration, confusion, and negative affect. Kyle describes an average lab as follows: “[The professors] present you with an experiment... and give the equipment to perform an experiment, and our lab manual just kind of guides us [with respect to] how this stuff works and what you can do with it. And basically they ask us to pick an experiment and test...just take a bunch of raw data and see how your experimental values for something compare to a theoretical [framework]” (Kyle, April 10th). Rather than adapting this narrative as a focus of the course, many students perceive it as a lack of instructor support. This may be partially rooted in (1) students' expectations of an active faculty role in “teaching” the relevant content and skills; and (2) a lack of explicit guidance on the part of the faculty in the regular student-faculty meetings, intermediate deliverables, experimental techniques training, etc., i.e., *contingency*. Whatever the specific cause of this perceived lack of instructor support for each individual student (i.e., specific *contingency*), all students interviewed indicate becoming increasingly confused and misguided about the purpose of the overall course and each individual lab within the course. Thomas comments: “... I’m given the set-up for the lab, I see what it is, and there’s a premise of what it is we’re doing. But after that what it is the [professors are] actually asking me... gets a little hazy” (Thomas, April 8th). Marco shares a similar experience with *Physics Laboratory*: “You’re expected to be prepared for lab and have already read the lab instructions, so that you already know what’s going on before you’re in the lab. [So] it’s not expected that [the professors] are there to tell you how to do

it” (Marco, April 12th). This lack of contingent instructor support perpetuates students’ perception of the lack of structure in *Physics Laboratory*. According to Marco, even though students may be confused with regard to what they are supposed to be doing in lab, the faculty do not provide any assistance because of their rigid expectations of student preparation. Accordingly, this overall lack of contingency leads students like Thomas and Kyle to remain frustrated and confused about the course’s content and goals.

C. Direct effects of dynamic scaffolding on self-efficacy

From the analysis above it is apparent that scaffolding in *Engineering Design* plays an important role in establishing and aligning student course goal perceptions with those intended by faculty. However, this is not the only effect that scaffolding has on students’ experiences. Our analysis indicates that the *gradual transfer of responsibility* and *increase in autonomy* perceived by students is another factor that contributes to students’ self-efficacy. As mentioned previously, the first two projects in *Engineering Design* involve a series of required intermediate deliverables. For the third project, these intermediate deliverables are no longer required, yet students are still expected to follow the design process steps outlined in the first two projects. Student autonomy increases as their only required interaction with faculty is a weekly meeting. The explicit structure of the first two projects thus becomes implicit for the third one.

In their interviews, students appear to be very observant of this fading faculty guidance and transfer of responsibility, highlighting it as one of the main features of the course. Students not only recognize an increase in freedom with the third project, but they also realize how the structure and guidance they received in the first two projects enable them to be autonomous. Marco comments on his experience working on the third project: “Now we go into class as a group and we’re already expected to know what to do because [the professors] taught us at the beginning of the year. We are just expected to work on our own and ask them for help if we need help” (Marco, April 12th). The key insight Marco has is that the structure of the first two projects provides him with knowledge and skills underlying a positive mastery experience. This realization of competency affords the necessary self-efficacy for open-ended design problem solving.

Comparing such experiences to those in *Physics Laboratory*, we infer that the initial course structure is essential in creating mastery experiences. Specifically, *Physics Laboratory* features high levels of student autonomy and lack of structured experiences starting with the very first assignment. Arguably, it is this environment that leads to students having trouble gaining a sense of mastery, impairing their self-efficacy. Isabelle is one such student who expresses a lack of positive mastery experiences in the beginning of the course: “[The professors] should explain things more at the beginning of the course because I was really confused, and I wasn’t the only one... everybody was confused, and nobody knew what was going on” (Isabelle, April 11th). Isabelle

attributes her confusion to the lack of structure in the beginning of *Physics Laboratory*, i.e., explicit contingency and presence of too much autonomy with too little faculty support. Because she perceives the labs to be poorly (or not at all) explained, she feels unsupported in her work, preventing her from gaining future mastery experiences.

From comparing the two courses, it appears that the initial structure in *Engineering Design* may be one of the critical factors responsible for generating mastery experiences and positive self-efficacy beliefs, allowing students to pursue open-ended problems. This does not say projects with high student autonomy are detrimental to students’ self-efficacy. In fact, not only do the students report positive experiences associated with the autonomy-heavy third project, our data suggest that the *transfer of responsibility* that occurs between the second and third projects significantly contributes to the development of students’ self-efficacy.

When students talk about the third *Engineering Design* project, a common theme that emerges is the idea of real-world experience. The high levels of autonomy simulate the amount of responsibility necessary in professional practice, causing many students to compare their projects to industry-level work. Gloria compares what she is doing in this course to her expected experiences in the engineering capstone project, where students usually tackle “real world” problems: “We’re trying to go through the engineering process, manage our own time, and do it just like we would do for [our school’s capstone project]” (Gloria, April 9th). Many other students also express excitement of doing “real” engineering work in the third project. Because students, aided by their previous project experiences, feel efficacious in their ability to succeed at this professional-level project, they also gain confidence in their ability to one day work as a professional engineer: “It seems [that] what I’m doing is what engineers do on a regular basis in their jobs. It’s what they’re paid for, and I’m getting really useful experience here doing this” (Betty, April 6th). After the first two projects, students are confident in their understanding of the design process and their ability to apply it. However, it is not until the third project that they start believing in their ability to perform engineering tasks at a professional level. These representative quotes suggest that this boost in engineering self-efficacy and overall agency stems from the increase of autonomy and added responsibility the students experience in the third project.

IV. CONCLUSION

Overall, students have higher self-efficacy in *Engineering Design* than in *Physics Laboratory*. Low self-efficacy beliefs in *Physics Laboratory* stem from negative mastery experiences while positive mastery experiences in *Engineering Design* are correlated with high self-efficacy. Analysis indicates that self-efficacy beliefs within a course are significantly influenced by students’ perception of course goals, which, in turn, are determined by the amount of contingent scaffolding and dynamic nature of autonomy support provided by faculty. A lack of scaffolding within *Physics Laboratory* leads to students’ course goal perceptions

that are misaligned with those intended by faculty, and we find a high correlation between this misalignment and low self-efficacy. Conversely, a strong sense of contingent scaffolding in *Engineering Design* allows students to recognize the faculty's intended course goals, and we determine a high correlation of such alignment with students' expressed feelings of high self-efficacy. Furthermore, the dynamic nature of *Engineering Design's* scaffolding results in a gradual increase in student autonomy, which may also play an important role in enhancing students' self-efficacy beliefs. These results have important implications to the curricular design, especially in the introductory engineering courses.

Although we identified many aspects of these two courses that may affect students' self-efficacy beliefs, both the current literature and our data further suggest that other factors may be contributing to establishing and maintaining students' self-efficacy. One factor which did not play into our analysis is group work's effect on self-efficacy. Many of the interviews involved detailed discussion of group dynamics and role assignment within project teams, and further analyses are needed to explore this question. Finally, although no gender trends emerged in our analysis, literature suggests that self-efficacy in engineering settings may be gender dependent [10,15,17-18]. In future work we hope to expand our analyses to include these factors, as well as others, in order to more fully understand how PjBL environment affects students' self-efficacy.

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Using Modern Graph Analysis Techniques on Mind Maps to Help Quantify Learning

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Abstract—In this work, we use a graph analysis tool to measure how student-created mind maps reflect learning. Mind maps consist of words and connections between words, and this visual tool helps illustrate how an individual understands how these words connect together in a field. From an analysis standpoint, mind maps are graphs consisting of nodes connected by edges. In the fall of 2011, students created three mind maps over the duration of a digital system design course, and at each of the three intervals, these mind maps were created with the same 20 terms that were introduced throughout the course. Each student's mind maps were then digitally encoded and analyzed using a modern graph analysis tool called GraphCrunch II. Our results show that a simple analysis of graph density is a poor indicator of learning since this metric does not capture a graph's structure, and it is this structure that reflects meaning and understanding by the learner. Instead, a metric called relative graphlet frequency distance (RGF-distance), which is calculated by comparing a golden mind map (expert created mind map) to each of the students mind maps, is used to analyze each students understanding of how these words relate. Our results show that learner's mind maps decrease in RGF-distance over the period of the course, and this means that the students are building graphs more similar to that of the golden model. We, also, see that the RGF-distance over the set of students compared to their grades on an exam or overall grade in the course has some correlation, meaning that these mind maps relate to grades in terms of the learners understanding of vocabulary, but the correlation is not strong. The ultimate goal of these tools is to provide the learners with a method of getting automatic feedback on their understanding as well as learning progress in particular topics.

I. INTRODUCTION

Concept maps [1], [2] and mind maps [3] are useful tools in education, and they can be used both in lectures as classroom assessment techniques (CATs) and outside the classroom for the learner to express ideas in a visual form. Mind maps are words/concepts connected by lines where a line indicates a relationship between the words, and concept maps (also called knowledge maps) have similar structure except the connecting lines have directionality (indicated by an arrows) and have associated prepositional phrases that indicate how the words are related. For this work, maps are mathematically known as graphs, and therefore, we can leverage research in the understanding of graphs to help analyze mind maps.

Our focus is on using modern graph analysis tools to evaluate in class, student-created mind maps. Our goal is to help build tools that learners can use with their mind maps to automatically give them feedback on their understanding of a

topic. To evaluate a map, either the map can be evaluated by an expert observer, or the map can be compared to a golden map generated by an expert. The first of these evaluation options is very difficult for computers to perform since the computer needs some inherent understanding of the topic itself. The later is the approach used since a machine can use the golden map and compare it to the learners map without any knowledge of the subject.

To compare learner mind maps to golden maps we use a tool called GraphCrunch II [4], which is a tool developed for analyzing the similarities between proteins. This tool uses a unique method to compare graphs and is easily applicable to mind maps. Over the 2011 semester of a course on digital design, we collected student mind maps (course beginning, post exam I, and post exam II). These mind maps were CATs where students had 10 minutes to create their maps that consisted of 20 terms, and these 20 terms were introduced throughout the semester. Each student's mind maps was then digitally encoded and analyzed using GraphCrunch II. Our results show that another metric, graph density (defined later), is a poor indicator of learning since this metric does not capture the graph's structure, and it is structure that reflects meaning and understanding by the learner.

Instead, a metric called relative graphlet frequency distance (RGF-distance) [5] is calculated by GraphCrunch II. Our results, with this metric, show that the majority of learners have a decrease in RGF-distance for their maps over the course, and this means that the students are building graphs more similar to the golden map. We consider this result evidence of student's learning the vocabulary of a field and the relationships between words. We, also, see that the RGF-distance for students compared to their grades on an exam or overall grade in the course has some correlation, meaning that these mind maps reflect performance in the course. However, the correlation coefficient is not strong enough to consider using the graph analysis tool as an assessment measure.

The remainder of this paper is organized as follows. Section II reviews previous work in analyzing mind maps and introduces more details about graphs and the GraphCrunch II tool to help the reader. Section III describes the experiment, and Section IV shows our results. Finally, Section V concludes the paper.

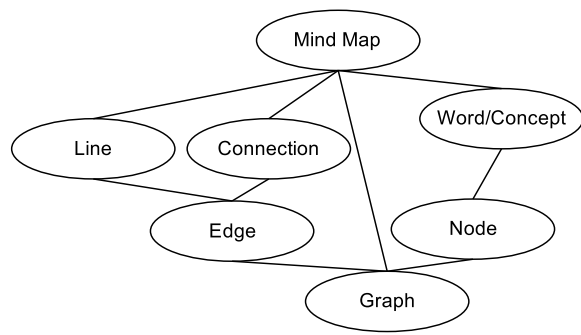


Fig. 1. Example of a mind map on the relationship between mind maps and graphs

II. BACKGROUND

Mind maps [3] are a visual tool that can be used to represent the connections between a number of concepts. These maps are useful CATs [6], and both the student and teacher can observe how concepts connect in the learners mind, which allows teachers to provide feedback. Figure 1 shows an example mind map that expresses the author's understanding of mind maps and how they relate to mathematical graphs. Basically, the words/concepts that are in a mind map are the nodes of a graph (circled bubbles), and the connecting lines between these words are edges of a graph. Concept maps [1], [2], also called knowledge maps, are more complex than mind maps since the edges are labeled with prepositional phrases. We do not analyze concept maps in this work, but they are also powerful learning tools with a valuable research literature that compliments and motivates this work. For a good introduction to concept maps, take a look at Novak's book, *Learning, Creating, and Using Knowledge: Concept Maps As Facilitative Tools in Schools and Corporations* [7].

A. Map Analysis Classifications

As described earlier, our focus is on automatically analyzing mind maps using modern graph analysis tools. To do this, we will compare student maps to a golden model; Ruiz *et al.* [8] called this type of scoring *comparison with a criterion map*. Ruiz identified another scoring mechanism called *score map*, which includes basic graph analysis techniques such as counting edges and nodes, and they describe a third option, *hybrid model*, that combines the two. Their work looks at five other studies with concept maps and categorizes them based on their scoring technique. In this work, our approach is the third choice, hybrid scoring, since we use the criterion map to assist the automated scoring.

Herl *et al.* [9] further categorize map analysis based on what the learner is allowed to do. They call maps that are restricted in construction as *closed*, which means the words and concepts are limited, and *open* maps are unrestricted. A number of researchers [10], [2], [11], have presented ways of defining closed maps for concept maps, and in our work, the mind maps are closed since we restrict the number of words/concepts that a learner can include in their maps.

B. Automated Map Analysis

As a precursor to automated map analysis, various methods of scoring a map have been proposed by researches, and a brief list of scoring metrics in the literature include the following:

- Concept map - count the number of valid propositions, levels of hierarchy, examples, and crosslinks [1] where weights can be introduced to each count ([12], [13])
- Concept map - a measure of *hierarchiness* which relates hierarchy in the map [8]
- Mind map - compare the scores on tests to the technique [14]
- Concept map - the more important a concept, the closer it is to the top of the tree [15]
- Mind map - have two independent experts score (sometimes with a rubric) the mind map on a scale two times with one week delay and compare correlation of ratings [16]

The scoring of maps has been challenged by many researchers in the literature [17], [18]. Kinchin and Hay [19] criticize the shortcomings of strict scoring of concept maps as a motivation to propose qualitative analysis of maps. Interestingly, one of their key contributions in this qualitative approach is looking for *spoke*, *net*, and *chain* like structures in a map, and these structures are internal graph structures that are captured by what will later be described as graphlets.

Early attempts at automating the analysis of maps and providing feedback focused on hint like mechanisms. A criterion map (called scaffold in these works) provides student creators with hints for their maps on what is missing and what does not belong [20], [21]. Conlon [22] built a system that used Novak's scoring mechanism and other artificial intelligent concepts to build an open concept map creation system that provided feedback to students. Our goal is study modern graph analysis tools for similar purposes.

C. Graph Analysis

We have already introduced concepts of *nodes* and *edges*. We should also mention that mind maps are classified as undirected graphs, which means that the edges do not have a direction, normally indicated by an arrow; concept maps, on the other hand, are directed graphs. In the rest of this section, we will provide a better understanding of the metrics compared as our experimental measures - density of a graph and relative graphlet frequency distance (RGF-distance). Note that mathematical formulas and definitions are provided in graph notation, but the reader does not need to understand this notation to understand this work.

The *density* of a graph is defined as the total number of edges ($|E|$) divided by the maximum number of edges that a graph could have ($.5 * |V| * (|V| - 1)$). For the graph in figure 1, the maximum number of possible edges is 21 and the number of edges is 9, so the density is $9/21$ or, approximately, 0.43. The greater this value, to a maximum of 1, means the more connectivity between the nodes within a graph.

Density measures how much connectivity there is in a graph. In terms of relating this to mind maps, we might hypothesize

that the more connected a mind map is then the more tightly related the topics are. If we compare metrics for a student map to the criterion map then we might say the closer these metrics are to one another than the global connectivity is more similar. The problem, however, is the structure of the mind map is not captured with simple metrics and students might be making wrong connections that somehow make the comparative metrics more equal.

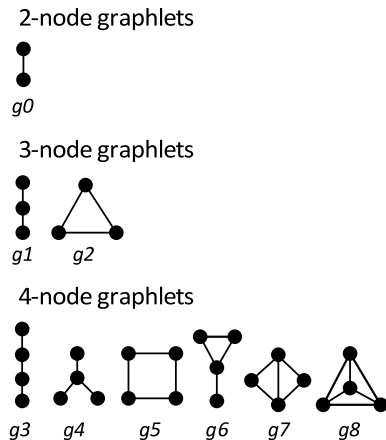


Fig. 2. Graphlets of size 2, 3, and 4

Before defining RGF-distance, we first introduce graphlets. Graphlets, formally, are “a connected network with a small number of nodes” [5] and these small graphs are non-isomorphic induced subgraphs of a larger graph. Figure 2 shows *all* the graphlets of size 2, 3, and 4. Note that the graphlet of size 1 is a single unconnected node and is not that useful.

The power of the graphlet is how it can be used to analyze a graph. The procedure developed by Przulj *et. al.* [5] is to search for all graphlets of size 3, 4, and 5 in a given graph. Based on the count of each type of graphlet, we then can construct a signature in the form (g1, g2, g3, g4, g5, g6, g7, g8, ..., g28, g29), where g1 is number of the first type of graphlet of size 3 shown in figure 2 and g29 is the count for the last graphlet of size 5. This signature can be compared to another graphs signature to get a measure of similarity, and Przulj *et. al.* used their technique to compare graphs representing biological structures such as proteins.

RGF-distance is a measure of the difference in frequency of graphlets of g1, g2, g3, ..., g28, and g29 appearing in the two graphs being compared. A detailed equation is presented in Przulj *et. al.* [5] and the reader can find the details on the calculation of RGF-distance. For this work, we must understand that GraphCrunch II will calculate this metric for us, and the smaller this number gets means the more similar the two graphs are.

RGF-distance captures the comparative structure of two graphs, and in terms of comparing student mind maps to the criterion map, we hypothesize that the lower the RGF-distance is means that students better understand the relationships

between concepts/words since their maps have more similar structure to the expert’s criterion map. This is the main hypothesis of this work.

III. SEMESTER MIND MAP EXPERIMENTAL SETUP

For our work, the goal is to automatically analyze student-created mind maps over a semester long course and observe how these students are learning the course vocabulary as reflected by their mind maps. The focus course for this experiment is a digital design course offered at the 200 level. The course starts with how transistors can be organized to make basic Boolean gates and ends at designing finite state machines using a hardware description language (HDL). From our perspective, the most challenging aspect for most students is the application of HDLs to design hardware as the language differs significantly from sequential programming languages that students are much more familiar with. However, mind maps only play a small part in understanding HDL application, and this work focuses on the students understanding of digital system vocabulary.

Table I shows a summary of our experiment. Column one describes the category, and column two and three lists the category type and specific details.

Our mind map experiments are on closed mind maps. Specifically, a list of 20 terms are provided that are introduced in the course. The following list of the 20 terms is ordered chronologically based on when the word/concept is introduced in the course. Note that by exam I, terms 1 through 15 have been introduced, and by exam II the remaining words have been presented. Also, note that the list order is randomly presented to the students. The list includes the following: Electricity, Transistor, Vdd, False, Digital, AND, Truth table, XOR, Schematic, Power, Timing, Binary, Decimal, Two’s compliment, Multiplexer, Sequential, Register, HDL, Always, FSM.

During the second class of the course, we introduce mind maps using an illustration of constructing mind maps for countries. We show how the mind map can be constructed differently depending on if we are thinking about geographical location, oil supply, or military alliances and enemies. After this basic training, we then show the list of 20 terms and give the students 10 minutes to create their first mind map. This is repeated after exam I and exam II with the same terms and the same amount of time. This means for each student who has chosen to participate (our IRB approved protocol allowed students to remove their participation agreement any time in the semester before final marks were released) could have created up to three mind maps over the semester.

To use these paper-based mind maps with graph analysis tools such as GraphCrunch II, the mind maps need to be digitally encoded. One of the digital formats that GraphCrunch uses is a simple line-by-line graph representation where two words are included on each line; the pairing of words on a line means that there is an edge between them. We built a simple key-press data entry program based on the first letters of each word to quickly encode the paper mind maps into a

TABLE I
A SUMMARY OF THE PROPERTIES OF OUR MIND MAP EXPERIMENT

| Evaluation Category | This Experiment | Details |
|---------------------|-----------------|--|
| Mind map option | Closed | Restricted to 20 terms |
| Evaluation | Hybrid | Criterion map that is used for scoring |
| Scoring metric | Various | Comparison of simple graph metrics to RGF-distance |
| Mind map creation | In class | 10 minute activity at the start of class |

digital form. Each student is given a numerical id, and each of their mind maps is encoded and a corresponding grade entry is labeled with their id. In this way, students become anonymous once all their data is in as per our IRB protocol. With the digitally encoded mind maps, the graphs are analyzed.

IV. EXPERIMENTAL RESULTS

The hypothesis is that the RGF-distance metric, which is a comparison of graph structure between student and the criterion mind maps, will decrease in value over time and show that student's mind maps reflect a better understanding of how the words and concepts in a field are organized. This learning will be examined in two ways; first, we expect that there will be some correlation between grades and RGF-distance, and second, over the course, we expect an individual's mind maps to show a better understanding of how the words/terms in a field relate. In addition to these two trends, we will first look at how simple graph metrics relate to RGF-distance assuming that these metrics can not capture structure that RGF-distance can.

A. Comparison of RGF-distance to other Graph Metrics

We speculate that the RGF-distance metric is a better metric for evaluating mind maps since it captures comparative graph structure. Here, we compare graph density to the RGF-distance metric in two ways to show that RGF-distance is more useful than simple metrics. First, for each set of mind maps the correlation coefficient is compared to the respective RGF-distance, and second, the metrics for the criterion model are compared to see if there is a relationship.

TABLE II
STATISTICS FOR THE GRAPH METRICS ON MIND MAPS

| Correlation - Density to RGF-distance | | | Golden Model Stats | | |
|---------------------------------------|--------|---------|--------------------|-------|---------|
| Course Start | Exam I | Exam II | Edges | Nodes | Density |
| -0.14 | -0.47 | -0.93 | 47 | 20 | 0.25 |

Table II summarizes this data. The first three columns show the correlation coefficients, and the last three columns show stats on the criterion mind map. In terms of the correlation coefficients between density and RGF-distance there appears to be none for the first two mind maps. However, for the post exam II mind maps, there is a high correlation. To understand if the correlation has any meaning, we look at the second aspect of analyzing this data, how does the density compare to the densities in the student mind maps. On average the density for the three sets of mind maps (0.16, 0.15, and 0.14

respectively) are all smaller than the density for the criterion map (0.25), which suggests the similarity is small. The best mind maps (as a measure of RGF-distances below 5) created in the post exam II do have the higher densities and are similar to the criterion maps density. This is not the case for the mind maps created at course start and post exam I, so we have to conclude that graph density could be a quick indicator of similarity that students could use as they create their mind maps, but by itself it is not sufficient to help students.

B. RGF-distance Relation to Grades

To examine how RGF-distance for student generated mind maps compares to scores on class exams, we will plot RGF-distance on x-axis and the exam or final grade score out of 100 on the y-axis. We will then plot a logarithmic regression line on the graph to get some understanding of the general relationship between grade and RGF-distance. Finally, we will calculate correlation coefficients between grade and RGF-distance for each time the mind maps were created to evaluate if there is a strong linear relationship.

Figure 3 shows these scatter plots. Starting with the graph in the upper left, the blue points are the mind map RGF-distance from the start of the course (n=40) compared to the student's grade, and the red points are the same but for the mind maps created post exam I (n=24).

One interesting observation is there is a shift of RGF-distance from the start of class to the first exam, which signifies that the mind maps are more similar to the criterion map post exam I. The trend line, in this first graph, suggests that there is some relationship between grade and RGF-distance, but the actual correlation coefficients are weak, -0.14 and -0.27 respectively. The second two graphs, which compare the mind maps post exam I and exam II (n=24), do not show a shift in RGF-distance between the two periods of time. This is probably due to the fact that the majority of vocabulary is introduced by the first exam and the shift would only be minor. We see similar trend lines to the first graph, and there is a high correlation coefficient for mind maps created after the first exam to the grade (-0.45 for exam II and -0.63 for final grade). However, since the number of participants and the specific participants at each stage (40 students for the class start mind map, 24 students for the post exam I mind map, and 24 students for the post exam II mind map) is different, these correlation and trend lines are only a hint of the relationship between mind map structure and grade. Interestingly, the correlation for the final mind maps RGF-distance to grades is not as high as post exam I (-0.31 for

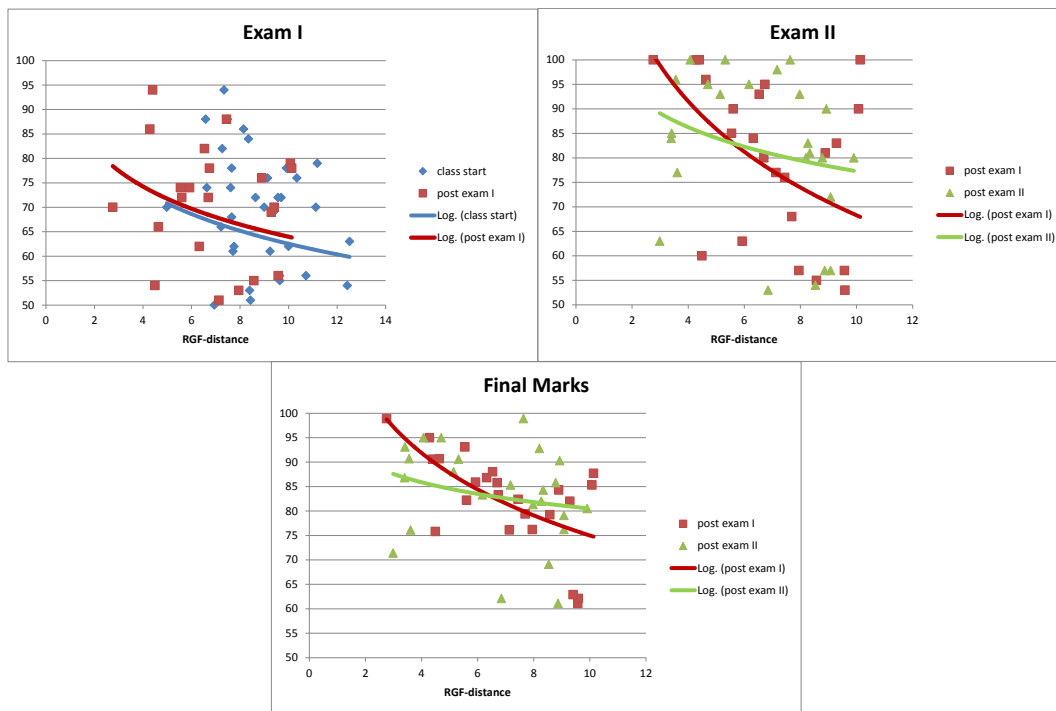


Fig. 3. Scatter plots for grade to RGF-distance on exams and overall grade with RGF-distance on the x-axis and grade point out of 100 on the y-axis.

exam II and -0.26 for final grade).

The greatest correlation is between final grades and post exam I mind maps with a correlation coefficient of -0.63. We hypothesize that mind maps RGF-distance compared to overall grade is a better comparison since the mind map is an indicator of understanding on how concepts connect, and this type of knowledge is more important to activities in the overall course, which is assessed on exams, labs, and projects. The exams, though needing an understanding of vocabulary, is more focused on testing students problem solving and design skills, which is not a good assessment of understanding how concept/words are related.

C. Individual RGF-distance Analysis

Figure 4 shows four graphs where each graph is a bin of students with a certain final grade range. Each graph shows the measure of RGF-distance (y-axis) for the students mind maps over the semester (x-axis); in the graph a line connects two points if they are for the same student and they have created mind maps at two adjacent times. Looking at all the graphs, we can see that for the most part, RGF-distance measurements decrease, meaning the student mind maps are becoming more similar in structure to the criterion map. We believe this is strong evidence supporting our hypothesis. The outliers to this trend tend to be found when comparing the RGF-distance measure from mind maps created post exam I and post exam II. Whether this reflects student confusion, poor performance on the mind map activity, or some other factor is unknown, but these trends are observable in each of the grade bins, and

therefore, is not related to students overall grade performance in the course.

V. CONCLUSION

In this work, we investigated the viability of using RGF-distance as a graph metric that could be used to automatically give students feedback on their own mind maps. We compared other simple graph metrics to verify that RGF-distance is a superior metric based on how it compares graph structure. Next, our results showed that there is some relationship between final grades and RGF-distance measured for student made mind maps compared to a criterion model. This relationship, however, was not strong, and we do not believe that mind maps could be used to assess students on activities that are not vocabulary focused. When understanding a field's vocabulary is the focus, the mind map evaluated in terms of RGF-distance could be used as a grading tool, but further exploration is needed in this area.

Our analysis of individual performance of a student over the term showed that mind maps, in general, improve over time based on a decrease in RGF-distance. This result is exciting since we could imagine a scenario where a student could use a tool over the term to see how their understanding of topic vocabulary has improved compared to their previous attempts. This type of scoring mechanism is useful to provide an overall evaluation of the mind map, but it does not provide a mechanism to provide detailed feedback to the learners.

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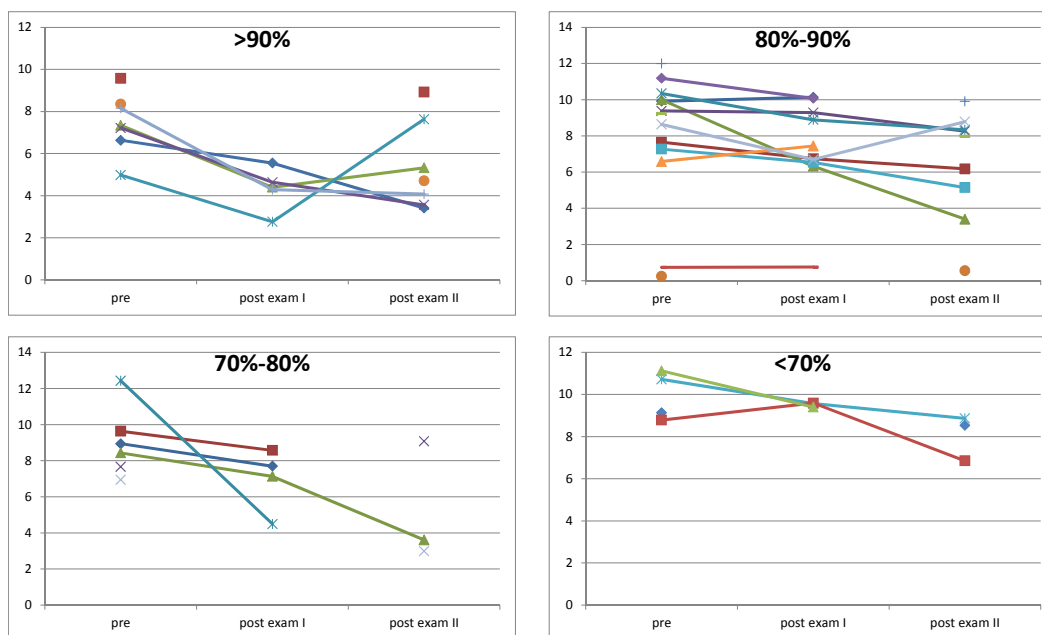


Fig. 4. Line graphs for student mind maps RGF-distance over semester sorted into final grade bins with time of mind map on the x-axis and RGF-distance metric on the y-axis.

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Work in Progress: Changes in Elementary Teachers' Noticing of Engineering Pre/Post Professional Development with Engineering

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Abstract—The addition of engineering to many state standards has created a need for effective teacher professional development. The Institute for P-12 Engineering Research and Learning (INSPIRE) facilitated summer engineering workshops for teachers in grades two to four. Participants completed the Noticing Activity, an assessment meant to gauge teachers' ability to notice and discuss engineering and its role in society. This work in progress describes the coding system being developed to analyze teacher responses. Analysis of teacher responses to the Noticing Activity will be used to determine what teachers notice about engineering in society and, later, help study how teachers discuss engineering with their students. Results from the coding will be used for programmatic evaluation and revision.

Keywords—component; Elementary Engineering, Teacher Professional Development, Assessment

I. INTRODUCTION

As the United States strives to increase the engineering literacy of K-12 students [1], the building of knowledge and understanding of engineering's vast presence in the world is critical to elementary teachers. The Institute for P-12 Engineering Research and Learning (INSPIRE) provides professional development designed to develop teachers' accurate perceptions of engineering so that they can engage in conversations with their students about engineering's role and presence in society [2]. Through INSPIRE's engineering professional development academies, elementary teachers are given an opportunity to learn about and engage in engineering activities, which ultimately leads to increasing their engineering literacy. The four stated goals for these academies prepare teachers to:

- 1) convey a broad perspective of the nature and practice of engineering;
- 2) articulate the differences and similarities between engineering and science thinking;
- 3) develop a level of comfort in discussing what engineers do and how engineers solve problems; and
- 4) use problem-solving processes (i.e. science inquiry, model development, and design processes) to engage P – 6th grade students in complex open-ended problem solving.

The goal of the Noticing Activity is to learn what elementary teachers' notice about engineering artifacts and engineers in action before and after a professional development

academy. Prior work [2] indicated that after one week long academy teachers increased their noticing of design considerations and the types of engineers that made these decisions. This paper presents a refined definition of the coding scheme for the Noticing Activity intended to measure change in teachers' recognition and articulation of engineering related goals and product design.

II. PURPOSE

The results of the Noticing Activity will aid in enhancing engineering learning for educators and students by supporting STEM instruction across the curriculum. Ultimately, such instruction will prepare future generations of STEM innovators.

III. METHODS

A. Participants

Elementary (grades 2-4) teachers' perceptions of engineering are being examined using a pre/post assessment administered to participants who attended a week-long summer engineering professional development academy in 2009 and a three-day follow-up in 2010. The first year, 2009, the participants ($n= 36$ pre, 35 post) engaged with curriculum that provided an overview of engineering. Teachers learned an iterative design process through hands-on design challenges. Teachers learned about the various engineering disciplines through the contexts of the design challenges and through a panel discussion with engineers. In the second year, 2010, a subset of the participants from 2009 (21 pre, 23 post) were engaged in activities aimed at deepening their understanding of the engineering design process, improving their ability to differentiate engineering and science, and expanding their perceptions of the role of engineers and engineering in society. Boyle, Lamprianou, and Boyle [3] revealed that teachers who participated in long-term professional development implemented greater changes to their teaching. Additionally, Garet, Porter, Desimone, Birman, and Yoon [4] indicated that time span and contact hours are two vital factors when investigating the effectiveness of teacher professional development. Our conjecture is that the repeated professional development experiences increase teachers' ability to notice and articulate engineering themes associated with products/process and the engineers responsible for making these products/processes possible.

B. Noticing Activity

Each year, participants completed a pre- and post- Noticing Activity that includes two photos of engineering; one is an engineered object (e.g. milk carton, water filtration, apple peeler), the other represents engineering in action (e.g. bioengineer in a farm field, environmental engineer testing water, and manufacturing engineer in plant). Participants responded, in a free-response format, to the following question about each photo: “From an engineering perspective, describe the object(s) or event that is the focus of this photo for you.”

IV. DEMONSTRATION OF CODING SCHEME

Researchers at INSPIRE have developed [2] and are now refining a coding system for cataloging teacher responses to the Noticing Activity. The initial coding scheme focused on factors of design and the structure, function and behavior of artifacts [2]. The revised system uses a flowchart format to better select codes defining teachers’ interpretation of photos of engineered objects and engineers at work.

The coding system has gone through four revisions with a most recent inter-rater reliability (IRR) estimate of 79%. The IRR is calculated by averaging the percentage of agreement for the coders (see an example in Table I). The total IRR is calculated by averaging the percent agreement for all coded items.

TABLE I. EXAMPLE OF IRR CALCULATION
(BOLD LETTERS INDICATE AGREEMENT)

| Coder | Codes for Response 1 | Agreement w/ other coders | Average percent agreement |
|---------|----------------------|---------------------------|---------------------------|
| Coder 1 | A, B, C, D | 75% | 68% |
| Coder 2 | B, C, D, E, F | 60% | |

Table II provides a sample of two teacher responses and the associated codes assigned. Each response provided by a teacher could earn multiple codes, depending on the information included in the response. The primary codes for objects deal with function, structure/parts, goal of the person creating the object, and design (who made it, design process steps, considerations, manufacturing). The primary codes for people deal with naming of the engineer (i.e., general engineer, specific engineer, no engineer mentioned), location of the activity, goal of the person, actions of the person, and design considerations.

V. FUTURE WORK

All participants’ pre- and post- responses for 2009 and 2010 are being coded and analyzed, and from this analysis, changes in what teachers notice about engineering and how they communicate their ideas about engineering and its role in society will be identified. Additionally, results will help answer

TABLE II. DEMONSTRATION OF CODING SYSTEM

| Response | Object/ Person | Codes and Explanation |
|---|----------------|---|
| Engineers designed this tool to improve our ability to easily and quickly peel fruits and vegetables. | Object | dwg : “Design-Who-General” code assigned when participant mentioned engineer with no specific reference to type ddg : “Design-Goal-General” code assigned when participant mentioned designing as a general goal of the person making the object. dgi : “Design-Goal-Improve Life” code assigned when participant mentioned improving our ability, therefore improving life. |
| Environmental engineer taking water samples to make sure that is safe. | Person | ns : “Naming-Specific Engineer” code assigned when participant mentioned a specific type of engineer. ac : “Action-Collect samples” code assigned when participant mentioned the engineer collecting water samples. cs : “Consideration-Safety” code assigned when participant mentioned safety as a consideration. |

questions about the effectiveness of this professional development model (intervention→ classroom implementation→ intervention→ classroom implementation). Future work will include a comparison of teacher changes and student changes (based on student assessments) to help determine the classroom impact of an engineering teacher professional development intervention.

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Using Robots to Teach Programming to K-12 Teachers

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Abstract— We present the results of a pilot study in which twenty K-12 teachers were introduced to LEGO NXT-G robot programming through a three-day summer workshop. Our aim was to give teachers the confidence and skills to start after-school robotics programs with their students. We present details on the workshop, including the approach we used to recruit teachers and an overview of the three-day course. We discuss the data gathered from the teachers following the workshop and also give our own recommendations for others who may wish to run a similar program.

Participants ranged from elementary school general classroom teachers to high school math, science, and even computer science teachers. Prior to attending our workshop, 89% of the teachers had little or no programming experience and generally were not very confident in their own ability to be able to learn how to program a robot. After completing the workshop, their confidence increased dramatically and they had a strong expectation that they would use the material with their students. A follow-up survey nine months later indicated that hundreds of students and many colleagues were impacted in the first year alone.

Keywords- *Computer Science Education; K-12 Teacher Education; Educational Robotics; Introductory Programming; Graphical Programming Languages*

I. INTRODUCTION

The U.S. Bureau of Labor Statistics projects that hundreds of thousands of new jobs will be created in Computer Science-related professions and that some of these occupations, e.g. computer software engineers, are among the fastest growing of all [1]. One would imagine that such predictions would lead to an increase in Computer Science education in US secondary schools, but in fact the opposite is true – the number of Computer Science related courses being offered in US high schools has actually seen a dramatic decline over the last several years [2].

Even if there were a sudden realization by school districts en-mass that it was imperative to introduce or increase their Computer Science offerings, there are very few teacher education programs that have the capacity or curriculum to adequately train pre-service teachers to become Computer Science teachers [2]. Part of the problem is that the K-12 educational standards for subjects like Computer Science and Engineering are not as mature as those for the more traditional

STEM areas such as mathematics, biology, chemistry, and physics [3].

Given this background, we were motivated to find a way to introduce more Computer Science concepts into non-Computer Science classrooms and after-school programs in middle and high schools. We felt that we would have the greatest impact by running workshops for teachers, who could subsequently bring back the material that they learned to their schools and affect many more students than we could hope to teach ourselves.

We chose to use the context of robotics because of the obvious appeal of the medium. Anyone who has walked into a classroom with a robot under his or her arm recognizes the power they have to attract the attention of a room full of students, be they K-12 or even post-secondary. However, some caution is warranted. A decade ago the educational robotics community was devastated when the addition of robots to an undergraduate-level computing course was found to *harm* learning [4]. The authors concluded that one critical factor was the lack of access that students had to the robots. This conclusion is supported by research into more traditional (non-electronic) classroom manipulatives which has shown the importance of giving students sufficient hands-on time with the manipulatives [5].

Fortunately, as robot hardware has become more affordable (and simultaneously more powerful!), studies have shown that when students have more access to robots they do not have a negative impact [6], and in fact there are indications that they may be beneficial [7,8].

In June 2011, we ran a pilot study in which twenty K-12 teachers were introduced to LEGO NXT-G programming in a three day workshop. The remainder of this paper describes the organization and implementation of the workshop itself as well as the results of data gathered from the teachers following the workshop and recommendations for others who may wish to run a similar program.

II. PREPARING FOR THE WORKSHOP

A. Finding an Engaging Context

Because we anticipated that the majority of our teachers would not have a specific need for computer science in their curricula, we wanted to give them a clear vision of how they

This program was supported by a Google CS4HS grant, <http://cs4hs.com/>

might use this material beyond the classroom. Thus we titled the program “Start Your Own Robotics Club: Robot Programming for Absolute Beginners” and included material on the FIRST LEGO League (FLL) Robotics program for 9 to 14-year-olds. Our hope was that after our workshop they would have the confidence and skills to start FLL clubs at their schools.

Many of the teams that participate in FLL competitions are based in after-school clubs and coached by teachers. FLL teams compete in two parallel activities: the research project and the robot game. In the research project, students explore an actual problem that scientists and engineers are trying to solve. Students develop their own solutions to the problem and present the results of their work to judges at the FLL event. In the robot game, students build a robot out of LEGO components, and program it in one of two specialized languages to move autonomously on a themed playing field to score points.

Of the three key tasks involved in FLL competitions: research, LEGO design, and programming, we felt it was likely to be the programming component that secondary school teachers will be least prepared to teach. Further, it was easy to imagine that many teachers would find the prospect of learning to program on their own too intimidating to consider coaching a team.

We ourselves have been involved in running an FLL event for many years now and have been impressed with the quality of work that the children do in preparation for the event and with enthusiasm and energy that they bring with them. Beyond our anecdotal observations, formal studies of the FLL program have shown that FLL increases student interest in science & technology, improves their understanding of how science can be used to solve real-world problems, and increases other important skills including teamwork, leadership, and planning [9].

B. Selecting Robot Hardware and Software

The LEGO Mindstorms robots [10] are the only robots approved by FLL, and the NXT-G software is one of only two FLL options, and these factors did have some influence on our choice of platform and software. We considered the ability to use FLL as a context to be an advantage, however this was not by any means the most important factor in our choice of this hardware and software – we could have easily decided to use an “after school robotics club” theme without any mention of FLL.

The Mindstorms NXT robots have many advantages for the middle and high school market. First and foremost, they are fairly robust – driving off a desk may (or may not) result in an explosion of LEGO bricks and beams around the classroom, but permanent damage is much less likely. The sets also come with an interesting assortment of sensors that work surprisingly well, and while it is hard to call the NXT robots inexpensive, they are relatively affordable and many schools have already purchased a few. Finally, while they may not be familiar with robotics or programming, most middle and high school teachers have at least some experience with traditional LEGO, which, we hoped, might reduce the “intimidation factor.”

The LEGO NXT can be programmed in a wide variety of languages [11], but as was previously mentioned, FLL only supports the two official languages supported by LEGO. Again, this did influence our choice of the NXT-G language, however much more important was our desire to use a visual programming language (following the scratch model) because we felt that would be less intimidating to teachers than a text-based language. Both NXT-G and LabVIEW (the other language supported by LEGO) are visual languages, however NXT-G is considerably simpler and thus we felt it was the better choice

C. Attracting Teachers to our Program: Minimizing Anxiety and Maximizing Value

1) Minimizing Anxiety: Removing the “Intimidation Factor”

It is our belief that anyone qualified to teach STEM (Science, Technology, Engineering, and Math) subjects at the secondary school level is highly capable of learning the basics of programming. However we are also very cognizant of the fact that many skilled math and science teachers have a fear of all things computer science – unfortunately we’ve heard statements like “computers just don’t like me” all too often.

Thus we took great care from the very beginning to emphasize to teachers that they would not be overwhelmed by our workshop. All of our literature emphasized that teachers would be learning a visual programming language and that no prior programming experience was required. We even subtitled our workshop “LEGO Mindstorms Programming for Absolute Beginners.”

2) Maximizing Value

We were fortunate to be the recipients of a Google CS4HS grant [12] to support our workshop. While we could have offered the workshop to the teachers free of charge, we chose instead to charge them a fee, but to give those who completed the three-day workshop a LEGO robot kit to bring home with them which alone was worth more than the cost of registration.

III. WORKSHOP DETAILS

A. Participants

Twenty teachers participated in our workshop. 17 of the 19 teachers who responded to our exit survey reported that they had little or no programming experience prior to attending our workshop.

While we originally advertised this workshop for middle school teachers, we attracted a much wider range. The teachers taught the following grades:¹

| | | |
|---------------------------|----------------------------|-----------------------------|
| 4 th grade: 4% | 7 th grade: 20% | 10 th grade: 6% |
| 5 th grade: 8% | 8 th grade: 18% | 11 th grade: 10% |

¹ Some teachers teach multiple grades, each teacher was counted once for each grade they taught, percentages are rounded to the closest integer value.

| | | |
|-------------------------------|---------------------------|--------------------------------|
| 6 th grade: 16% | 9 th grade: 6% | 12 th grade: 10% |
|-------------------------------|---------------------------|--------------------------------|

The teachers taught the following subjects:²

| | | | |
|----------------------------|---------------------------------------|----------------------------|----------------------------|
| Math: 42% | Elementary: 8% | Computer Science: 4% | Pre- engineering: 4% |
| General Science: 12% | 6 th grade resource: 4% | Physical Science: 4% | Special Ed: 4% |
| Chemistry: 8% | Biology: 4% | Physics 4% | Technology: 4% |

B. Duration

Our 3 day workshop ran from 8:30 a.m. to 5:00 p.m. In the exit survey, two of the teachers indicated that they felt the days were very long (though we also had comments that the length was just right or even too short). Our days were much longer than many other teachers' workshops run at our university; those typically run from 8:30 a.m. to 1:30 p.m. or 3:00 p.m.

We have a certain reluctance to shorten the length of the day simply because it is very difficult to imagine what we might cut. One obvious way to shorten the day would be to reduce the significant time (roughly 2 hours per day) we had allocated for breakfast, lunch, and breaks. We had intentionally put these extended breaks into our schedule in order to offer the teachers many opportunities to meet and interact informally with their colleagues so that they might form relationships that they could use during the school year, but are considering reducing them in future workshops.

C. Academic Topics

1) NXT-G Programming

As would be expected, roughly 75% of the academic time in the workshop was spent on NXT-G programming. This included lessons on simple outputs (displaying pictures and text on the NXT's small LCD screen and controlling motors), sensors (using the touch and light sensors), and programming concepts (loops, event handling, conditionals, functions, and variables).

2) FIRST LEGO League "Prep School"

Half of the remaining academic time was spent discussing topics relevant to those interested in starting FIRST LEGO League (FLL) Clubs at their schools. In addition to an overview of the FLL program, we included modules on the art of LEGO design, coaching students as they plan and carry out their research project, and preparing students for the judging process.

D. Other Ways to Integrate Computer Science into the Classroom

Each day, we gave teachers a break from robot programming by offering an introduction to another tool that they might find useful in their classrooms or in after-school programs. Our focus was on tools that they could use in their classrooms without having to buy additional hardware. We presented two other programming environments, Scratch [13, 14] and Alice [15, 16]. We also introduced Computer Science Unplugged [17] as an easy way to introduce Computer Science topics in their classrooms without needing a single computer.

E. Workshop Format

We used a variety of formats to teach the academic topics, including:

1) Interactive Robot Programming Lessons

These begin with a brief introduction to a topic, followed by a series of step-by-step programming examples that the instructor would walk the teachers through (the teachers would follow along by programming their own robots in parallel with the instructor). These lessons would conclude with time for hands-on exercises for the teachers to try individually or in small groups. Undergraduate teaching assistants were on hand to help keep the lessons moving by helping out when individuals got stuck.

2) Lectures

The FLL topics were presented as a set of short lectures during which teachers were encouraged to interrupt with questions. The "other ways to integrate Computer Science into your classroom" talks were lectures with some hands-on components.

3) Hands on Differentiated Instruction

Teachers were provided with sets of exercises of increasing difficulty and encouraged to pick the exercises that they felt were most appropriate. Faculty and undergraduate teaching assistants were available to help as needed.

4) Demonstrations

At the end of the workshop, the teachers demonstrated their favorite programs to each other.

IV. GATHERING DATA

A. The "Exit Survey"

At the end of the workshop we asked participants to complete an on-line survey which included detailed questions about their experience. Teachers were given the option of including their email address in the survey or remaining anonymous. Nineteen of the twenty teachers participating in the workshop completed the survey. Throughout this paper we use the term "exit survey" to refer to the data gathered from this survey.

² Some teachers teach multiple subjects, each teacher was counted once for each subject they taught, percentages are rounded to the closest integer value.

B. The "Follow-up Survey"

In March 2012, roughly 9 months after the workshop, we emailed our workshop participants and asked them to complete another on-line survey which was completely anonymous. Eleven of the twenty participants completed this survey. Throughout this paper we use the term "follow-up survey" to refer to the data gathered from this survey.

While we wish we could have had a better response rate, our rate of 55% is actually quite respectable – the teachers had no incentive to complete the survey, and one teacher reported that he was unable to access it – his school blocked access to the survey web site!

We are considering a variety of ways to improve follow-up responses in future workshops. Options include simply letting teachers know during the workshop that we'll be surveying them later and asking for their help, making the course textbook be an extra that they receive only if they agree to do their best to fill out the follow-up survey, or actually offering them an incentive at the time of the follow-up survey.

V. EVALUATING THE EFFECTIVENESS OF THE WORKSHOP

In this section we discuss our goals for the workshop and use the data from the exit and follow-up surveys to evaluate our success in achieving them.

A. Goal: Increase Teacher Confidence

As mentioned earlier, a major goal of this work was to demonstrate to the teachers that they were capable of learning and teaching this material. 89% of our teachers had little or no programming experience before attending our workshops. We mistakenly neglected to ask them about their confidence in teaching Computer Science concepts, but we did ask them two related questions on the exit survey, specifically:

"Prior to taking this class how confident were you that YOU would be able to learn to program a robot?" Result: **2.68** on a scale of 1 ("Not at all confident") to 5 ("Very confident")

"Now that the workshop is over, how has your confidence changed?" Result: **4.21** on a scale of 1 ("Much less confident") to 5 ("Much more confident").

B. Goal: Impact at least 100 students in the 2011/2012 school year

The results of our exit survey indicated that our teachers were anticipating impacting between **327 and 469+** students in the 2011/2012 academic year alone.³

Expectations immediately following a summer workshop such as ours can certainly differ from the actual results achieved during the school year when teachers have much less time and many more demands of their time and energy. We must admit to being somewhat nervous when we sent out the

follow-up survey, but that anxiety was quickly replaced with excitement as the data came in:

- Approximately **200** students have been exposed to this material in the classroom.
- Approximately **70** students have been exposed to this material outside of the classroom.
- The teachers anticipate that approximately **75** additional students will be exposed to this material during the remainder of the school year.
- The teachers also introduced the material to almost **20 non-students** (other teachers as well as principals and other administrators).

Of course, these data are based on the 55% of teachers who chose to respond to our follow-up survey. It is difficult to imagine how to extrapolate these results to the full set of teachers. One might imagine that the teachers who did not respond were the ones who did not use the material. It seems unlikely that all 9 of the remaining teachers did not expose a single additional student to the material. We expect that was true for some, but probably not all, particularly since the survey was completely anonymous. Indeed 3 of the 11 teachers who did respond reported that they were not using any of the material this year. Of those three, two indicated that this was because of school-related issues beyond their control. Furthermore, as was mentioned above, at least one school district blocked access to our survey web site.

C. Goal: Integrate Computer Science Topics into both the School Day as well as Extra-Curricular Activities

As the numbers above indicate, teachers are using this material in and out of the classroom. We were actually surprised by the ratio reported by the teachers: we anticipated that teachers would find it difficult to integrate our material into their classroom curricula, and thus the majority of the students impacted would be in after-school clubs. In fact, there are almost three times as many students being exposed to this material in the classroom!

D. Goal: Improve Teacher Attitudes Towards Computer Science

Attitude towards computer science is very difficult to measure quantitatively and we are working to improve our survey questions for subsequent workshops to better assess this question. Nevertheless, one thing is clear from the data - the teachers were very pleased with our program. In response to the following question on the exit survey: "How strongly do you agree or disagree with the following: Overall, I found this workshop to be worthwhile," we scored **4.68** on a scale of 1 (Strongly disagree) to 5 (Strongly agree). Additionally, in response to the question "Would you recommend this workshop to a colleague?" we scored **4.79** on a scale of 1 (Not likely at all) to 5 (For sure!)

We hope that the teachers' attitudes towards computer science have indeed improved, and that they have passed this on to their students.

³ We asked teachers to report how many students they expected to be exposed to the material next year. They were offered the following sequence of choices: [0, 1-5, 6-10, 11-20, 21-30, 31-49, 50+]. The number that selected each range, respectively: [0, 2, 2, 7, 5, 1, 2]

VI. RECOMMENDATIONS

Given the astonishing impact that one small workshop can have, we hope that others will follow our lead and establish similar workshops in their communities. In this section we discuss some of the techniques and tools that we used in our workshop that we think worked particularly well.

A. Hardware

We gave each teacher a LEGO Mindstorms Education NXT Base Set [18] along with the NXT-G software [19]. We strongly prefer the education set over the commercial set because it comes with a well-designed storage box and includes diagrams explaining how to store all the parts in an organized way. While this may seem at first seem to be a trivial detail, in practice it is so important for classroom use that we felt it essential to include this recommendation in this paper. The Education Base Set also includes a rechargeable battery pack which is important for anyone who doesn't have access to a vast supply of AA batteries.

The primary disadvantage of the Education Base Set is that the software is sold separately.

B. Student Teaching Assistants

We had 5 Computer Science undergraduate students that we hired to work with the 20 teachers during all of the lecture and hands-on periods. During the lectures, it was quite common for a teacher to say things like, "wait, what do I press?" or "my screen looks different" or "mine won't download." Without the student TAs this would have been very disruptive and slowed us down a lot. Instead, the TAs jumped in as needed and clarified and/or solved most problems very quickly. The teachers gave them rave reviews:⁴

"They were great very helpful, they told you how to fix a problem but left you to do it so that you learned but if you could not get it they showed you how to fix it."

"They were amazingly nice, professional, fun and patient!"

"Very knowledge and always willing to help. Did not make you feel stupid."

C. Teachers Programming their own Robots in Parallel with the Instructor

Because we targeted our workshop at teachers with little or no programming experience, having them actively follow along seemed essential to giving them early confidence. Teacher comments on the exit survey indicate we succeeded:

"[The first day was a] great intro day, not too scary!"

"This was a very fun day. Speakers and students made it seem possible to master programming."

D. Hands-on Differentiated Instruction

By the end of the first day it was very clear that some of the teachers, perhaps due to prior experience, natural ability, or

even confidence level, were keen to work on more difficult problems, while others wanted to take things very slowly. So that night we modified the day 2 hands-on exercises to offer the teachers a wide range of options – everything from "try to rewrite the programs we wrote in lecture on your own without peeking at your previous solutions" to "try one of the advanced FIRST LEGO league challenges." We had teachers at both extremes. This worked so well we repeated it on day 3.

"For me, I felt the unstructured time was great for all of us to work on our own projects. I would have been completely lost if it weren't for your wonderful TA's."

"Really enjoyed having time to work on our own and program our own stuff."

E. Mid-Course Surveys

We asked teachers to fill out mid-course surveys twice on day one (at lunch and late afternoon) and in the afternoon on day two. The surveys had four simple questions: two about the pace of the workshop, one asking if there were any unanswered questions, and the final one asking for any other comments. While mostly they served to reassure use that, on the whole, things were going well, we did get the occasional question or suggestion that was useful.

F. One Robot Per Participant

This is obviously expensive, and we were particularly fortunate that our grant funds enabled us to give each teacher their own robot to use at the workshop and bring back to their school afterwards. Having one robot per participant was not only useful during the lessons – the most enthusiastic teachers could bring the robots home in the evening to explore further. Even more importantly, teachers had the robot at home all summer to prepare for classes and clubs in the fall.

G. Building the Robots Prior to the Workshop

Each teacher was given a pre-built robot at the start of the workshop. While there is certainly a learning curve to working with LEGOs, even with detailed instructions and experience building the same base multiple times, we found the process time consuming. Had we left this task to the teachers we would have lost several hours that were better spent focusing on programming.

H. Giving each Participant His or Her Own Flash Drive

We handed out flash drives every morning and collected them at the conclusions of day one and two so we could add material. During the workshop this meant that they had quick and easy access to sample code, executables (including a full version of the Scratch programming environment), and workshop slides. Of course they took the drives home with them and now have a record of everything we did in one convenient place

I. Each Teacher Bringing His or Her Own Laptop

We advertised the workshop as "laptop recommended," planning on loaning one to any teacher who didn't bring one along. In retrospect, there is a huge value to the teachers going

⁴ Minor grammatical and spelling errors have been corrected in teacher quotes throughout this document.

home with the software and all of their programs on their personal laptop, and we're very pleased they all brought one. In addition, one teacher brought a netbook whose screen was too small to display all of the panels on the LEGO NXT-G software window making it (initially) unusable. We loaned her a laptop and one of our TAs managed (with significant effort) to find a way to display the different panels in individual windows. Had the teacher not brought her netbook to the class, she would have assumed that she couldn't use the LEGO software on a small screen. Instead, the whole class learned that there is a solution to this problem, and we posted the solution on the web so that they (and others) can find it in the future.

VII. CONCLUSION

It is quite remarkable that a single small workshop can have such a significant impact on a community. Twenty teachers who were, as a group, very unsure about their ability to learn to program robots left after three days with dramatic increases in their level of confidence. These teachers brought the material back to their schools, and by the end of *this academic year alone* several hundred students will have been exposed to the material, along with tens of other educators and administrators.

We hope that this paper will encourage others to develop similar workshops. Perhaps together we will be able to change the way computer science is introduced to young people, and that eventually computer science will become a significant part of middle and high school curricula across the country.

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The Effect of University Research Experiences on Middle Level Math and Science Instructors Perceptions

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Abstract—TERMS (Transitioning Engineering Research to Middle Schools) is a Research Experience for Teachers (RET) project that targets the middle school teachers who teach the students most at risk for losing interest in science, engineering, and mathematics. As most students advance through middle school science classes, their attitudes toward science and math become more negative. The middle grades are a critical period for students, representing the period most beneficial to provide engaging academic opportunities. The TERMS project strived to develop curriculum and experiences for the middle grades by placing the teachers into a community of practice. The research component of the project was enhanced over three years; the teachers wrote research papers, developed research boards for science fairs, and gave research presentations. The program has improved teacher perceptions towards engineering research and teaching. This is evidenced by a survey that was adapted from one available to the RET network. The survey looks at the satisfaction with the RET experience, the extent that the faculty mentor met RET expectations, the success of the RET experience, the impact of the RET program on the RET personally, level of engagement, and learning experiences. Research results are provided from additional surveys that examine teacher perceptions towards research and science and mathematics teaching through the context of engineering.

Keywords- Middle level, research experience, teacher perceptions, community of practice

I. INTRODUCTION

The motivation for engaging some of OSU's most productive faculty in K-12 engineering educational experiences stems from critical needs at both national and local levels. Nationally, calls to action—i.e. Rising Above the Gathering Storm [1]—strongly urge policymakers to strengthen and build the United States' research infrastructure. These reports paint grim pictures of the country's technological and economic future if steps are not taken to improve and diversify STEM education. It is clear that in training the scientific workforce of the 21st century there must be more collusion among all stakeholders in education. The faculty members involved in STEM are passionate in believing action must be taken. At the local level it is becoming a high priority to increase recruitment of students entering the engineering program, particularly females and ethnic minorities. This project - Transitioning Engineering Research to Middle Schools (TERMS) - helps to foster sustainable long-term solutions to recruiting and

diversity issues. A key question is how to best create a sustainable pipeline of qualified and diverse students into a program focused on retaining them once they enter. TERMS is synergistic with, draws from, and builds on other engineering education efforts at OSU. These include *Engineering Students for the 21st Century*, an undergraduate department level reform; several CCLI awards that focus on bringing research into the classroom; and locally funded programs for K-12 schools.

TERMS addresses needed development of human resources in the state of Oklahoma by creating a network of teachers across the state who engaged students in technical subjects. This aspect of professional development is critically needed in middle schools since national standards are moving away from a teacher-oriented format focused on topics towards inquiry oriented science learning. TERMS created, tested, and disseminated age-appropriate, inquiry-based course materials aimed at middle school audiences. These course materials will focus both on transitioning research into the classroom, the engineering design cycle and emergent phenomena.

II. DESCRIPTION OF TERMS

The TERMS project is a combined REU (Research Experience for Undergraduates) and RET program that engages teachers in middle grades (6th-9th) and undergraduate engineering students in research. Teachers and undergraduate students were matched with a faculty mentor on a coherent, focused research project. All research emphasized a single theme - how engineers understand, design, fabricate, and test materials and structures whose overall properties are determined by collective interactions of their parts or *emergent phenomena*. Each research team transitioned the results of their research to projects that can be undertaken in the middle school classroom; training in how to enable this transition is a key component of TERMS.

TERMS is built around four distinguishing features. The first aspect of this project is that TERMS targets the middle school teachers who teach the students most at risk for losing interest in science, engineering, and mathematics. As most students advance through middle school science classes, their attitudes toward science become more negative and their interests decrease most in the seventh grade [2-5]. The middle grades are a critical period for students, representing the period most beneficial to provide engaging academic opportunities.

Focusing on teachers and students in the middle grades targets a population which is not being served by existing local activities. While there are several programs focusing on students and teachers in high school—*Project Lead the Way* [6] for example—there are few designed for lower grades. TERMS additionally focuses efforts on student populations—women and under-represented minorities—who can add diversity to OSU’s engineering program. One key question is whether it is appropriate for 6th through 9th grade science and math teachers to undertake focused research experiences. To address this concern TERMS builds on a large body of prior knowledge and experience that has shown teachers in the middle grades can be successful in transitioning research experiences to educational activities [7-13]. Additionally TERMS paired teachers with undergraduate REU students (apprentice engineers) who have experience with instrumentation and engineering applications teachers may lack.

A second distinguishing feature is that TERMS focuses on a coherent, timely, and important research topic that falls in Pasteur’s Quadrant [14] addressing both basic science and application. *TERMS research focuses on how to engineer materials and structures whose behavior is determined by the collective interactions of their parts.* This is an active research area at OSU with programs in biological and medical materials, photonic materials, and colloidal self-assemblies. Facilities and experience exist locally to provide a needed breadth and depth of research experiences. Research on developing conceptual understanding [15] has shown that misconceptions about “direct” processes are easier to correct than misconceptions about “emergent” processes. It is also known that it is more difficult to correct a misconception when the correction requires a shift between ontological domains—i.e. direct to emergent—than if it remains in the same domain [16]. By focusing on research that emphasizes understanding emergent processes TERMS better equips teachers to understand then teach students ways to understand the interdependent processes vital to complex systems.

The third unique aspect of TERMS is that participants were taught effective ways to transition research into the classroom by engineering faculty who have successfully done so. The cohort of teachers and REU students devoted approximately one day each week to creating inquiry-based projects appropriate for K-12 students that are drawn from their research. OSU had a very successful NSF Department Level Reform project—*Engineering Students for the 21st Century* (ES21C)—that developed a process for taking research into undergraduate classes. Engineering faculty familiar with this process drew upon examples from existing undergraduate laboratories to teach key aspects of the process to participants.

Finally TERMS was informed by in-depth analysis of others’ RET experiences to address key elements of a successful research experience. An independent evaluation of RET participants [17] suggests specific improvements to the RET program that TERMS addresses. These include:

- Involvement of low income school districts and drawing several teachers from a single school district. TERMS

focused on local school districts, many that serve low income and Native American populations.

- Development of ongoing collaborative relationships that extend beyond teachers time on campus and supported by detailed orientation and professional development sessions at the start of the RET experience.
- Research faculty mentors that are engaged and interested in helping develop low cost curricular materials for K-12. The use of these faculty mentors as well as undergraduate students that help to serve as research translators were to improve the experience of the teachers.

III. THEORETICAL FRAMEWORK AND RESEARCH QUESTION

The community of practice framework [18-20] suggests that a group can be created with the goal of gaining knowledge specific to a field. Lave and Wenger [18] specifically looked at how apprenticeships help people learn. It is through the process of shared common experiences and information that group members can learn from each other and understand the specific field. Placing the teachers in a research lab as a team and providing them authentic experiences can generate a rich learning and understanding about engineering as they gain relevant expertise. Therefore, having the teachers participate as a community of practice (i.e. an engineering research team) can help teachers’ understanding and perceptions of engineering and therefore their confidence and perceptions of teaching engineering to middle school students.

This framework gives rise to the main study research question for this paper: Does the placement of teachers into a community of practice – teachers in engineering research teams – improve their perceptions of engineering and of teaching engineering?

IV. STUDY CHARACTERISTICS

This study involves 6th-9th grade teachers in combined research and K-12 content development. The program consisted of pre-visit preparation, a six week summer research experience, and follow up academic interactions between RET teachers, OSU faculty, REU students, and middle schools students. The undergraduate students and the teachers formed a team to allow for appropriate translation of the laboratory experiments to the classroom. Additionally, curriculum was developed for the middle level classrooms. The teachers for the program are math, science and technology teachers from rural and Native America districts in Oklahoma. The most recent cohort (from summer of 2011) also had two preservice teachers involved as well as two high schools students (that are entering college in the fall of 2011).

This particular study of the TERMS project is to examine the perceptions of teachers about engineering and teaching engineering. To develop teachers’ confidence, one day each week was devoted to the professional development of the teachers. During this time, the teachers were engaged in the development of several deliverables to develop information for students and curriculum for their classrooms. These included lesson plans, flyers, pamphlets, videos, and implementation calendars. The lesson plans were developed to transition the

research to their classroom, the flyers, pamphlets and videos were to provide project information to superintendents, principals, other teachers, students, and parents about the project. The implementation calendars were developed to see when exactly teachers were covering engineering in their classrooms.

As the research component of the program was enhanced, seven research specific tools were focused on (see Figure 1) to help the teachers gain confidence in research skills and to help them communicate their research results to a variety of audiences. The first deliverable that the teachers had was a lab book where they documented the activities accomplished in the lab. The teachers also maintained a journal where they recorded thoughts and comments about their research and curriculum implementation during the entire year. The teachers prepared a narrative that examined the effectiveness of the summer research program, the effectiveness of their curriculum unit, and the impact on their students. The teachers of the 2011 cohort prepared professional quality research papers that have been compiled into a research compendium. Finally, the teachers prepared research posters for their classroom, power point presentations, and science fair boards. The completion of their research projects plus these deliverables provided confidence and experience to the teachers.

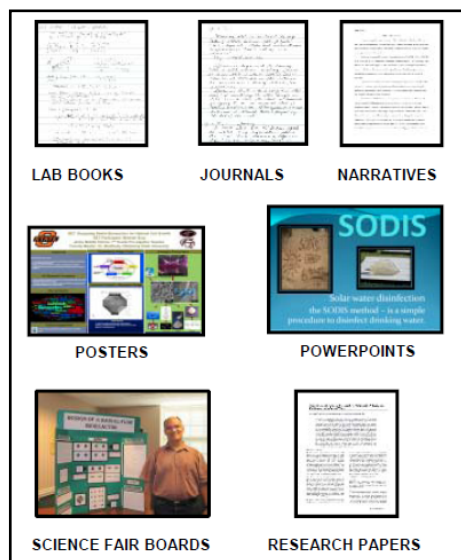


Figure 1. Teacher Research Deliverables

V. STUDY DEMOGRAPHICS

The TERMS program commenced in 2009 and had three cohorts (2009/2010, 2010/2011, 2011/2012). The teachers were selected from districts with low socioeconomic status and a large number of ethnic students. The teachers themselves came from multicultural backgrounds.

2011-2012 Teacher Demographic Information:

N= 8 In-service (5 MS/JH mathematics and 3 MS/JH science teachers) and 2 Pre-service Science
Mean Age – 39 (ages range from 28 to 50)
Years Teaching – 12 (five with 10 or more years and 3 between 5 to 9 years of experience)

Gender – 6 females and 4 male

Ethnicity – 7 Caucasian, 1 Asian, 1 Hispanic, and 1 American Indian

Misc: All but one person was traditionally certified. The one non-traditionally certified has been teaching for 14 years.

2010-2011 Teacher Demographic Information:

N= 8 (4 MS/JH mathematics and 4 MS/JH science teachers)

Mean Age – 38 (ages range from 28 to 48)

Years Teaching – 8.6 (three with 14 or more years and 5 with from 1-9 years of experience)

Gender – 7 females and 1 male

Ethnicity – 6 Caucasian and 2 American Indian

Misc: For two of the eight teachers, teaching is their 2nd career. 3/8 teachers are not traditionally certified in a BS program - (BS degrees in HPER, Animal Science, and Physical Therapy) (all 3 teaching MS/JH science; these BS degrees tend to require strong science backgrounds). 2/8 teachers have a BS degree in Elementary Education (both teaching MS mathematics). The remaining 3/8 teachers have a BS in either secondary mathematics or science.

2009-2010 Teacher Demographic Information:

N= 6 (3 MS mathematics and 3 MS science teachers)

Mean Age – 38

Years Teaching – 9 (one with 28 years and the others from 1-8 years of experience)

Gender – 5 females and 1 male

Ethnicity – 5 Caucasian and 1 American Indian

Misc: For two of the six teachers, teaching is their 2nd career. 4/6 teachers are not traditionally certified in a BS program. (BS degrees in History, German, Agriculture, and 1 not reported). The remaining two have a BS degree in Elementary Education.

VI. RESULTS AND DISCUSSION

Tables I, II and III give results from three surveys. These surveys were administered after the six week summer research experience. While the number of participants in each cohort is small (N=6, 8, 8 for 2009, 2010, 2011 respectively), an analysis by each cohort allows for the examination of overall changes in teachers' perceptions over the three study years. After analysis of year one data, researchers determined they needed additional information on the effect of the RET experiences thus the survey's whose data is reflected in tables I and II were developed. Thus, for these two instruments only two years of data is reported.

The teacher self-evaluation instrument shown in Table I was developed by the researchers as a way for teachers to reflect on their experiences and provide researchers with information on what teachers felt they had gained from the RET experience. To gain a better picture of the teachers RET experience, at the completion of the 6 week experience, teachers were asked to evaluate their experience by ranking the extent to which they believed they had developed insights or made contributions to their faculty mentors research. The instrument contained ten 5-point Likert-scaled questions (1=strongly disagree to 5=strongly agree) with each question followed by a comment section where teachers could further elaborate on their choice or their thoughts on the question.

The results shown in Table I show a high confidence and perception after the six week summer research experience for both cohorts for nine of the 10 statements. The two cohorts from 2010/2011 and 2011/2012 gave similar high results for all elements with the exception of question 3, “I contributed to my faculty mentors research project.” The increase of 1.7 points for the 2011/2012 cohort comes from the increased emphasis on research over the development of large curriculum units and the focus on writing high quality research papers.

TABLE I. TEACHER SELF EVALUATION OF RESEARCH EXPERIENCE FOR TWO COHORTS (2010/2011)

| Question | Average Rating (2010 N=8/ 2011 N=8) |
|---|---|
| I developed insights into the process of scientific research. | 4.8/4.9 |
| I developed an appreciation of the daily work of a scientific researcher. | 4.8/4.8 |
| I contributed to my faculty mentors research project. | 2.5/4.2 |
| I believe that I improved my science skills during the RET experience. | 4.6/4.9 |
| I demonstrated an increased enthusiasm toward science as a real world activity. | 4.8/4.8 |
| I accepted constructive criticism in a professional manner. | 4.8/4.7 |
| I adjusted to the challenges of the laboratory environment. | 4.8/4.8 |
| I believe that my lab placement was worthwhile for me as a teacher. | 5.0/5.0 |
| I shared ways that my faculty mentors research could be used in my classroom. | 4.9/4.5 |
| I believe that my experience persuaded my faculty mentor that this program as worthwhile for them and for myself. | 4.9/4.7 |

Strongly disagree (1) to strongly agree (5)

Further examination of the results in Table I show, that the teachers gave high ratings for developing insight into the process of research, appreciation for what researchers do, challenges of laboratory research, and application of the research to the classroom. The application of the research to the classroom is particularly noteworthy as this is the overall goal of the Oklahoma State University RET, to translate research to the middle school classroom. The teachers felt that the lab placement was worthwhile for them and also felt that the faculty mentors found the program valuable. This comment is worth noting because the faculty members that have been involved in the program have been truly engaged in the process and it is good that the teachers recognize that the faculty feel the program is worthwhile. The faculty mentors were selected specifically based on their experience with K-12 students and teachers, undergraduate research and other characteristics that made them particularly well- suited for this program.

Table II represents another self-developed post program survey with 25 questions that focusses on the teacher's assessment of the overall program. This instrument has questions that pertain to teachers perceptions of their confidence and understanding related to RET experiences. The first section deals with teachers perceptions of a change in their skills or understanding as it relates to RET experiences. Section

2 questions pertain to teachers' perceived confidence and understandings of what engineering is about. Section 3 questions pertained to how they perceived their abilities and skills as they pertained to working with their students. On this instrument, teachers rated their responses on a 6-point (1=strongly disagree to 6=strongly agree) Likert-scale.

TABLE II. TEACHER SELF EVALUATION OF PROGRAM FOR TWO COHORTS (2010/2011)

| Question | Average Rating (2010 N=8/ 2011 N=8) |
|--|---|
| I am capable of contributing to engineering research. | 4.8/5.7 |
| My skill in interpreting results of an experiment has increased. | 4.4/5.3 |
| My ability to analyze data has increased. | 4.3/5.3 |
| My confidence to conduct engineering research has improved. | 4.9/5.7 |
| I am confident in my understanding of the techniques and instrumentation used in engineering research. | 4.9/5.1 |
| My ability to integrate theory and practice has increased. | 4.4/5.0 |
| My faculty mentor was extremely helpful. | 6.0/6.0 |
| I am confident in my understanding of how engineers work on real-world problems. | 5.1/5.4 |
| I am confident that I understand the engineering design process (cycle). | 5.1/5.4 |
| I understand emergent phenomena. | 5.1/4.5 |
| I have a better understanding of how engineers think. | 5.0/5.1 |
| I understand the role science plays in engineering. | 5.5/5.4 |
| I understand the role mathematics plays in engineering. | 5.5/5.3 |
| I often do engineering work in my own life. | 4.3/4.6 |
| Engineering is a social profession. | 5.0/5.5 |
| Most engineers work alone. | 2.0/1.6 |
| My confidence to share engineering process with middle school students has improved. | 5.4/5.9 |
| I have a better understanding of how engineering can be incorporated into the MS curriculum. | 5.4/5.5 |
| I have a better understanding of how engineering concepts tie to math and science PASS. | 5.3/5.3 |
| Middle school students aren't capable of learning engineering. | 1.1/1.2 |
| I am confident that I can share a variety of engineering careers with my middle school students. | 4.5/5.1 |
| I am confident that I can develop curriculum involving engineering concepts for my middle school classroom. | 5.5/5.3 |
| I am confident that I can help other teachers incorporate engineering concepts into their classroom instruction. | 5.0/5.2 |
| I am confident that I will be better prepared to answer those “where will I ever use this” questions. | 5.0/5.5 |
| If given the opportunity, I would repeat this experience. | 5.5/5.6 |

Strongly disagree (1) to strongly agree (6)

For almost all of the questions in Table II, the 2011/2012 cohort had higher confidence and understanding than the 2010/2011 cohort. This again comes from the increased emphasis on research and research paper writing over extensive curriculum development.

For the questions on research (the top seven of table II), the teachers rated the program and their ability highly. The largest differences between the two cohorts are seen for question 2, “I am capable of contributing to engineering research” (0.9

difference), question 5, “My ability to analyze data has increased,” (1.0 difference), question 6 “My skill in interpreting results of an experiment has increased” (0.9 difference), and question 9, “My confidence to do conduct engineering research has improved” (0.8 difference). See bolded items in Table II. Again the teachers rated their faculty mentors highly and this was the highest rated element of these seven questions.

The next nine questions of Table II deal with the teacher’s confidence in understanding engineering and emergent phenomena. For both cohorts their confidence and understanding of engineering was high. The program particularly focuses on understanding emergent phenomena and the design cycle, and this emphasis translated to teacher confidence in these areas. The teachers also appreciate how science and engineering play a role in engineering and how engineers work on real world problems.

The final nine questions of Table II focus on the translation of the research into the middle school. The highest rated question is that the teachers have improved confidence in sharing the engineering process with their students. They understand how engineering can be incorporated into their classroom and have the confidence to do so. They see how engineering can address the Oklahoma Standards (PASS – Priority Academic Student Skills). The teachers feel that they have the knowledge to share engineering careers with their students. Additionally, they feel that they have the ability to help other teachers introduce engineering into their classroom. They have the confidence that their students can learn engineering as well. Finally, they rated the program very highly and would repeat the program if given the opportunity to do so.

Table III shows the results for a post survey that was developed by the RET network (www.retnetwork.org). This survey is a 52 item survey that asks questions about a variety of components of the program. Table III presents 27 of the questions that look at confidence and attitudes particularly related to research and teaching. This post survey was given to all three cohorts. The results show an increase in post teacher attitudes and perceptions over the three years as formative assessment was used to improve the program. Most of the 2011 responses to the questions were the highest for the three years.

The first section of Table III contains questions on the impact of the RET program on the teachers personally. The highest rated question was for “It stimulated me to think about ways I can improve my teaching.” Also rated highly was “I believe I will be a more effective teacher” and “It increased my motivation to see out other experimental professional development activities.” The RET experience gave the teachers confidence to become better teachers. The lowest agreement was for the question about changing career paths. Of the 20 teachers involved in the program (2 of which were preservice), 18 are still in the teaching profession, one became a college advisor in the biology department, and one plans to come to OSU for graduate school in chemical engineering.

TABLE III. RET NETWORK SURVEY QUESTIONS RELATED TO SELF-EFFICACY FOR ALL COHORTS (2009/2010/2011)

| Impact of the RET Program on the RET personally | |
|---|--|
| To what extent do you agree with each of the following statements concerning the impact of the RET program on you personally? | Average Rating 09/10/11 N=6/8/8 |
| It increased my confidence in myself as a teacher | 2.5/3.4/3.4 |
| It elevated my enthusiasm for teaching | 3.0/3.4/3.5 |
| It increased my interest in research and the ways that science, mathematics, or technology can be applied | 3.0/3.8/3.6 |
| It stimulated me to think about ways I can improve my teaching | 3.1/3.5/3.9 |
| I believe I will be a more effective teacher | 3.0/3.3/3.8 |
| It increased my interest and ability in networking with teachers and other professionals | 3.0/3.6/3.6 |
| It increased my motivation to seek out other experimental professional development activities | 3.1/3.3/3.8 |
| It increased my commitment to learning and seeking new ideas on my own | 3.5/3.1/3.6 |
| It changed my career direction | 1.6/1.6/2.2 |
| Learning Experiences | |
| Q: To what extent, if any, do you feel that your experiences each of the following types of learning as a result of your participation in the RET? | Average Rating 09/10/11 |
| I gained a greater understanding of the applications of science, mathematics, or technology in everyday life | 3.3/3.8/3.7 |
| I acquired greater understanding of fundamental concepts in science or mathematics | 3.1/3.3/3.3 |
| I became familiar with new materials and equipment that I can use in my teaching | 3.0/3.5/3.6 |
| I learned about innovative ways to use standard materials and equipment in my field | 2.6/3.5/3.4 |
| I increased my knowledge of current issues in scientific or mathematical research | 3.0/3.6/3.7 |
| I gained a greater appreciation of the difficulties some students encounter when learning science or mathematics | 3.8/2.6/3.2 |
| I better understand how collaborative inquiry can be done successfully | 2.6/3.1/3.6 |
| I increased my knowledge of careers that utilize science, mathematics, or technology | 2.8/3.4/3.2 |
| Level of Engagement | |
| Q: To what extent, if any, did you engage in each of the following types of activities during the RET? | Average Rating 09/10/11 |
| I collaborated in ongoing research with regular staff from the organization | 2.7/1.6/3.4 |
| I designed and implemented my own research or investigation under supervision from a mentor | 2.0/3.1/3.7 |
| I assisted in the process of developing, modifying, or documenting applications of science, mathematics, or technology for my mentor/sponsor | 2.5/2.6/3.4 |
| I operated instruments, equipment, and other technologies | 3.2/3.8/3.8 |
| I participated in conducting research or collecting data out in the field | 2.2/3.0/3.2 |
| I read academic literature or journal articles | 2.5/3.3/3.1 |
| I wrote about the work that I was doing and shared it with my mentor(s) or other professionals at the site | 2.5/3.6/3.9 |
| I wrote a paper that was suitable for submission to a professional journal | 1.3/1.6/2.4 |
| I gave a presentation on what I learned or an activity that I developed | 2.0/3.0/3.6 |
| I accessed information from the Internet that contributed to the work I was doing | 3.0/3.5/3.5 |

1-not at all, 2-small extent, 3-moderate extent, and 4-great extent

The second section of Table III contains questions on the learning experiences provided the teachers. The highest agreement was for the statements about understanding the use

of STEM in everyday life and knowledge of current issues in STEM.

The third section of Table III presents teacher agreement for 10 questions. The highest agreement is for writing about their work. The teachers wrote a research paper. Interestingly, the teachers didn't feel as confident that the papers were suitable for submission to a professional journal. The 2011 year teachers recognized their high level of research engagement.

The results of the three surveys presented in Tables I, II and III show the ability of the Oklahoma State University RET TERMS program to increase the confidence of the teachers in their instructional abilities, their understanding and ability to translate engineering research to the classroom and gave them improved perceptions in a variety of areas.

VII. CONCLUSIONS

This research study provides results for the main research question: Does the placement of teachers into a community of practice – teachers in engineering research teams – improve their perceptions of engineering and of teaching engineering? According to the results presented in Tables I, II and III, the answer is yes. These results are specific to perceptions at the end of a six week university research experience.

For the three cohorts (communities of practice) studied, the teachers showed an increased confidence in themselves as teachers as well as an enthusiasm for teaching, allowed them to network with other teachers and have an improved perception of professional development opportunities. They also gained confidence in themselves in their understanding of engineering and their ability to teach their students engineering. They feel that they are more conversant with engineering research methods and engaged in a variety of productive research endeavors. They feel that they produced quality research results and published these results using a variety of mechanisms.

While not part of the presented study, it can be anticipated that the improved perceptions of the teachers towards their abilities and understandings of engineering will impact their students learning. If the teachers feel more confident, they will begin to engage their students in meaningful classroom experiences. This will help to address the need presented in the introduction of the paper that middle level students need to be provided with meaningful learning experiences.

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Work in Progress:

ACTIVATE: Advancing Computing and Technology Interest and innoVAtion through Teacher Education

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Abstract—In the Northern Appalachian region around Pittsburgh, PA, many high schools do not have computer science courses, so students are not introduced to this critical subject that is needed for most technical career paths. Our unique strategy is to invite current high school science, technology, engineering and mathematics (STEM) teachers, in Pennsylvania, West Virginia, Ohio and Maryland, to participate in 3 summer workshops showing how to incorporate computing concepts into existing STEM courses. By working with teachers on how to assimilate programming and computational thinking into their classrooms we will effectively reach a large population of students in areas where computer science classes are not available. In this paper, we outline the current state of the project and some of the data we have collected. Future goals for this project include performing a rigorous evaluation of teacher impact and developing the workshop materials for wider dissemination.

Keywords: outreach, professional development, computational thinking

I. INTRODUCTION

In the Northern Appalachian region surrounding Pittsburgh, Pennsylvania, computer science is taught in very few high schools. Most students are not made aware of the potential of computing as a field of study and a career that is in demand. Our project tries a novel approach. The ACTIVATE program reaches out to high school teachers of science, technology, engineering and mathematics (STEM) teachers in the Northern Appalachian region around Pittsburgh, where many schools lack essential resources for teacher development and have little support for special programs to interest students in computing careers. According to a recent study, "it is difficult to build a successful computer science program without any knowledge of the field of computer science, or interaction with other computer science teachers." [1] By training teachers in computing principles, we hope to add computing topics to existing STEM courses to increase student awareness of computing and to build a stronger community of computing teachers across the region.

Students are often exposed to STEM-related disciplines through the Advanced Placement program. Figure 1 below shows that the number of schools offering computer science AP classes has remained stagnant over the last decade while all

other STEM disciplines have a significant increase in the number of schools offering these subjects. Figure 2 shows that, as compared to surrounding east coast states, the number of students taking the AP Computer Science A exam is lowest in the Northern Appalachian region. [2]

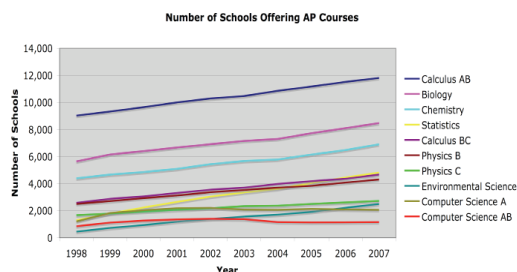


Figure 1. Number of schools offering AP courses related to STEM, 1998-2007.

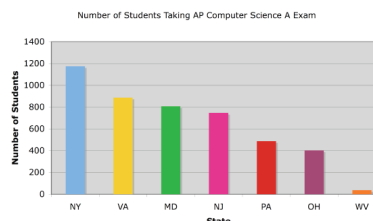


Figure 2. Number of students taking AP Computer Science A exam in Pennsylvania and surrounding states in 2007.

Low student interest in computing careers is in stark contrast with high demand for high-tech employees in this region. Pennsylvania added 6,400 jobs to its high-tech sector in 2006, making it the 7th largest cyber-state in the nation with 210,200 jobs. [3] According to a recent report (covering through 2005), the southwestern Pennsylvania region contains 805 software firms and 92 hardware firms, employing more than 16,900 people with a total annual payroll of approximately \$1 billion. [4]

II. WORKSHOP STRUCTURE

Given the gap between student interest and potential career opportunities in computing, we have developed a series of week-long intensive workshops for high school STEM teachers

in Pennsylvania, West Virginia, Ohio and Maryland, to provide training to enable STEM teachers to introduce programming and computational thinking within their curricula. In order to reach teachers at different levels of preparation and different needs, we have offered three workshops each summer since 2009: Computing with Alice, Computational Thinking using Python, and Java Programming for Math and Science.

Each workshop features four days of instruction to teach the participants the important programming and computational principles and then a fifth day where teachers create an application (using Alice, Python or Java) that illustrates integrating these concepts and techniques into curricular topics they currently teach in their classes. Through presentations and discussion, teachers are encouraged to challenge stereotypical views and to see computing as an exciting and diverse field in which both girls and boys can contribute and excel. We also provide training and guidance to participating teachers who wish to promote computing to a wider audience in events such as assemblies in their home schools and at in-service days for teachers, administrators and guidance counselors. More information can be found at <http://www.cs.cmu.edu/activate>.

III. PARTICIPANT DATA

ACTIVATE has enjoyed diverse teacher participation over its first three years. Of the 179 teachers attending these workshops, 56.4% taught in Pennsylvania, 26.3% in Ohio, 8.9% in West Virginia, and 8.4% in Maryland. A large majority (81.6.0%) taught in public school and 34.6% had more than ten years of teaching experience. As for subject areas taught, some teachers (19.0%) taught multiple subjects. The largest group of teachers teach computer science (47.5%), with mathematics second (43.6%), and science third (22.9%).

In a pre-workshop survey, respondents were asked to rate on a scale of 1 (none) to 4 (quite a bit) their previous knowledge and teaching experience with selected programming languages. More than half answered 1 (none) or 2 (very little), regarding knowledge of and teaching experience in each of the listed programming languages. There were two languages, BASIC and Java, with which computer science teachers indicated a rating of at least 3 (some knowledge and teaching experience). Overall, respondents had limited knowledge and little experience with programming prior to the workshops.

Also, respondents were asked to rate, on a scale from 1 (very uncomfortable) to 5 (very comfortable), their own comfort level with computer-related teaching practices. Over 90% rated themselves with scores 4 or 5 in encouraging students to use computers in and out of class. Also, more than half rated themselves with scores 4 or 5 in their ability to implement instructional activities designed to build students' advanced computer skills (e.g. requiring students to analyze data using software).

IV. PRELIMINARY RESULTS

At each ACTIVATE summer workshop, pre- and post-workshop surveys were given. The surveys included 13 to 15 scaled questions for which participants were to rate their ability to perform and teach concepts and skills

covered in the workshops. Across three years, 99.2% of these questions yielded pre to post increases. Increases ranged from 15.7% to 89.4% and in each year more than half of the questions showed increases greater than 50.0%.

In an effort to measure impact on participant content knowledge, a content assessment was given at the end of each workshop. In 8 of the 9 workshops, respondents mean score was over 70.0%, with highs of 86.0% in Alice (2011) and 84.4% Computational Thinking (2011). The only exception was in the Java (2009) workshop. Subsequently, the first Java assessment data led to significant changes in the Java workshop curriculum. The cumulative assessment average has increased from 65.3% in 2009, to 76.3% in 2010, and 82.7% in 2011.

A year after attending a workshop, teachers were sent a follow-up survey. Nearly all follow-up survey respondents from both 2009 (94.3%, n=50) and 2010 (97.4%, n=37) workshops indicated they plan to use workshop material in new or existing courses in math, science and computing courses. High percentages of 2009 and 2010 respondents, 88.7% (n=47) and 94.7% (n=36), respectively, *agreed* or *strongly agreed* that attending the workshop(s) gave them a better understanding of the practical use of programming. Similarly high percentages *agreed* or *strongly agreed* that the workshop(s) gave them a better sense of how to prepare students for future computer related study, 83.0% (n=44) in 2009 and 89.5% (n=34) in 2010.

Finally, follow-up interviews with workshop participants have yielded interesting findings with regard to classroom impact. In particular, respondents cite that after utilizing workshop materials and practices, their students' showed increased interest and ability to pursue additional study in computer programming, and its practical application. One participant explained the impact of her ACTIVATE workshop in particularly succinct terms: "It certainly increased my background so I could give them some perspectives about math and computers, which made a lot of connections for them because you know they live in a world of technology, animation, and computers."

V. FUTURE WORK

After one additional set of summer workshops in summer 2012, we plan to analyze all of the collected data from the four years of workshops to determine overall effectiveness of this project in updating existing STEM courses to include computational thinking, building teacher communities to share computing activities, and increasing student awareness of computing in the Northern Appalachian region.

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Work in Progress: Theory meets practice: The impact of immersive science teaching experiences on pre-service science teachers' self-efficacy

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Abstract—This work in progress paper addresses efforts to provide authentic, reflective practice in STEM education for pre-service elementary teachers through a partnership between an institute of higher education (IHE) and a public school (PS). Early results are supported by research on school-based partnerships and indicate innovations for meeting challenges to deepen and sustain the partnership for all stakeholders.

Keywords— school-based partnerships; STEM; pre-service; elementary

I. INTRODUCTION

Science and engineering education in the elementary grades is strongly supported by the National Academies of Science [1]. However, pre-service elementary teachers frequently lack familiarity with scientific ways of thinking and often feel unprepared to teach science [2]. Most elementary teachers are not science majors; many tend to view science as a difficult subject. These two factors contribute to an avoidance of teaching science at the elementary level [3]. In particular, the lack of self-efficacy in teaching science among elementary teachers has been documented by several studies [4] [5] [6]. Teachers with a high degree of self-efficacy are more likely to plan lessons with rigorous standards and not give up on poorly performing students than a teacher who has low-self efficacy [7].

Evidence from school-based partnerships between institutes of higher education (IHE) and public schools (PS) has demonstrated promise as an effective strategy for improving pre-service elementary teachers' self-efficacy to teach science [8]. For example, pre-service teachers who integrated theory and practice by planning and teaching a science lesson at a local elementary school, showed an increase in science teaching self-efficacy on the Science Teaching Efficacy and Belief Instrument-Preservice (STEBI-B) [9]. A similar study of pre-service elementary teachers found improved attitudes toward science as measured by the science attitude scale [10].

Generally the literature supports IHE/PS partnerships as successful models for teacher education. However, such partnerships often fail due to challenges related to resources and institutional structures [11].

In recognition of both the potential that such school-based partnerships hold for preparing elementary science teachers and the challenges to sustainability of such programs, this paper is the first in a proposed series that describes the interventions and outcomes of a IHE/PS partnership between a university school of education and urban elementary school in Boston Massachusetts in an effort to identify elements of an effective and sustainable IHE/PS partnership.

Problematic for the sustainability of IHE/PS school-based partnerships are the investment and commitment of both the PS and IHE faculty [12]. Both cohorts need to benefit from the collaboration. Additionally, IHE faculty are frequently reluctant to participate if their outreach efforts do not contribute to Retention, Tenure, and Promotion (RTP) [13]. Rouse and Clawson [14] identify benefits in three categories: material benefits such as salary, supplies; solidarity benefits such as rewards and recognition; and purposive benefits such as the intangible reward for helping a group achieve highly valued goals. The following paragraphs describe initial strategies that address these concerns of the IHE/PS partnership.

II. DESCRIPTION OF THE COLLABORATION

LaChance recommends that lasting partnerships begin by building trust through the accomplishment of initial successful activities together [15]. During the past three years, the IHE has funded a coach to support the PS principal, has funded a bus to transport students to the PS, and has invited PS teachers to make guest presentations in an urban education course that also is taught at the PS. During the past three years the IHS has hosted a STEM day for the PS 4th graders during which they participated in science activities designed and led by pre-service teachers in an elementary methods course. This collaboration has been low risk while serving to forge a working relationship among the IHE and PS stakeholders leading to a commitment to pilot a school-based model for university pre-service teachers at the PS.

Beginning in the fall 2011, the PS science specialist and IHE faculty collaborated to provide a clinical experience for nine undergraduate junior pre-service teachers in the elementary science methods course. The goal was to provide mentored,

Authentic science teaching experiences that foster self-confidence and knowledge of pedagogical strategies to teach elementary science effectively. Two teams of pre-service teachers were assigned to teach one third and fourth grade science class respectively. The teams were each assigned a topic based on the district's science curriculum: life cycles for grade three and animal studies for grade four. The teams were charged with creating lessons aligned with the Massachusetts Science/Technology Curriculum Frameworks using the 5E instructional strategy. The pre-service teachers began by observing exemplary models of science teaching followed by reflection on essential components of classroom inquiry. During the subsequent six weeks, each pre-service team led the elementary students through a series of three lessons and created discovery stations for the children to explore topics, collect data, and keep science notebooks in the interim between classes. Pre-service teachers received feedback following each session from the elementary science specialist, university instructor, and peer pre-service teachers.

III. DISCUSSION

Pre-service teachers from the fall 2011 cohort were given a pre and post-test of the Science Teaching Efficacy Belief Inventory version B (STEBI-B) developed by Riggs and Enochs as metric for self-confidence. Preliminary results suggest that the school-based clinical experience had a positive effect on pre-service teachers' self-efficacy. However, the small $n=9$ precludes a meaningful claim.

Focus groups with the pre-service teachers indicated that planning and teaching lessons for real elementary students was overall positive and regarded as more valuable for teacher preparation than planning lessons without opportunities to implement the lessons. The responsibility of teaching third and fourth graders added intrinsic meaning, motivation, and accountability for the pre-service teachers. Both the PS and IHE faculty agreed that the program is promising not only for the pre-service teachers and elementary students, but also for faculty at both institutions: K12 students experience a diversity of science teaching strategies, in-service teachers grow professionally through exposure to instructional methods and mentoring roles, and higher education faculty garner insight into the real-world applications of theory. The synergy also suggests the potential for research to be translated into practice, and for practice to generate research.

The preliminary findings strengthened the conviction of both IHE and PS cohorts about the potential of the partnership to benefit all stakeholders, with full knowledge that such partnerships are not without challenges. Among these are logistical issues such as travel to the school, adequate space and time, RTP, and concerns regarding material and solidarity benefits addressed by Rouse and Clawson.

With these caveats in mind, the PS principal and school of education dean as well as key faculty collaborated to address

growth and sustainability of the program. With respect to material support, it was agreed that the elementary school will provide office/classroom space for pre-service classes and the IHE will fund the renovation and provisioning of the space. The IHE has also hired a program manager to ensure a smooth flow of information between schools, oversee logistics, and manage communication among pre-service teachers, in-service teachers, and elementary students. The elementary methods science courses will be co-taught by IHE and PS faculty on-site, fostering a deeper immersion of the pre-service teachers in both science and regular classrooms and solidarity among IHE/PS faculty. Faculty at the PS will be titled at the school of education in an adjunct capacity to reward and recognize PS teachers. It is too early to gauge any impact on RTP.

As the program progresses, we propose a longitudinal study with several cohorts: pre-service teachers as they progress through student teaching and begin as practicing professionals, elementary students who participate in the program, and IHE/PS faculty in the context of material, solidarity, and purposive benefits as they relate to sustainability.

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Computational Science Programs: the Background Research

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Abstract— There are many good reasons for an academic institution to pursue the addition of an undergraduate program in computational science. However, poor planning can lead to wasted time, money and resources, and ultimately a failed program. To create a viable program, it is essential to have buy-in from the computational faculty and science faculty, as well as the administration. In addition, it is important to understand the skill-set desired by the potential employers and graduate programs, and to design a curriculum around those needs keeping in mind the expertise of the faculty involved. This paper strives to share what was learned from over a year of background research on what it takes to have a successful computational science program.

Keywords- *Computational Science, Bioinformatics, Interdisciplinary, Curriculum Design*

I. INTRODUCTION

There are many good reasons for an academic institution to pursue the addition of an undergraduate program in computational science. Scientific disciplines, particularly biology, have recognized the need for quantitative services in their research. Computing within a context has proven to attract women, and aid in retention. There is grant money available for interdisciplinary studies in the STEM disciplines. In 2009, Computational Science was touted as one of the 5 majors on the rise by the *Chronicle of Higher Education* [1].

Unfortunately anecdotal evidence has suggested that some that start computational science programs are disappointed. Of the four participants on a SIGCSE 2011 panel discussing newly formed computational science programs, two admitted that their programs were not thriving [2]. Subsequent conversations with professors at other universities revealed similar difficulties that were attributed to poor planning or lack of buy-in from key players.

When we in the Mathematical, Information and Computer Sciences (MICS) department at Point Loma Nazarene University (PLNU) decided that we wanted to create a minor in computational science we determined to do the most thorough job possible of researching curriculum, employment opportunities, industry-desired skill sets, interest of the science faculty, possible interdisciplinary projects, and potential pitfalls. We read papers and reports, conducted interviews with people in

industry, visited labs, read textbooks, perused university catalogs and job requisitions, attended lectures, researched potential grants, and participated in numerous conversations with the scientists at our university.

This paper is designed to share what we learned about the field of computational science, how we gathered information about potential curriculum, the curriculum we have chosen based on our study, and our general strategy for the choices we made.

II. WHAT IS COMPUTATIONAL SCIENCE?

It is hard to produce a universally accepted definition of the term *computational science*. In a recent survey regarding computational science administered by the authors to a gathering of 66 mathematicians and computer scientists, only 15% were able to articulate a reasonable definition of the term. The authors have chosen to embrace a definition provided by the Society of Applied and Industrial Mathematicians (SIAM). Computational science is “*The integration of knowledge and methodologies from mathematics, statistics, and computer science to analyze and solve problems from the STEM disciplines*” [3].

Computational science encompasses sub-disciplines such as computational biology, computational chemistry, computational physics, research genetics, bioinformatics, scientific programming, and biostatistics. Computational activities in support of research in the sciences have included scientific visualization, mathematical modeling, image processing, database design and normalization, user-friendly interface design, scripting for information flow, statistical analysis, design, customization, and analysis of algorithms in support of DNA sequencing and genomics, development of parallel algorithms for modeling and processing of large amounts of data, data mining, data fusion, and design of experiments and clinical trials. The emphasis put on each of these activities may change what computational science looks like in a particular instance.

III. WHY MAKE THE EFFORT?

Encouragement for creating computational science programs is coming not only from industry, but from academic guilds on the computation side as well as on the science side. Furthermore, universities are recognizing that in addition to providing a degree that leads to an in-demand

career, there are side benefits for the institutions that house these programs.

A. Future Research Requires It

There are science-related problems that can't be solved in the laboratory alone. The prime example is the mapping of the human genome. While scientists contributed the genomic understanding, the pattern matching algorithms and computing power required was largely a result of contributions made by mathematicians and computer scientists. The volume of scientific data that can now be collected is growing rapidly, and needs to be searched, analyzed and organized. The call for computational assistance to scientists continues to expand, creating a great demand for people trained to meet the need.

B. Academic Guilds are Requesting It

In 2006 SIAM published a study entitled *Computational Science and Engineering for Undergraduate Students* in which they report on current undergraduate programs in the computational sciences, and encourage the formation of additional programs [3]. This report provides 4 reasons for the creation of computational science programs: interdisciplinary research is increasing, and will play an important role in future discoveries; it provides an opportunity to attract a more diverse student body into computing; it would train future K-12 teachers on what computing looks like in "real-life"; there are funds available for undergraduate experiences and K-12 outreach. We expand on some of these reasons in subsequent sections.

On the science side, *BIO2010*, a report published by the National Academy of Science and funded by the Howard Hughes Medical Institute (HHMI) and National Institutes of Health (NIH) strongly encourages the biology education community to include computation in their coursework noting: "while much of the postgraduate research in biology is enhanced using computational methods, biology educators have not adapted curriculum to introduce students to these computational tools" [4].

Another publication addressing the need for computation in science education is *Math and Bio 2010: Linking Undergraduate Disciplines*. This research was a joint project of the Mathematical Association of America, the American Association for the Advancement of Science and the American Society for Microbiology. They suggested that "The objective of increased quantitative education would be accomplished by introducing quantitative concepts and methods into biology courses while at the same time making biological concepts more prominent parts of courses in the mathematical and computer sciences" [5].

The Chemistry community is also aware of the need to include computation education. Computational Chemistry for Chemistry Educators is a program of the National Computational Science Institute that seeks to provide chemistry faculty with ideas for including computational approaches in the courses they teach. The focus is on using computers to help students learn chemical principles via

such techniques as modeling, data manipulation and graphing, and computer algebra systems.

C. The Institution Benefits from It

For PLNU, the initial reasons for pursuing a program in computational science were the abundance of life science companies in the region providing employment and internships, our close relationships with the scientists who share our building and the desire to provide concrete applications for our applied mathematicians and computer scientists. Additional benefits seem to be recruitment and retention of women into computer science, excellent venues for undergraduate research with available grant money to support that research, and support of the science education community which is demanding that more computation be built into its curriculum.

There is debate over whether contextualized computing education has a positive or negative effect on our students. Guzdial asserts that while contextualized teaching might not help students learn more, research shows that it does provide relevance, leading to improved retention [6]. According to this study, both Media Computation and Robot contexts have proven helpful. Science could provide another interesting context.

Recruiting students as majors in computer science has been an area of concern for many years. The concern is especially great for females. A 2006 report revealed that only 3% of all males in the freshman class intended to major in computer science, but for women, the percentage was an alarming .4% [7]. There is evidence that computational science is a way to interest more women in computational majors. A study involving over 600 high school students in pre-calculus and calculus courses included a survey asking questions about a potential major in computer science [8]. This study revealed that the number one reason female students would consider a major in computer science was if it was in the context of using it in another field. This study supported the findings by Fisher et al. that women are more interested in computing if it has a purpose [9]. Computational science provides that context and purpose. One of the first computational science programs for undergraduate students was developed as an emphasis of a computer science major at Wofford College [10]. Of the 18 students who graduated from the program between 2002 and 2007 in this small college in South Carolina, 44% of them were women.

At the time of this writing, many research funding opportunities are drying up for economic reasons. Funding for research and curriculum development in the computational sciences is a notable exception. The National Science Foundation (NSF) currently has multiple grant opportunities available for both undergraduate research and curriculum development. Funding is available from private organizations such as the HHMI as well.

IV. WHAT WILL IT TAKE?

What must be in place for a new computational science minor or major program to succeed? Research has shown

that the program must receive support from faculty members across the computational and bench science disciplines, from administration, and from local industry as providers of potential projects and internships.

A. Administrative Support

Administrative buy-in is essential. Most programs will have to be built with cooperation across science, mathematics, and computer science departments. Consequently, administration needs to work to help eliminate disincentives to these collaborations. Problems can occur with regard to teaching credit and facilities. The *Chronicle of Higher Education* reported such a problem at Oregon State University when it wanted to expand its computational physics program to other sciences. Faculty members in the other sciences were resistant because they “tended to see computational work as peripheral, and as something they would not get rewarded for at promotion and tenure time” [11]. *BIO2010* suggests “increasing recognition and rewards for faculty who teach outside of their department, possibly by allocating credit hours for teaching based on the department of the faculty member instead of the department listing the course” [4].

B. Faculty Support

Buy-in from faculty across the disciplines is crucial too. Not only will it be helpful for faculty from other departments to teach content in the program, but these faculty members will be indispensable for encouraging students to enter the program. They may also be prime providers of examples and projects.

Enthusiasm from faculty in the sciences is not as easily gained as one might expect. Computer scientists are used to interdisciplinary work because we build tools for others, scientists are not. At PLNU, faculty members from the MICS department interact with faculty members from the science departments everyday due to shared facilities. However, when we initially asked how our department could help support the work of our bench scientist colleagues, we were met with quizzical looks. Even the biologists were unaware of the copious literature in their discipline describing how they can benefit from computational support.

One particular biologist was doing cancer research which involved image processing. The processing, though redundant, was done mostly by hand. When we suggested a way to automate the process, the biologist was thrilled. Not only did he appreciate the elimination of what he saw as tedious work, he valued the increased precision of this more objective type of analysis. As the conversation continued, we discussed creating more user-friendly interfaces to the programs that they already used, script-writing to improve information flow, and other similar ideas.

C. Relationships with Local Industry

One of the top recommendations from the SIAM report was that the curriculum should explicitly include practical

experience in interdisciplinary collaboration. Internships are one of the ways to achieve this goal.

In an effort to start building the necessary relationships with those in industry and to better understand the challenges of computational and bench scientists working together, we wanted to set up interviews with people working in interdisciplinary teams at the life science companies in the area. This proved to be a more difficult task than expected. Using contact information from corporate websites led us to people who were quite confused by our request. The words “computational science” tended to cause them to direct us to the IT department. We eventually had more success by asking for scientists that used computing in their work. Still, people were hesitant to help. We gained one excellent interview via this blind contact, but the others came through personal referrals. These interviews are discussed further in section 5B.

Even with support from administration, faculty colleagues, and local industry, the challenges of working across disciplines should not be underestimated.

V. ADDITIONAL CHALLENGES

Once the science faculty is convinced that a partnership could be beneficial, there is the challenge of actually working together in research and in building an interdisciplinary curriculum.

A. Working in Interdisciplinary Teams

Communication can present a huge challenge when working in interdisciplinary teams. Each discipline has its own unique vocabulary. Even having recently reviewed biological concepts, we found ourselves having to recall definitions as we interviewed biology faculty members, causing us to miss part of the conversation. Similarly, terms that we would use in casual conversation were a mystery to our colleagues. Section 5B discusses the importance that employers place on communication skills. Practice in communicating across disciplines should be intentionally included in any computational science curriculum.

Beyond language differences are differences in how we approach research. While computer scientists and applied mathematicians may take the “let’s see what happens” approach, scientists tend to have a very pointed and narrow focus due to the scarcity of resources. Use of a sample either changes or destroys it. Consider our biology colleague working with cancerous tumors. Once he has applied the treatment to the tumor, that sample cannot be used again.

It is not essential that we understand everything about the complementary field of study. As Tyman points out “biologists do not need to be proficient in the development of algorithms, but need to understand the algorithmic process. This parallels the computer scientists’ need to understand how PCR [Polymerase Chain Reaction] works. Computer scientists need not master the process of actually running a gel, but they should be aware of the process so that they understand its limitations” [12].

B. The Challenge of the Curriculum

Curriculum is another significant challenge. Since there seems to be a lack of agreement as to the definition of computational science, it is difficult to determine what should be included in the curriculum for a related program. The authors of the SIAM report observe: “It should be noted that the successful development of a specific flavor of a computational science and engineering program depends on the structure and mission of a particular university, the collection of faculty expertise and most importantly on pragmatic considerations (i.e., which and how many courses can be approved by the institution? What are the local politics?)” [3].

Teaching resources, such as textbooks, that address the specific emphasis of a program can be hard to find. In addition, locating textbooks that appeal to, and are at the right level for both science students and computational students can be a challenge. For introductory classes, the level is not such a consideration. However, the appeal might be. Science students seem to be used to a different kind of content than computational students, with the former more comfortable with the concrete, and that later quite comfortable with the abstract.

Our approach to determining curriculum content was to consider 4 areas:

1. Skills (both hard and soft) requested by companies employing computational scientists
2. Prerequisite courses desired by local graduate programs
3. Expertise of the interested faculty members
4. Resources available for textbooks and projects

To determine the skill-set required by companies in our region, we examined job requisitions for computational scientists from employment sites such as monster.com, careerbuilder.com, and indeed.com. We made a list of both the hard (academic) skills and the soft skills requested for each position.

We thought that it would be important to focus our curriculum in a way that met the needs of the computational science industry in our area. This would be helpful for future local employment and internship opportunities. Our initial search was restricted to local employers only. Ultimately we did expand our search. In general, the skills requested were not region-specific, but rather job-specific. Searching on the keyword “computational” we found 27 biology-related positions, 7 chemistry-related, 4 physics-related, and 2 scientific programming jobs which supported the other 3 areas.

Fig. 1 displays the hard skills most requested by the 40 job requisitions examined. The most frequently requested skills on the left are generally technical skills that are relevant to most computational science positions. Molecular biology ranked highly due to the high number of biology related jobs, but chemistry positions also asked for this knowledge. The less frequently requested skills on the right side of the graph were linked more closely to specific types

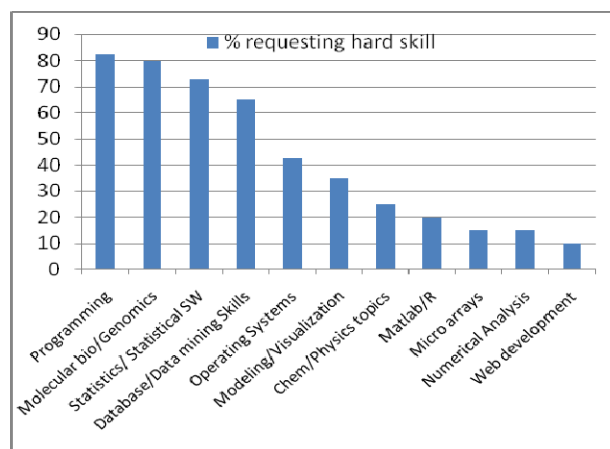


Figure 1. Hard Skills Most Requested

of jobs. For example, numerical analysis skills were linked to the computational chemistry and physics positions.

The programming category includes both high level languages and scripting languages. Many requisitions asked for either, but 45% specifically requested scripting. Another interesting distinction was in the operating system category. While almost half of the requisitions wanted strong operating systems skills, UNIX/Linux proficiency seemed to be emphasized. Skills requested less than 10% of the time, but more than once included clinical trial and experimental design (8%), machine learning (5%), testing (5%), and parallel or high performance programming (5%).

Fig. 2 presents the soft skills most often explicitly requested. Not surprisingly, communication skills top the list. Teamwork was emphasized by 42.5% of the job requisitions. 32.5% specifically mentioned the ability to work with an interdisciplinary team, reinforcing earlier observations that building interdisciplinary experiences into the curriculum is crucial.

In an attempt to confirm our findings on skill sets, and to understand better how professionals in the computational sciences worked together, we conducted interviews with those in industry. We asked about the computational aspects of their current projects, about the challenges of bench and

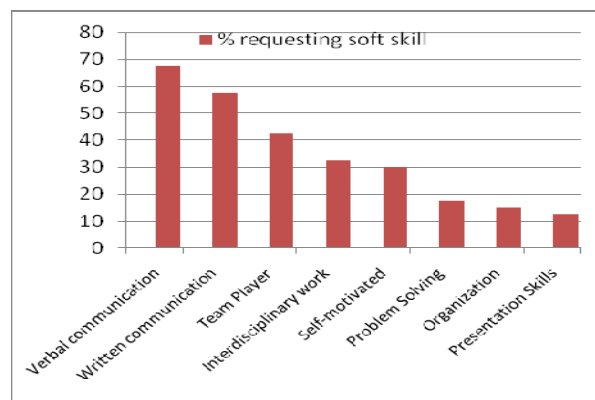


Figure 2. Soft Skills Most Requested

computational scientists working together, and for their content recommendations for the students coming both from the computational side, and from the science side. For the most part, these interviews confirmed what we had learned from the job requisitions and other sources.

Our first interviews were with a molecular biologist and a bioinformatician working together at the Salk Institute in La Jolla, CA [Singer, Sankar, personal communication]. They agreed that the number one challenge was to be able to communicate in a concise and constructive way so that each party understands the problem, possible solutions, and limitations. Typically, the computational person needs to understand the scientific problem and experimental limitations, and the scientist needs to understand computational limitations such as available analytical tools and problem complexity issues.

To that end, each of them needs to understand a little of what the other person does. The biologist was emphatic that every biology student should get a little scripting. He or she should understand basic statistics and experimental design as well as the tools and techniques (databases, motif finding software, mapping software, visualization software) available to the computational peer.

The computational counterpart should have a basic knowledge of molecular biology, understand basic biology techniques (PCR, sequencing, cloning) and tools (Basic Local Alignment Search Tool (BLAST), Bowtie), be adept at statistics, be able to analyze the complexity of an algorithm (frequently for pattern matching), and be a competent programmer in both a high level and scripting language. Much of the algorithmic software used is open source, and often customization is required. They also made significant use of MATLAB and R along with UNIX. The bioinformatician was adamant that the student have some practical experience prior to applying for a job.

Our second interview was more on the computer science side. We met with the Vice President of Wireless Health and Life Sciences and two Senior Directors at Qualcomm [Jones, Ziv, Niznik, personal communication]. Here the computational work involved the fusion and analysis of data gathered wirelessly from different biological and chemical sensors. In this case, the work required much computational knowledge with only basic biological knowledge and vocabulary. The skill-set emphasis here was strong computational expertise (programming and analytics), the ability to deal with large amounts of data, and superior soft skills. It was essential that the future employees have the ability to communicate and work in an interdisciplinary team, and to be able to think about solving problems from multiple perspectives. Once again, the need for interdisciplinary projects within the curriculum is clear.

Our final interview was with the Director of Bioinformatics and Biostatistics at the Scripps Translational Science Institute in La Jolla, CA., providing a mathematical point of view [Schork, personal communication]. This conversation focused on the importance of scripting and biostatistics. Biostatistics, we were reminded, has less emphasis on probability and great emphasis on inference

based decision making. In addition, there are limitations on the amount and types of data available. The importance of scripting for changing the format of data and for process automation was brought up multiple times. We were assured that both of these skills could be easily translated to different subareas of computational science such as cheminformatics.

Many of the computational science programs are at the graduate level, and a good number of the jobs in computational science require graduate degrees. Consequently, providing students with classes that prepare them for future education should be a consideration. The graduate programs in our area seem to focus on bioinformatics. As a result, we were encouraged to include statistics and database courses in our curriculum.

As noted in the previous section, the curriculum at a given institution will be influenced by expertise and interest, politics, and even resources. Schools with access to super computers might emphasize parallel and scientific computing. Oregon State has a computational physics program because only the Physicists were interested. At the University of Wyoming, interest came from the departments of Botany, Computer Science, Mathematics, Mechanical Engineering, Statistics, and Zoology & Physiology. At PLNU, support came from faculty in Computer Science, Mathematics, Biology, Chemistry, and Physics, and our curriculum choices reflect that.

Content in a computational science program can be created in a variety of ways. Certainly some new classes will have to be implemented. Interdisciplinary projects and research experiences will have to be devised. However, many of the classes currently in our curriculum can be retooled to include modules from complementary disciplines. A database course can use scientific databases as examples, and BLAST for searching and analysis. A Genomics course could incorporate Perl or Python to demonstrate pattern matching in searching for motifs.

Even the development of modules might sound overwhelming. Fortunately, repositories of modules are becoming more available. One example of open educational resources is the *Connexions* project of Rice University. A search of this site returned results for modules with content for teaching biology to computer scientists, for teaching bioinformatics to biologists, and examples of assignments for both. Other universities providing open courseware with resources such as lecture notes, slides, projects and labs include Johns Hopkins Bloomberg School of Public Health, MIT, and the University of Washington. *Math and Bio 2010* includes an essay that supplies profiles of projects merging mathematics, computer science and biology at universities such as Davidson College, Harvey Mudd College, James Madison University, Montana State University, and the University of Redlands. [13] The *Computational Science Educational Resource Desk* provides online resources including applets, links to papers from the new *Journal of Computational Science Education*, and links to a variety of tutorials, courses and workshops related to computational science.

VI. OUR CONCLUSIONS

At PLNU, we decided to begin by building a minor in computational science. Our curriculum has been approved, and our science colleagues are enthusiastically referring students to the minor that begins in the Fall of 2012. The minor is designed to allow MICS students (computer science and mathematics) to gain enough knowledge in one of biology, chemistry or physics to be able to help scientists with the computational needs in their research. In a similar way the minor is also designed to expose biology, chemistry and physics majors to enough computational techniques to help them identify when a Mathematician or Computer Scientist could help with their research.

As a small university with limited resources, we need to use, and re-tool, as many existing courses as possible. We have tried to make sure to cover the most requested hard skills, and explicitly provide opportunities to practice soft skills emphasizing cross-discipline communication and teamwork. We include a track for each of the sciences, so that students can get their science content from biology, chemistry, or physics. Our science counterparts have suggested the sequence of classes that provides the most opportunity for computational content with limited prerequisites. The MICS department will help with the computational modules to be included.

Table 1 shows the courses that have been approved for our minor. The minor assumes a major in one of the disciplines shown, so even though the total number of units is approaching 30, many will overlap with courses already required for the student's major. The numbers in the table indicate the semester units for the course, with a blank cell indicating that that course is already a part of the major. For example, all of these majors require calculus, and none of them currently include the new Python/UNIX Scripting course that will be created. Only the Physics major currently includes a course in MATLAB in their curriculum.

Since courses in scripting and UNIX that are accessible to non-CS majors and meet the specific needs of the scientists do not exist, this course will be created. Its content will include scripting for process automation, data manipulation, visualization, and image processing. In addition, a more accessible database course will be implemented that will look at many of the scientific databases in existence, and the tools used to search them.

At least one section of the existing computational courses in this list will be re-tooled with scientific modules. The statistics course will focus on data analysis, and experimental design. The calculus course will add some modeling content. The MICS department currently has three venues to support student projects: senior honors projects, service learning projects, and supervised internships. Science students can enroll in any of these to join with computational students for an interdisciplinary project.

We anticipate measuring the success of our minor in the following 3 ways:

TABLE 1: MINOR CURRICULUM

| | Math | CS | Bio | Chem | Physics |
|-------------------------------|-------|--------|-----|------|---------|
| Calculus | | | | | |
| Statistics | | 2 | | 2 | 2 |
| Intro Computer Programming | | | 3 | 3 | 3 |
| UNIX/Python Scripting | 2 | 2 | 2 | 2 | 2 |
| MATLAB | 1 | 1 | 1 | 1 | |
| Databases | 2 | | 2 | 2 | 2 |
| Interdisciplinary Project | | | 3 | 3 | 3 |
| Science(7-16) (4 count as GE) | 7-16* | 7-16* | | | |
| Units beyond GE and major | 9-19* | 10-19* | 11 | 13 | 12 |

* Units depend on science option chosen

1. The ability of students to understand a culminating interdisciplinary problem and suggest appropriate tools
2. Continued growth in the program population
3. Feedback from employers and graduate programs

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Introducing Parallel Programming to Traditional Undergraduate Courses

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Abstract—Parallel programming is an important issue for current multi-core processors and necessary for new generations of many-core architectures. This includes processors, computers, and clusters. However, the introduction of parallel programming in undergraduate courses demands new efforts to prepare students for this new reality. This paper describes an experiment on a traditional Computer Science course during a two-year period. The main focus is the question of when to introduce parallel programming models in order to improve the quality of learning. The goal is to propose a method of introducing parallel programming based on OpenMP (a shared-variable model) and MPI (a message-passing model). Results show that when the OpenMP model is introduced before the MPI model the best results are achieved. The main contribution of this paper is the proposed method that correlates several concepts such as concurrency, parallelism, speedup, and scalability to improve student motivation and learning.

Keywords—Parallel Programming; Computer Science and Engineering; Education; Learning Evaluation

I. INTRODUCTION

Researchers and educators have discussed when parallel programming should be introduced in undergraduate courses (e.g. Computer Science and Engineering) [1][2]. Due to the importance of qualified human resources for the new era of multi/many-core architectures, parallel programming is of great relevance [3][4][5][6]. Personal computers, workstations, and high-performance computer clusters are based on parallel architectures but to exploit them fully it is important to program in parallel. To reduce processing time, the workload needs to be divided into several parts to be executed simultaneously. In this context, we can find issues relating to algorithms (concurrency and granularity), operating systems (process/thread synchronism, scheduling and mapping), memory and networks (architecture and communication overhead), and performance evaluation (speedup, scalability and efficiency).

During the typical four-year Computer Science course, algorithms are discussed in the first two years and all the concepts required to understand the impact of parallel programs are covered by the end of the third year. For this reason, there are two possible methods of introducing parallel programming: i) beginning the concurrency/granularity

discussion during the first algorithm discipline; or ii) beginning all discussion once sequential programming concepts are consolidated. The first method requires a fundamental change in the curriculum and the second method adds one discipline to the beginning of the fourth curriculum year.

This paper describes a two-year experiment on an undergraduate Computer Science course. The discipline called Concurrent and Distributed Programming starts in the 7th semester after concepts relating to sequential Computer Science theory are consolidated. The main challenge is to exploit parallel programming models divided into shared-variable (memory) and message-passing (network). The following problem/question is considered: When can parallel programming models be introduced to improve the quality of student learning?

This paper is based on two hypotheses: i) MPI (Message-Passing Interface) is introduced first since more time is required to learn a new programming paradigm based on network exploitation; and ii) OpenMP (Open MultiProcessor) is introduced first since it is easier to learn programming based on memory. The goal is to evaluate and propose a method of introducing parallel programming to a traditional curriculum.

The results show that when MPI was introduced first, only OpenMP programs were concluded correctly by students. However, when OpenMP was introduced first, 100%, 78% and 22% of student groups developed programs based on OpenMP, MPI, and MPI/OpenMP, respectively. All groups achieved performance speedup. The results can be explained by feedback: i) students find it easier to exploit concurrency in OpenMP and achieve their first speedup results; ii) OpenMP speedup results stimulate new efforts to achieve the same MPI results; iii) MPI is difficult and the time taken to develop a first MPI program reduces the time taken to develop an OpenMP program.

In conclusion, OpenMP should be introduced first in order to create the conditions and foundations on which to program with MPI. The contribution of this paper is the method that shows phases and timeline when both models and all related concepts are introduced.

This paper is organized into the following sections: Section II presents related studies, Section III describes the proposed

method, Section IV shows the evaluation results, and Section V presents the conclusions.

II. RELATED WORK

Parallel computing has been an important issue since the 80's and 90's [7-10]. Educators showed how to introduce parallel computing to improve the quality of human resources by focusing on architectures, algorithms, and processing. An entire curriculum based on parallel computing is proposed by Nevison [11]. Currently, changing an entire curriculum is difficult. However, the popular multi-core processors can help us with this task.

Butler, et al. [7] proposed the use of a set of tools to implement parallel algorithms combined with operating system concepts and artificial intelligence problems in order to obtain performance speedup. Meredith [8] experimented with introducing parallel computing as a natural part of the undergraduate curriculum while Johnson, et al. [9] described parallel computing as the future of computer science. Therefore, the idea is to introduce concepts on data structures for freshmen courses. The proposal is to use laboratories to develop tools and methodologies in order to improve student learning. Kurtz and Alsabbagh [10] proposed a method of introducing parallel computing based on workshops in small universities with no parallel equipment and no research experience in this area. The proposal is based on simulators and web site materials for teaching concurrency, parallel algorithms, architectures, semaphores, and other concepts.

A recent related study discussed the impact of ubiquitous parallel computing hardware on computing curricula. LeBlanc and Wrinn [1] demonstrated the importance of re-examining the sequential programming curricula in order to migrate to parallel programming. Students need to understand the fundamentals of concurrent programming before designing concurrent systems. Thus, they proposed a computing ontology based on concurrent programming.

Brown and Shoop [12] also described the importance of teaching topics related to parallelism and concurrency. For this reason, they proposed a method of flexible modules based on

programming exercises, supplementary materials, and online communities of educators and contributors. The modules can be used for introducing parallelism in several disciplines.

Lammers, Brown [13], and Gross [2] proposed the introduction of parallel programming in the first year. Teaching parallelism for undergraduate students in their first year is a challenge. Gross [2] described a set of concepts that are present in future disciplines in a common computer science curriculum but it is a difficult task to correlate all of them.





This paper evaluates the introduction of parallel programming to traditional undergraduate courses after having consolidated sequential programming, operating systems, computer architecture and networks. The proposal is to exploit several concepts (e.g. concurrency, granularity, performance and process/thread scheduling) and to correlate them when the student has the ability to discuss and understand the impact of a parallel solution (including architecture and software). The main contribution is to demonstrate the greater impact of introducing the shared-variable programming model before the message-passing model.

III. PROPOSED METHOD

This section presents the method which was applied to four classes over the course of two years. The idea behind the method is to achieve the best results with regard to the learning of parallel programming. However, there is an important issue which changes the final learning results: the question of when to introduce the parallel programming model as an experimental activity.

Table I shows the phases and the timeline for introducing each concept related to the discipline. It is important to highlight two phases: i) programming with OpenMP (Open MultiProcessor), and ii) programming with MPI (Message-Passing Interface). The results presented in this paper demonstrate that learning is better when OpenMP is introduced first, compared to introducing MPI first. This section describes the importance of each phase and how they are related to the choice of parallel programming model as an experimental activity.

TABLE I. PHASES AND TIMELINE

| <i>Phases</i> | <i>Description</i> | <i>1st month</i> | <i>2nd month</i> | <i>3rd month</i> | <i>4th month</i> | <i>5th month</i> |
|---------------|---|------------------|------------------|------------------|------------------|------------------|
| 1 | Parallel Architectures | X | | | | |
| 2 | Concurrency, Synchronism and Barriers | | X | | | |
| 3 | Programming Model Concepts | | X | | | |
| 4 | Parallel Algorithms, and Granularity | | X | | | |
| 5 |  Programming with OpenMP  | | | X | | |
| 6 |  Programming with MPI  | | | X | | |
| 7 | Performance Evaluation and Optimization | | | X | | |
| 8 | Scheduling, Mapping, and Affinity | | | X | | |
| 9 | Experimental Work | | | X | X | X |
| 10 | Classroom Activities | | | | X | X |
| 11 | Laboratory Activities | | | | X | X |

The Parallel Architectures phase is introduced to teach students the evolution of parallel computing. This phase is important for demonstrating trends and current parallel architectures that demand parallel programs. Flynn taxonomy, shared and distributed memory models, general-purpose architectures, graphic processing units, multi/many-core processors, hardware multi-threading support, and cluster and grid computing are examples of the subjects presented. Thus, the method begins the explanation of parallel programming by demonstrating where the programs will be executed. Moreover, students are also forced to think about how to program for a distributed architecture, such as a cluster. The moment at which students consider how a sequential program can be executed in a computer cluster or in a multi-core machine is an important opportunity to rethink previous concepts.

The second phase discusses concurrency, synchronism, and barriers. In this phase, it is important to take into account the difference between concurrency and parallelism. There exists a myth that concurrency is bad due to competition for resources. However, concurrency is a good characteristic for programs. Looking for concurrency in a sequential code means identifying the parts of the code that can be executed out of order. These parts are independent and can therefore be executed in parallel (e.g. threads or processes). At this point, it is important to relate parallelism, multi-threading, synchronism and barriers. Operating System (OS) books present us with an important characteristic of OSs known as pseudo parallelism. This is where OSs extract “parallelism” from the speed of a single core for changing threads in execution. However, current machine infrastructures offer us native parallel architecture based on several cores to execute multiple threads or processes. At this point, students can learn the importance of several processes sharing different data. The synchronism obtained from barriers is important for maintaining data integrity while considering data sharing and concurrency. Barriers are strategies in the parallel code to synchronize threads in order to avoid access to shared variables or input buffers. Beginners can develop parallel programs without attention to synchronism. Thus, the program achieves a high speed but the result can be incorrect. The second phase of this method is also about communicating the influence of shared data in the execution and synchronism of threads.

The third phase is based on programming models and is divided into two approaches: shared variable (memory exploitation) and message passing (network exploitation). In this phase, only concepts are presented. The discussion is based on data communication and exploring performance while considering architecture and program scalability. First of all, data communication through shared variable is based on memory. Typical multi-core computers have multiple cores sharing the same memory. However, memory has a scalability problem. It cannot scale while a parallel program increases in complexity, number of operations or data movement. In this scenario, thread concurrency represents negative competition which reduces the efficiency of memory bandwidth. At this point, the computer cluster is presented as an alternative with scalability. Through this architecture, message passing is the model used for data communication using the network. For a large parallel program, a computer cluster can scale thanks to

the network, however, scalability is a compromise of performance. Therefore, students learn that there are two types of scalability: i) architecture, and ii) program. For instance, architecture is related to memory and the network where the network has scalability. Program is related to data movement across the architecture. Although the network has scalability, the message passing can introduce a communication overhead that reduces the computational performance. To complement this phase, some concepts relating to application models based on graphs and machine abstract models are presented.

The fourth phase is designed to appear after programming models. The idea is to ask students: Can this algorithm be parallel (e.g. Fig. 1)? After a discussion, we verify that concurrency is independent of programming models. Next, whether or not an algorithm has concurrent parts and the responsibility of the programmer for adapting memory or network exploitation is discussed. The usage of shared variables or message passing is part of a programmer decision and is related to the available parallel architecture. When the students identify the concurrent parts, it is time to demonstrate the impact of granularity. How can coarse or fine grain be correlated with performance and scalability? Looking for concurrency in a rank sort algorithm (Fig. 1), we can divide the external *for* into *n* parts. Each part is a thread responsible for finding the rank of the value present in vector *a[i]*. The grain of each thread is finer than the process grain that generates each thread. A small grain means a small number of operations to compute. As a consequence, a thread takes less time to finish the computation than the sequential program. However, we have *n* threads in parallel competing for memory (read and write communication). Therefore, there is a memory overhead which increases the final processing time (computation + communication). If there are more threads (finer grain), there is more communication. Computation and communication need to be balanced in order to achieve performance and scalability.

```
for(i=0; i<n; i++){
    rank = 0;
    for(j=0; j<n; j++){
        if((a[i] < a[j]) || (a[i] == a[j] && j < i))
            rank++;
    }
    b[rank] = a[i];
}
```

Figure 1. Rank sort algorithm

Programming with OpenMP is the fifth phase. In this study, the best results were achieved when OpenMP was presented before MPI. The proposal is to exploit the students' ability to program using sequential logic. It is important to take into account that data movement is based on shared variables. This is the difference between parallel and sequential programming. Students learn OpenMP *pragmas* and how to identify concurrency in order to exploit parallelism. The problem is the use of shared and private variables in order to achieve performance with correct results. Laboratories are available for this phase which is characterized as a hands-on approach.

Programming with MPI is not different. For this sixth phase, a hands-on approach is necessary and laboratories are

also available. This phase considers the new programming paradigm based on message passing. The students are presented with a different programming style based on MPI calls to exploit the network. A typical cluster has distributed memories and each computer has a private memory without remote access. This architecture demands programming which involves sending and receiving calls based on network packets. The main problem related to this phase is how to exploit the network without scalability reduction and, consequently, performance reduction. Moreover, the students need to learn how to introduce MPI calls by changing the sequential algorithm at a deeper level than using OpenMP *pragmas*. According to evaluation results, a program based on MPI requires more time to develop and achieve performance. For this reason, it is important to motivate students by first introducing parallel programming based on shared variables, namely through OpenMP. At the end of this phase, hybrid programming based on MPI/OpenMP is presented. Fig. 2 illustrates a cluster composed of seven dual-core machines. This is a good example that demands memory and network exploitation. OpenMP threads communicate by shared variables, while MPI processes establish communication through the network. The hybrid approach attempts to utilize the best aspects of each programming model in order to achieve high performance and scalability.

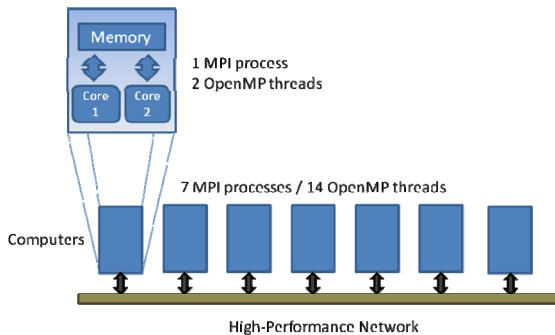


Figure 2. Hybrid Approach (MPI/OpenMP)

The seventh phase is based on performance evaluation and optimization. The students learn about evaluation and code optimization after discussion of the following topics: libraries, algorithms, granularity, concurrency, synchronism, and architectures. Amdahl Law, Efficiency, and Speedup topics are then presented and the students are taught that a high-performance parallel program depends on the programmer using the available materials correctly (e.g. software and hardware). The students learn how to program but also how to evaluate their programs. In addition, several techniques for optimizing code are presented. For instance, loop unrolling, inline functions, efficient compiler usage, and performance monitors are discussed.

When a sequential program is executed in a sequential architecture, the Operating System performs the task of process scheduling. This task is important to ensure high-performance process execution (“pseudo parallelism”). However, when a parallel program is executed in a parallel architecture, in addition to scheduling, there is another important task known as process mapping. When (scheduling) and where (mapping)

to execute a process/thread are now the important factors for achieving high performance. For this reason, processor and memory affinity can be used to reduce the communication overhead through network or cache misses. Fig. 3 illustrates an example of thread mapping. The application graph shows the dependence between threads and a difference number mapped on cores. We can conclude that to achieve high performance, the grain of each thread should be different and the mapping should be balanced. The mapping decision is important because it can reduce the communication overhead and increase the processing time speedup by computation.

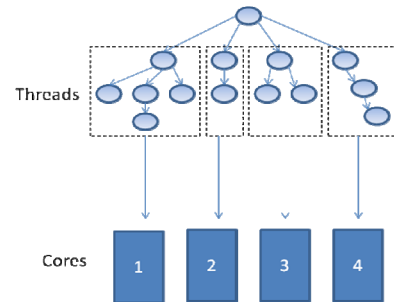


Figure 3. Threads Mapping

Phase 9 consists of discussion of the experimental work. The students form groups and choose a sequential program from previous disciplines that can be exploited in terms of concurrency and parallelism. This is the point at which a professor should prompt the groups to begin with OpenMP (shared variables). Normally, parallel programs based on OpenMP function quickly and this motivates students. After this step, MPI (message passing) is introduced and the desire to see a parallel program functioning helps students to persist with their work. The evaluation results (Section IV) reveal that the best score was achieved by the last class which followed this method fully. To conclude the experimental work, the students write a scientific paper to summarize all the knowledge learned in the discipline.

Phases 10 and 11 are dedicated to discussing experimental work (phase 9) and to conducting student evaluations. The students present their work-in-progress in the classroom and laboratory. The classroom activities are based on typical technical sections of conferences. The laboratory activities are based on experimental work evaluation. These activities occur in two steps to present intermediate and final results. In the laboratory, the students demonstrate the parallel program and execute it for tests. In the classroom, the students show slides that summarize the problems, goals, contributions, proposals, results and conclusions presented in the scientific paper written by them.

IV. EVALUATION RESULTS

This section presents the results of the proposed method based on its evolution. Each result presents a gradual decision from the first class to the fourth class. The fourth class had the full proposed method described in Section III.

Table II shows the results obtained from the first class. The method introduced MPI first and OpenMP afterwards.

Furthermore, the students could decide which programming model to use. Although MPI was introduced first, the expectation of a fast speedup caused a migration of all experimental work to OpenMP. All groups concluded their OpenMP programs but no group concluded the MPI version. The small amount of time taken to finish the work after the change of model reduced the number of groups that achieved speedup (33%). All groups wrote the scientific paper. The students began the work in the 4th month.

TABLE II. FIRST CLASS

| Class 2010-1 (21 students) | | | | | |
|----------------------------|--------|-----|--------|---------|-------|
| Group | OpenMP | MPI | Hybrid | Speedup | Paper |
| G1 | yes | no | no | yes | yes |
| G2 | yes | no | no | no | yes |
| G3 | yes | no | no | no | yes |
| G4 | yes | no | no | no | yes |
| G5 | yes | no | no | no | yes |
| G6 | yes | no | no | yes | yes |
| Total | 6 | 0 | 0 | 2 | 6 |
| % | 100% | 0% | 0% | 33% | 100% |

Table III shows the results for the second class. The method was the same as that applied to the first class apart from the fact that the students began the experimental work in the 3rd month. Although the students had more time to conclude the work, no group used the MPI model. Therefore, MPI as a first model still reduced the students' expectation of producing good work. The positive feedback was that all groups achieved a speedup in their respective parallel programs based on OpenMP. All groups wrote the scientific paper.

TABLE III. SECOND CLASS

| Class 2010-2 (22 students) | | | | | |
|----------------------------|--------|-----|--------|---------|-------|
| Group | OpenMP | MPI | Hybrid | Speedup | Paper |
| G1 | yes | no | no | yes | yes |
| G2 | yes | no | no | yes | yes |
| G3 | yes | no | no | yes | yes |
| G4 | yes | no | no | yes | yes |
| G5 | yes | no | no | yes | yes |
| G6 | yes | no | no | yes | yes |
| Total | 6 | 0 | 0 | 6 | 6 |
| % | 100% | 0% | 0% | 100% | 100% |

Table IV also shows a method where MPI was introduced first. However, all student groups were required to develop parallel programs based on OpenMP and MPI. Although the reason for presenting MPI first is that it takes longer to develop a parallel program, the results continued to be poor. For the

third class, all groups achieved speedup using the OpenMP model but one group did not finish the scientific paper.

The extra time required to develop a parallel program based on MPI is not enough to explain this performance. The reason for it must be in the order in which the parallel programming models are presented. Thus, OpenMP was introduced as the first model since the previous classes obtained good results. It is likely that the subsequently improved results using MPI are the result of improved motivation. Fast performance speedup, in terms of development, could be the answer found in OpenMP programs.

TABLE IV. THIRD CLASS

| Class 2011-1 (19 students) | | | | | |
|----------------------------|--------|-----|--------|---------|-------|
| Group | OpenMP | MPI | Hybrid | Speedup | Paper |
| G1 | yes | no | no | yes | yes |
| G2 | yes | no | no | yes | yes |
| G3 | yes | no | no | yes | yes |
| G4 | yes | no | no | yes | yes |
| G5 | yes | no | no | yes | no |
| Total | 5 | 0 | 0 | 5 | 4 |
| % | 100% | 0% | 0% | 100% | 80% |

Table V shows the results for the fourth class. For this class, the method is the same as that described in Section III. OpenMP was introduced first and all student groups were required to develop parallel programs based on OpenMP and MPI. Moreover, all groups had to evaluate a hybrid approach (MPI/OpenMP) program. The results reveal that this was the best performing class. 100% of groups developed OpenMP programs, 78% of groups develop MPI programs, and 22% of groups developed hybrid programs. All groups achieved speedup but only 89% of groups wrote a scientific paper.

TABLE V. FOURTH CLASS

| Class 2011-2 (41 students) | | | | | |
|----------------------------|--------|-----|--------|---------|-------|
| Group | OpenMP | MPI | Hybrid | Speedup | Paper |
| G1 | yes | no | no | yes | yes |
| G2 | yes | no | no | yes | no |
| G3 | yes | yes | no | yes | yes |
| G4 | yes | yes | no | yes | yes |
| G5 | yes | yes | no | yes | yes |
| G6 | yes | yes | yes | yes | yes |
| G7 | yes | yes | yes | yes | yes |
| G8 | yes | yes | no | yes | yes |
| G9 | yes | yes | no | yes | yes |
| Total | 9 | 7 | 2 | 9 | 8 |
| % | 100% | 78% | 22% | 100% | 89% |

Fig. 4 summarizes the results. It is possible to see that for all metrics the fourth class achieved the best results using the proposed method. The scientific paper is an exception in comparison to the first and second class. However, the experimental work of the fourth class was larger and this could explain the reduction. Some important student feedback relates to OpenMP. This programming model is easier to understand and to program. The motivation to develop an MPI-based program is a consequence of good experiences of OpenMP.

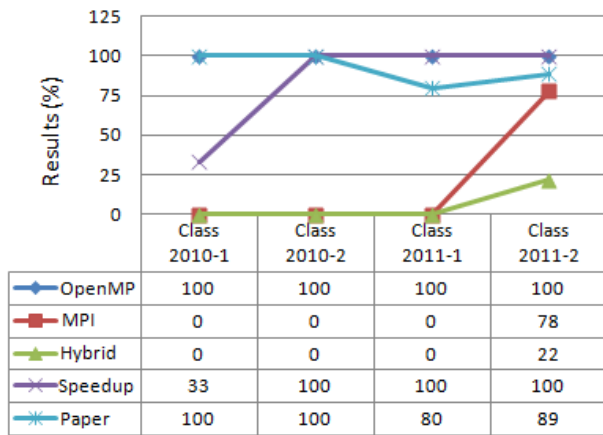


Figure 4. Evaluation Results

V. CONCLUSIONS

The new era of parallel architectures demands the speedy introduction of parallel programming. Multi-core processors, clusters and many-core architectures are available and current professionals need to know how to program them. Parallel programs are the best option for exploiting parallel architectures with efficiency, performance, and scalability. Therefore, traditional undergraduate courses require a discipline that connects several concepts to parallel programs in order to understand the influence, for example, of networks, memory, and operating systems.

The proposed method demonstrates that the shared-variable programming model is easier to understand. Students can quickly learn how to achieve high-performance speedup relative to sequential programs. Based on the motivation generated from the OpenMP model, new programs based on MPI can also achieve performance speedup. The evaluation results present the evolution over a two-year period, as shown by Fig. 4. The proposed method based on phase 5 (OpenMP) and phase 6 (MPI) exploited programming ability and generated the motivation to conclude programs with OpenMP and MPI with efficiency.

Two indirect results were observed in the fourth class, as follows: i) one paper submitted to a conference, and ii) two undergraduate dissertations focused on parallel computing are in development. Therefore, the proposed method achieved its

goal. More students are learning different parallel programming models through experimental activity. For this reason, it is possible to highlight the proposed method as the main contribution of this paper.

Future study will focus on improving the method in order to achieve better results, especially for MPI and hybrid programming approaches. Furthermore, there is currently a discussion taking place, influenced by the results of this paper, with regard to changing the Computer Science curriculum to introduce concurrency and OpenMP in the first year.

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A system to help teaching and learning algorithms

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Abstract— One of the big challenges that teachers and students face at early stages of CSET (Computer Science, Engineering, and Technology) courses are the difficulties related to teaching and learning algorithms. Usually, such knowledge is presented during introductory programming related disciplines, when students are also presented to some programming language to describe simple algorithms. Therefore, they need to learn not only the new language but also a formal way to describe the solution of problems using that language. This is much different from any formalism they were presented in their previous student's experience. This paper presents iVProg, a system conceived to overcome some of these difficulties by using visual programming. Some experiments were conducted during three years to evaluate students' performance without the system support and with it using different didactic approaches.

Index Terms — *algorithms; visual programming; learning system; introductory programming; free software.*

I. INTRODUCTION

One of the big challenges that teachers and students face at early stages of CSET (Computer Science, Engineering, and Technology) courses are the difficulties related to teaching and learning algorithms [1][2]. Usually, such knowledge is presented during introductory programming related disciplines, when students are also presented to some programming language to describe simple algorithms. Therefore, they need to learn not only the new language but also a formal way to describe the solution of problems using that language. This is much different from any formalism they were presented in their previous student's experience.

Moreover, students are also presented to some programming environment in order to edit, debug, compile and run programs they built and that describe algorithms to solve some proposed problems. Such an overload of new information may decrease student's motivation and compromise their performance, occasionally leading to course abandon.

In order to overcome this problem some attempts of using visual systems to support the learning of introductory programming were proposed [3][4]. Such systems adopt the drag-and-drop approach to guide students on building programs without any concern related to the programming language syntax and semantics. They also offer the possibility of compiling and running programs within them, which avoid the use of programming environments at the initial stage of learning algorithms and programming.

This paper presents a free system called iVProg that offers visual programming features to support both, introduction to algorithms and the principles of programming, considering

teaching and learning aspects. It can run in any desktop, web browser, or integrated to a web-based Learning Management System, such as Moodle. Nevertheless, the paper main contribution is related to the results of some experiments conducted with iVProg, in order to evaluate possible gains while teaching and learning algorithms and programming using it.

II. RELATED WORK

Many researchers dedicated efforts to develop pedagogical methods and educational software to support processes of teaching and learning algorithms and programming. Hazzan et al. [5] made an overview on the main teaching methods based on available educational software, different forms of class organization, and mentoring software development projects.

Existing educational software that support teaching and learning algorithms and programming differ in several ways, e.g. some of them work offline, other work online and a few in both modes [3][4][6][7][8]. Since the number and approaches adopted for educational software is considerable, Rongas et al. [9] proposed four different categories to classify them: (i) integrated development interfaces; (ii) visualizing systems; (iii) virtual learning environments, and (iv) submission systems. Since iVProg is based on the Visual Programming paradigm, our interest relies on visualizing systems. Among them, there are two systems that present many commonalities with iVProg: Alice [3] and Scratch [4]. In fact, both are visual programming software, with open source licenses, that allow online testing as iVProg. However, only iVProg presents the possibility of online edition and integration to Learning Management Systems, such as Moodle.

Scratch was conceived at Massachusetts Institute of Technology and it allows students to learn some important mathematical and computational concepts through an easy and friendly interface [10]. The system use the mouse as interaction instrument where students drag-and-drop some code components to build the algorithm. Students are able to create animations, simple games, musics, interactive histories, and more. It is possible to watch animations and play Scratch games through the Internet, there is also an interesting online repository of Scratch projects, but algorithms edition is only available offline. Furthermore, it is not integrated into a LMS.

Alice was developed at Carnegie Mellon University. The system uses the creation of 3D animation and interactive histories to motivate learners during the processes of developing skills in algorithms design and acquiring computational concepts. Alice also uses drag-and-drop as interaction method, and, such as Scratch, it is not integrated into a LMS.

Initially, Scratch was designed for K12 and high school students and Alice for undergraduate students of introductory courses in Computer Science. Both of them focus the engagement of the students and try to let their first contact with programming easier with a lower cognitive load during the process [11]. In the next session, we are going to explain how iVProg was built and justify our focus on lowering the cognitive load for the student.

III. IVPROG OVERVIEW

iVProg [12] is a system that derives from the Alice system in a way it was built as a simplified version of Alice to run in web browsers and to be used by Brazilian students that, generally, don't speak English. Therefore, it follows Alice license as an open source code and is also coded in Java. It's important to know that iVProg was adapted to teach algorithms using the procedural programming approach while Alice adopts an object-oriented approach. Moreover, in order to make possible the use of iVProg in web browsers it was needed an important reduction of the Alice's original code, which is more than 140Mb heavy. Currently, iVProg code is under 10% of Alice's one. Nevertheless, it was built as an iLM (Interactive Learning Module) [13].

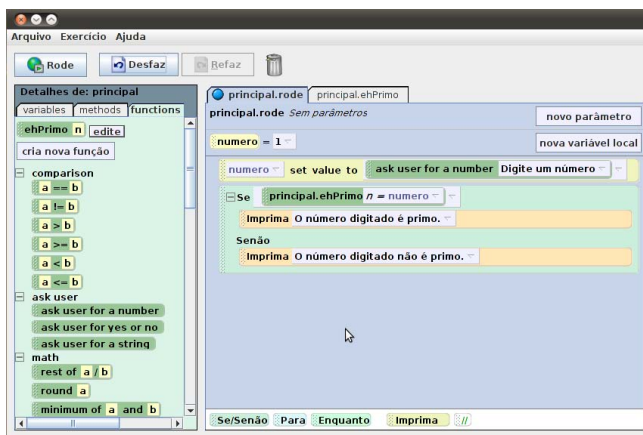


Figure 1 Screenshot of iVProg.

The main functionalities available in iVProg are the ones related to visual programming, such as the possibility of using drag-and-drop to build functions and methods in a program that is built within the system. In fact, there are pre-defined buttons for comparison between variables, for the most used mathematical functions, and for the main programming constructs, such as *if-then-else* and *loops*. Figure 1 shows the screenshot of iVProg. In the left side there are the aforementioned buttons, in the right side is the workspace, where the program is built, the horizontal menu bar presents buttons for running the program, undo/redo functionalities and a wastebasket for discarding program components. Another important functionality that iVProg maintains from Alice is that the system prevents some common mistakes students use to do, such as variable attribution instead of equality between variables content.

Although iVProg is a simple version of Alice, it also presents the additional functionality of communicating with web servers, which allows it to be integrated to Learning

Management Systems (LMS), such as Moodle [14]. By being integrated into LMS, it can foster the development of digital content in a collaborative manner and the use of several LMS resources combined with iVProg in order to visualize the results of activities that were performed by students and sent to the LMS.

iVProg has been used in the last editions of an introductory programming discipline with success, and some experiments were conducted to evaluate how does the system influence the learning of algorithms and programming. Two experiments were described in the next section. Currently the system is being rebuilt in order to be compliant with a framework our research group developed to serve as basis for any iLM and facilitate their maintenance and evolution [15]. The version used in the experiments is available at <http://www.matematica.br/ivprog/iVprog2011.jar>.

IV. EXPERIMENTS

The experiments took place during two semesters of an introductory programming discipline (MAC110), in an undergraduate course of Mathematics. A blended learning approach [16][17] was adopted, since besides being a face-to-face course, there were several assignments to be done at distance weekly.

The idea was to investigate if the use of iVProg could improve the understanding of how to solve problems algorithmically and how visual programming would impact the ability of using an imperative programming language (such as C) in a traditional programming environment.

The first experiment involved students of MAC110, in an undergraduate course of Mathematics during the first semester of 2010. It was a controlled experiment, in a laboratory with observers. The second experiment involved classes T1, T2 and T3 during whole semesters of 2005, 2010 and 2011, respectively. In the following subsections the experiments were described and their results were presented. Discussion about the results is provided in a section dedicated to it.

A. Observed Exercises

The first experiment was conducted with 6 students, volunteered, randomly divided in two groups, G1 and G2. Each one was asked to solve two exercises in a period of one hour. An observer, that would annotate the number of mistakes related to syntax and the number of times the program was run until the student evaluate it as correct, was aside of each student.

Students from group G1 would do the exercises using iVProg at the beginning and using a C traditional programming environment. Students from group G2 would do the same exercises using the C language in a traditional programming environment at the beginning and using iVProg after. In both cases the exercises would be done individually without advice of anyone.

The experiment goal was to analyze the initial hypothesis that the system would simplify the programming task for newcomers in programming.

Participants answered a questionnaire composed of two questions: (Q1) *Do you know the C language? If yes, how experienced are you?* and (Q2) *Did you already attend MAC110? If yes, what was the programming language and*

environment used? and start doing the exercises. After solving each exercise, the student would send it to the LMS.

TABLE I
RESULTS OF OBSERVATION – EXPERIMENT 1 - G1

| | | GROUP 1 | | | |
|--------------|----|-----------|-----------|-----------|---------|
| | | student 1 | student 2 | student 3 | average |
| | Q1 | no | no | no | - |
| | Q2 | yes | yes | no | - |
| E1 iVProg | a) | 2 | 1 | 3 | 2,0 |
| | b) | 1 | 2 | 3 | 2,0 |
| | c) | 0 | 0 | 0 | 0,0 |
| E1 C | A) | 9 | 5 | 15 | 9,7 |
| | B) | 2 | 1 | 5 | 2,7 |
| | C) | 2 | 1 | 2 | 1,7 |
| | D) | 1 | 0 | 1 | 0,7 |
| E2 iVProg | a) | 8 | 2 | 14 | 8,0 |
| | b) | 1 | 1 | 2 | 1,3 |
| | c) | 0 | 0 | 0 | 0,0 |
| E2 C | A) | 16 | 5 | 21 | 14,0 |
| | B) | 4 | 5 | 5 | 4,7 |
| | C) | 4 | 1 | 2 | 2,3 |
| | D) | 4 | 5 | 2 | 3,7 |

The exercises are:

E1- Build a program that has two numbers as input parameters and returning their average.

E2 – Build a program that ask for a natural number N and a sequence of N numbers as input parameters and print the large and the smaller numbers of the sequence in the screen.

Each observer would annotate the following items for exercises done using iVProg:

- a) time in minutes to solve the exercise;
- b) number of times that use the RUN button;
- c) number of times that syntax or logical mistakes were discovered.

Each observer would annotate the following items for exercises done using C:

- A) time in minutes to solve the exercise;
- B) number of times the program was compiled;
- C) number of times the program run;
- D) number of times that syntax or logical mistakes were discovered.

Only one student of Group 2 answered Q1 positively and only one student of each group hadn't attended MAC110 previously. Nevertheless, as we can see in Table I and Table II, it seems that had attended MAC110 before did not influenced in the experiment result.

Table I shows the results of observations with G1. The time spent to solve E1 using C was 5 times longer than using iVProg, even had been solved it immediately before using iVProg. For exercise E2 such a discrepancy was smaller, just 2 times longer, indicating that as students hadn't previous knowledge about the C language (answer Q1) they learned about it while solving exercise E1. This is also visualized in the average column, lines a) and A). Nevertheless, all students did both exercises using iVProg and C, in an interval from 13 minutes (student 2) to 53 minutes (student 3).

Table II shows the results of observations with G2. This group started doing E1 using C and, having solved it, did the same using iVProg. Same steps where followed to exercise E2. As it can be depicted from Table II, only student 4 did both exercises using C and iVProg, spending 68 minutes to finish them, even having previous knowledge about the C language (answer Q1) and had attended MAC110 before (answer Q2).

Students 5 and 6 couldn't finish exercise E2 using both C and iVProg. They had focused on solving debugging problems and forgot the main goal that was to give an algorithm solution to the problem. This was not observed in G1, since an algorithm was defined and tested using iVProg before solving the same problem in C. For E1, the time spent for all students to solve it using C was almost 10 times longer than the used to solve it using iVProg. For exercise E2 we cannot analyze such a discrepancy since only one student did it until the end of the experiment schedule.

TABLE II
RESULTS OF OBSERVATION – EXPERIMENT 1 – G2

| | | GROUP 2 | | | |
|--------------|----|-----------|---------------|---------------|------------|
| | | student 4 | student 5 | student 6 | average |
| | Q1 | yes | no | no | - |
| | Q2 | yes | yes | no | - |
| E1 C | A) | 23 | 50 | 35 | 36 |
| | B) | 4 | 10 | 11 | 8,33333333 |
| | C) | 2 | 1 | 11 | 4,66666667 |
| | D) | 3 | 6 | 10 | 6,33333333 |
| E1 iVProg | a) | 2 | 5,0 | 2,0 | 3,0 |
| | b) | 1 | 1,0 | 1,0 | 1,0 |
| | c) | 0 | 0,0 | 0,0 | 0,0 |
| E2 C | A) | 30 | didn't finish | didn't finish | 30 |
| | B) | 5 | - | - | 5 |
| | C) | 4 | - | - | 4 |
| | D) | 4 | - | - | 4 |
| E2 iVProg | a) | 13 | didn't finish | didn't finish | 13,0 |
| | b) | 5 | - | - | 5,0 |
| | c) | 3 | - | - | 3,0 |

A. Experiment II – using iVProg in formal courses

The main goal was to analyze iVProg influence in the learning process of algorithms and programming in an undergraduate course of Mathematics. It was conducted during 3 years during one academic semester a year (18 weeks) of an introductory programming discipline (MAC110). The experiment involved 3 classes, T1 (without using iVProg), T2 and T3 (using iVProg with different didactic approach), all of them from the same course and discipline, and having the same lecturer.

In T1, algorithms and programming were introduced using a system that simulates a computer (iCG) and adopted an assembly-like programming language during 5 weeks, in a laboratory. High-level commands in C were inferred from the low-level model. This system had a compiler to its machine language and is freely available at <http://www.matematica.br/icg/icg.jar>. From week 6 to 18 only the traditional programming environment was used, but classes took place in classroom. For this reason, only 5 exercises were solved online and other 3 exercises, more complex, involving modeling the problem solution before going to code, were left as homework. Learning assessment was made through the exercises and two theoretical exams, in classroom, at weeks 11 and 18.

In T2, algorithms and programming were introduced using only iVProg during 6 weeks. From week 7 to 11 both, iVProg and a traditional C programming environment were used to solve the proposed exercises. From week 12 to 18 only the traditional C programming environment was used. Classes took place in a laboratory with at most two students by computer. The exercises proposed were related to: average of n numbers; algorithm of Archimedes for GCD; evaluate the n term of Fibonacci's; tests involving types, such as char and int; calculate cos(x) using Taylor's series; vectors: sorting using an

auxiliary function, binary search, representing sets and verifying when a vector is a permutation one. An amount of 33 exercises/programs were done using iVProg and 20 using the C language, most of them solved online. It is important to observe that during the weeks where iVProg and C were used in parallel, exercises were first solved using iVProg and after using C. Learning assessment was made through the exercises and two exams: the first online in the laboratory, one student per computer, at week 11, and the second was theoretical, in classroom, at week 18.

TABLE III EXPERIMENT 2 – T1, T2 AND T3 LEARNING ASSESSMENT

| | T1 - 2005 | | T2 - 2010 | | T3 - 2011 | |
|-------------|-----------|----------|-----------|----------|-----------|----------|
| | Average | variance | Average | variance | Average | variance |
| freq. | 56.48% | 0.109 | 72.92% | 0.0702 | 71.02% | 0.061 |
| exam1 | 3.28 | 8.3 | 5.59 | 8.7 | 5.85 | 5.64 |
| exam2 | 4.33 | 17.02 | 3.47 | 4.92 | 6.36 | 7.29 |
| non-C | 7.0 | 20.5 | 9.26 | 0.35 | 9.59 | 0.65 |
| C | 4.28 | 18.7 | 8.51 | 0.43 | 9.08 | 0.74 |
| final grade | 4.06 | 10.44 | 4.59 | 6.31 | 5.24 | 6.19 |

In T3, algorithms and programming were introduced using the same approach of the one adopted in experiment 1 for G1: the use of iVProg and a traditional C programming environment in parallel. From the very first lecture, students solved proposed problems using iVProg and after that, the same problem was solved using C. Therefore, the idea was using iVProg to find the algorithm that solved the problem and C to learn some programming language. Nevertheless, since some programming concepts such as *file manipulation*, *strings* and *pointers* are not implemented in iVProg, the last 4 weeks of the course were whole made using just C. Thus, 25 problems were solved using both iVProg and C and 04 problems using only C. Learning assessment was made through the exercises and two exams. The first exam occurred at week 11 and was composed of 2 theoretical questions and 3 problems to be solved in the laboratory, individually, using iVProg or C. The second exam occurred at week 18 and was composed exclusively of theoretical questions, to be solved in classroom.

In order to compare the influence of iVProg to support the learning of algorithm and programming, we evaluate the averages of exams 1 and 2, non-C (iCG -T1 or iVProg - T2 and T3) and C exercises and the students' frequency at classes for T1, T2 and T3. Table III shows these results.

Considering the frequency at lectures, T2 and T3 presented higher attendance average than T1. This may represent that T2 and T3 was more motivated than T1, but there is not any conclusion. Concerning the grades students obtained in exam 1, average was increasing from T1 to T3, but from T1 to T2 the growth was bigger. In this case the result was strongly related to the use of iVProg, since students did the exam using it. Nevertheless, average grades of exam 2 indicate that the contact with the C language from the very beginning had influence on it, which is theoretical and C-based. This could be explained by comparing the grades of T2 (where C was introduced after 7 weeks of lectures) with T1 and T3.

Moreover, comparing the performance of students from T2 and T3 with T1 we may infer that the use of iVProg improved understandability related to algorithms. Also, the adoption of iVProg combined to a C programming environment from the

very beginning benefited students understandability about the C language.

V. USABILITY ISSUES

The first time iVProg was used in a formal course was with T2. In order to evaluate some usability issues, the following question was made to students at the very beginning, in order to evaluate their familiarity with computers and its influence on the usability assessment: *Q1) How many hours a day do you spend using a computer?* The results show 3.31 hours/day as average time, and let us considered that they are familiar enough with computers and iVProg usability would not be influenced by difficulties related to computer misuse.

A questionnaire composed of quantitative (*Q2-Q4*) and qualitative questions (*Q5-Q7*) was applied to T2 at the end of semester, in order to assess iVProg usability. For better understanding and organization, we present each question associated with its motivation and results.

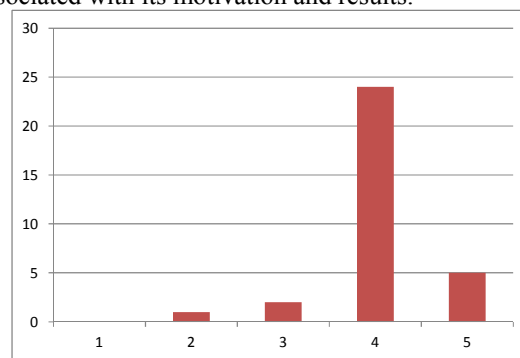


Figure 2 Answers of Q2

Q2) iVProg can be classified as ____, considering its visual aspect.

1. Uncomprehensible;
2. Hard to comprehend;
3. Neutral;
4. Comprehensible;
5. Very Comprehensible.

The goal of this question was verifying if iVProg user interface was comprehensible. Figure 2 shows that 75% answered that iVProg is *comprehensible* or *very comprehensible*.

Q3) In your opinion, iVProg is, in its first use:

1. Very hard;
2. Hard;
3. Neutral;
4. Easy;
5. Very easy.

The goal of this question was discover how comfortable students felt at the first sight with iVProg. Figure 3 shows that 42% answered that iVProg was *neutral* or *easy* to use in their first sight, but a significant number of answers (38%) considered iVProg hard to use at the first sight.

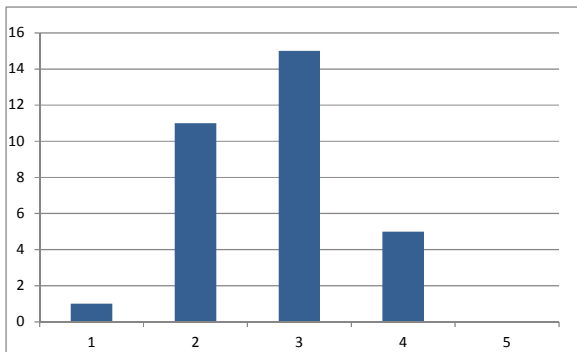


Figure 3 Answers of Q3

Q4) In general, solving exercises using iVProg is:

1. Very unpleasant;
2. Unpleasant;
3. Neutral;
4. Pleasant;
5. Very pleasant.

The goal of this question was discover how comfortable students felt using iVProg while solving exercises. Figure 4 shows that 46.8% answered that iVProg is *neutral, pleasant* or *very pleasant*, but it was classified as *unpleasant* or *very unpleasant* by 53.2%. This was explained in the qualitative part of the questionnaire, where students reported some bugs that occurred while using iVProg.

Qualitative questions are given next, and after some answers will be commented. Q5) *Would you please specify the main advantages of programming using iVProg compared with C?*; Q6) *Would you please specify the main advantages of programming using C compared with iVProg?*; Q7) *Is there any resource you would like to find in iVProg?*.

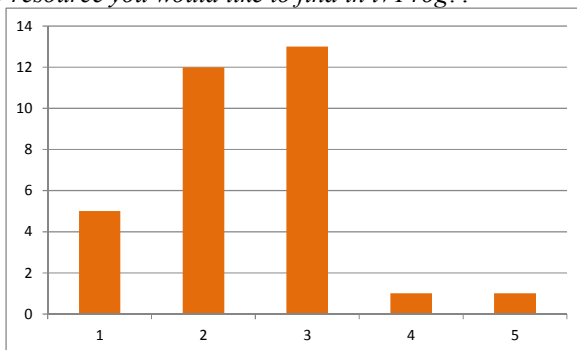


Figure 4 Answers of Q4

In general, advantages of iVProg compared with C are related to the fact that in iVProg the programmer doesn't need to be concerned with the syntax of the language, which is something very important while using C or any other programming language. Also, the use of the drag-and-drop functionality for the main programming commands, instead of typing all of them in C, kept users away of typos. Several answers stated that by using iVProg they could focus on the solution of the problem as an algorithm, instead of issues related to the language.

Concerning the advantages of using C compared with iVProg, answers were related to the time to compile complex

programs, the need of organization and method to comprehend the language syntax in order to use it correctly.

Answers to these questions indicate that iVProg, and visual programming in general, may benefit newcomers in programming.

Nevertheless, answers to the last question give some hints about improving iVProg, since they suggested that iVProg could generate an executable file from an iVProg program; the building of an area for storing programmed functions to be reused, among others.

VI. DISCUSSION

The experiment 1 and the results obtained in 2010 lead us to adopt, in 2011, an approach to smooth the introduction of the C language and its associated programming environment based on the use of both: iVProg and C from the very beginning. iVProg was used to find algorithmic solution to problems and then solve the same problems using C. Comparing the results from 2010 and 2011, we realized that students do improve their understanding about both algorithms and programming.

In general, students had considerable difficulties on dealing with the C language compiler and finding the syntax errors. Therefore, their attention was deviated from the real problem, that is to find an algorithm solution to a problem, to these debugging issues. This fact could significantly decrease their motivation during the course. In the other hand, we believe that iVProg, by reducing the cognitive load during the process, could partially solve the motivational problem.

VII. CONCLUSION AND FUTURE WORK

In this paper we presented iVProg, a visual programming system, as a tool that may enhance the understanding of algorithms and programming during introductory programming disciplines of CSET courses.

Experiments indicated that it does improve understanding about algorithms and may improve the understanding of a programming language such as C when used in combination of it from the very beginning.

The system is being fully redeveloped using a Software Product Line approach [15] in order to simplify its architecture and clean its code with the aim of facilitating its maintenance and evolution. This new development will turn possible the configuration of iVProg as a tool to support the learning of programming for several audiences: from kids to adults.

Also, we intend to implement the automatic assessment support to students' assignments, which will provide immediate feedback for students and reduce teacher's workload. Therefore, teachers may focus their attention to the teaching process and programming techniques. Moreover, since iVProg is an iLM, it can be integrated to Moodle using iAssign [18] and all the functionalities related to assignments reports may be benefited from the automatic assessment feature.

ACKNOWLEDGMENT

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The Impact of a Scientific Computing Prerequisite on Student Performance in a Linear Systems Course

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Abstract—Programming can be an important part of a linear systems (a.k.a., signal and systems) course, as programming projects help to solidify mathematical concepts and provide students with a means to visualize and interpret signal and coefficient behavior. However, students often struggle with programming, leading to frustration that minimizes learning and worsens student attitudes toward the material. To address that need, the Kansas State University (KSU) Electrical & Computer Engineering (ECE) Department recently added a required course, *ECE 540 – Applied Scientific Computing*, to the ECE curricula to ensure more overall C programming exposure and to serve as a prerequisite to *ECE 512 – Linear Systems* and other courses that require programming. This paper presents initial assessments of student preparedness for C programming projects in the Fall 2011 and Spring 2012 offerings of *ECE 512* following this course prerequisite change. The primary assessment mechanisms are pre- and post-project surveys that address students' proficiency in C, where the survey results are compared to similar surveys offered in prior semesters unaffected by the new course. These analyses indicate greater overall confidence in C programming, a better understanding of the supporting development environments, and an overall improved attitude toward Linear Systems programming projects.

Keywords—C programming, convolution, Fourier analysis, numerical analysis, scientific computing, signals, systems

I. INTRODUCTION

A. Motivation

A linear systems course that addresses time- and frequency-domain signal concepts is a mainstay in electrical and computer engineering curricula. Experience in teaching this course indicates that students can carry out calculations for Fourier series coefficients and Fourier spectra that help them perform acceptably on handwritten homework and exams. However, these students can have trouble visualizing coefficients graphically or interpreting coefficient behavior outside of recipe-based analyses – they lack the higher-level understanding [1, 2] that aids with long-term retention. Programming projects can help in this regard, since a minimal correct understanding of the mathematical relationships is needed to numerically implement the process. Further, computers allow one to view calculation results in interesting ways, which aids retention. Research

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geared toward computation, hands-on learning, and retention supports these assertions [3-5].

The problem is that many students continue to struggle with programming, and the inability to program sensibly and efficiently leads to frustration that minimizes learning and worsens student attitudes toward the core material. While research has shown that programming efficiency, even with highly trained individuals, can vary dramatically from person to person [6-9], the sensible implication is that the previous KSU Electrical Engineering (EE) and Computer Engineering (CMPEN) curricula were lacking in preparatory programming experience; the traditional introductory programming courses were simply insufficient. This message has been affirmed by the authors based on greater than 10 years of more-than-anecdotal classroom experience with *ECE 512*, supplemented by student comments on end-of-year teacher evaluations and in-class project surveys.

In response, the Kansas State University (KSU) Electrical & Computer Engineering (ECE) Department added a new, required scientific computing course (*ECE 540 – Applied Scientific Computing*) to the ECE curricula (while keeping the overall required hours the same) to ensure more exposure to C programming and to serve as a prerequisite to *ECE 512 – Linear Systems* and other upper-level courses with a programming component. The three-fold goal was to improve students' attitudes towards these courses, to provide these students with a skill set that would increase learning, and to make these students more marketable to potential employers. This new course affirms programming fundamentals introduced in earlier courses and also touches on statistics, linear algebra, and optimization.

This paper presents initial assessments of that curricular change in the context of the aforementioned Linear Systems course, specifically with regard to students' capabilities in (and attitudes toward) C programming as applied to the numerical calculations that support applications such as sliding windows, convolution, trigonometric Fourier series, and discrete Fourier transforms (Fourier spectra). Two forms of assessments were employed: (1) pre- and post-project surveys that address specific C programming concepts in addition to the learning objectives for the core material and (2) end-of-project evaluations based on rubrics that address project sub-areas in support of the stated learning objectives. These assessments occurred over the span of several years, ensuring the inclusion of data acquired before and after the addition of the scientific computing course to the ECE curricula.

B. Course Descriptions

ECE 540 – Applied Scientific Computing (3 credit hours) is a junior-level, single-semester lecture course required of all KSU EE and CMPEN students. The prerequisites for this course are C Programming (CIS 209 || 308) and Introduction to Probability and Statistics (STAT 510). Topics include numerical properties of floating-point numbers, series convergence, transcendental function computation (e.g., $\cos()$, $\sin()$, and $\exp()$), matrix algebra, and statistics. All algorithms are implemented in C or C++. Although C programming is a course prerequisite, students come into the class with a wide range of backgrounds and programming competency. Early assignments focus on basic C programming, whereas later assignments focus more on the numerical and theoretical aspects of the problem domain.

The purpose of the class is to prepare students to program in C so that they may address numerical problems in senior ECE courses. Faculty find that most students retain little of the training from their lower-level programming classes, which are also directed at programming more generic problems. This class was therefore developed to form a bridge between the programming basics and more advanced numerical problems to be solved with C programming. Thus, Applied Scientific Computing (ASC) focuses on the latter, with an emphasis on good fundamental programming and debugging skills.

ECE 512 – Linear Systems (3 credit hours) is a junior-level, single-semester lecture course required for all KSU EE and CMPEN students. The prerequisites for this course are C Programming (CIS 209 || 308), Circuit Theory II (ECE 511), and now Applied Scientific Computing (ECE 540). This course generally provides tools to analyze signals and systems in the time and frequency domains. Topics include categories of signals encountered in system analysis, time- and frequency-domain system response, Fourier series and transforms, filters and signal distortion, discrete (sampled) signals and signal reconstruction, and computational tools for analysis and simulation of linear system behavior.

This course was chosen by the KSU ECE faculty as a venue where (a) programming would supplement the core material as a means to engrain signal analysis concepts in student memory and also allow students to better visualize signal features in the time and frequency domains and (b) students would receive additional exposure to C programming prior to graduation, since C programming is a skill set that continues to be of interest to companies that hire KSU EE and CMPEN graduates.

II. METHODS

The following section presents the approach used by the authors to assess student *preparedness*, meaning their ability to program in C upon entering ECE 512. The intent is to gauge the effect of the new ECE 540 course for its primary intended purpose, which is to provide adequate programming training for follow-on courses, thereby facilitating student learning by removing barriers to programming (whether real or perceived) that the students had faced in the past.

A. Overall Approach

Various computational projects have been assigned to Linear Systems students in the last ten years [10-12]. Pre- and post-project assessment surveys have occasionally been a reasonable means to gather student self-assessment data regarding their comfort level with the facets of those projects, including the project learning objectives and the related areas of programming.

For the work presented here, these surveys provide the initial baseline data against which follow-on data will be compared. More specifically, survey data from semesters prior to Spring 2011 (the first semester where ECE 512 would possibly involve students that had already taken the newly offered ASC course) are compared against more recent survey data, where the majority of the students are expected to have taken ASC. Pre- and post-project data are compared for the two populations, and these results are discussed in more detail in Section III. *RESULTS & DISCUSSION*. While numerous data elements could be compared, the initial focus is on pre-project assessments of the different areas of C programming related to Linear Systems projects – assessments which have the highest likelihood of indicating student *preparedness*, or the level of student comfort and ability relative to the programming tasks required for successful course completion.

B. Computational Projects in Linear Systems

The flow diagram in Fig. 1 illustrates a sequence of broad tasks that would be typical of software projects addressed by students in this Linear Systems course. In these types of projects, students write code that, e.g., extracts data from input text files, processes those data, stores the results in one or more output files, and then creates MATLAB scripts that allow one to plot the results. These projects typically address both the time and frequency domains within the context of topics such as time-domain filtering via convolution, compact Fourier series coefficients computed from signal samples, magnitude/phase spectra from Fast Fourier Transforms (FFTs) applied to discrete data, and frequency-

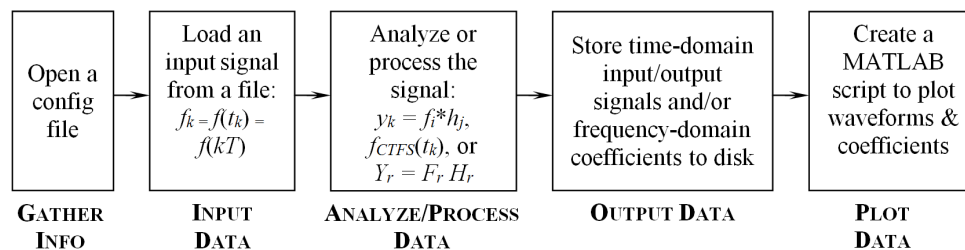


Figure 1. High-level program flow for a typical ECE 512 project.

domain filtering via linear convolution. During this process, students learn to better apply software-development approaches and data structures that promote efficiency and code maintainability. This usually means short C `main()` functions, header/source file pairs, structures that hold object data, functions that pass references to these structures, dynamic memory allocation/deallocation, file input/output, and a reliance on arrays and pointers.

Table I lists the projects that are relevant to this paper. The Spring 2007 and Spring 2009 project were offered prior to the time when the ECE 540 prerequisite was put in place. The Fall 2011 and Spring 2012 projects were offered after the prerequisite requirement became effective. All five project installments rely on a very similar code base that utilizes a predetermined set of header/source files to accomplish the general program flow illustrated in Fig. 1.

TABLE I. LINEAR SYSTEMS PROJECTS AND STUDENT REPRESENTATION

| Semester | Project Areas | Student Population |
|-------------|---|---------------------------------------|
| Spring 2007 | Trigonometric Fourier Series | 29 without ECE 540 |
| Spring 2009 | Sliding Windows; Trigonometric Fourier Series | 30 without ECE 540 |
| Fall 2011 | Trigonometric Fourier Series; Discrete Fourier Transforms | 10 without ECE 540 13 with ECE 540 |
| Spring 2012 | Unit Impulse Response; Discrete Fourier Transforms | 3 without ECE 540 20 with ECE 540 |

C. Pre- and Post-Project Assessment Surveys

Each project is designed to meet specific learning objectives. For example, the following are the learning objectives for a *compact trigonometric Fourier series* project that utilizes the general code base and the flow diagram in Fig. 1. *Upon completion of this project, each student should be able to do the following:*

- **Explain** how a signal can be constructed from sinusoidal building blocks
- **State** the mathematical relationships between trigonometric and compact trigonometric Fourier series coefficients
- Properly **sample** a periodic signal so that numerically determined Fourier series coefficients are equivalent to those calculated by hand
- Numerically **calculate** the Fourier series coefficients for a discrete data set
- Numerically **reconstruct** a data set given its Fourier series coefficients
- **Describe** a signal (its spectrum, bandwidth, primary energy range, etc.) based on Fourier series coefficients that exemplify its frequency domain character
- **Arrange** source code in a manner that promotes reuse and protects proprietary information
- **Organize** information in structures that facilitate bookkeeping and function-level parameter passing.

Prior to beginning each project addressed in Table I, students were asked to fill out a pre-project assessment

survey to gauge their level of starting expertise. For the first part of the survey, they were asked to address the learning objectives:

On a scale of 1 to 5, rate your level of comfort/familiarity with the respective learning objectives. Here, “1” means no comfort and “5” means high confidence.

They were then asked to rate their proficiency relative to the areas of C programming germane to the project:

This project will also address facets of C programming. On a scale of 1 to 5, note your level of proficiency in the following areas, where a “1” denotes no proficiency and a “5” denotes a solid understanding of the concept.

In most of these surveys, students were then asked to respond to open ended questions related to the subject area. Responses to some of these questions are summarized in Section III. *RESULTS & DISCUSSION*. Upon completion of the project, the students were then given an identical survey to gather their post-project viewpoints regarding the learning objectives and the related facets of C programming.

The following data/calculations were tallied/performed for each survey item relative to the projects noted in Table I:

- Pre-project rating
- Post-project rating
- Pre-post difference (post rating minus pre rating)
- Average pre, post, and difference scores for an entire class of students
- Summary metrics for each class
- Side-by-side comparisons of these metrics for the various semesters, with a goal of identifying trends.

C programming areas of interest are listed in Fig. 2 in the next section. Note that survey data are only analyzed for students that passed the class in each respective semester. In semesters where some students had taken the ECE 540 prerequisite and some had not (e.g., Fall 2011), survey responses are tallied for each student subset.

D. Other Assessment Data

While student self-assessment surveys and project rubrics can be useful for gathering quantitative data, anecdotal observations can also provide meaningful insight. Some of these observations are presented in the next section.

III. RESULTS & DISCUSSION

A. Pre- and Post-Project Survey

Representative data from the pre- and post-project survey results are tallied in Fig. 2. These data represent the four separate semesters recorded in Table I (S07 = Spring 07; S09 = Spring 2009; F11 = Fall 2011; S12 = Spring 2012). The first column contains the C programming areas that were addressed in the surveys. (The items in a blue font were not incorporated on the original survey from Spring 2007.) The following three columnar groups represent data for pre-project averages, post-project averages, and pre/post differences. For example, for the category of “Calculation of

| | Pre-Project Averages | | | | | | Post-Project Averages | | | | | | Difference Averages | | | | | |
|--|----------------------|------|------------|------------|-----------|------|-----------------------|------|------------|------------|-----------|-----|---------------------|------|------------|------------|-----------|-----|
| | | | F11 F11 | F11 w/o | F11 w/ | | | | F11 F11 | F11 w/o | F11 w/ | | | | F11 F11 | F11 w/o | F11 w/ | |
| C Programming Area | S07 | S09 | All | 540 | 540 | S12 | S07 | S09 | All | 540 | 540 | S12 | S07 | S09 | All | 540 | 540 | S12 |
| Calculation of mathematical expressions | 4.1 | 4.3 | 3.9 | 3.7 | 4.2 | 4.3 | 4.3 | 4.6 | 4.5 | 4.2 | 4.7 | - | 0.1 | 0.3 | 0.5 | 0.6 | 0.5 | - |
| Standard I/O in a console application | 3.9 | 3.7 | 3.7 | 3.2 | 4.2 | 4.2 | 4.1 | 4.7 | 4.4 | 3.9 | 4.7 | - | 0.2 | 1.0 | 0.7 | 0.9 | 0.5 | - |
| File input/output | 3.4 | 3.7 | 3.6 | 3.4 | 3.8 | 4.1 | 4.1 | 4.7 | 4.5 | 4.0 | 4.8 | - | 0.7 | 1.0 | 0.8 | 0.7 | 1.0 | - |
| Reading from and writing to arrays | - | 3.8 | 3.5 | 2.8 | 4.1 | 4.3 | - | 4.6 | 4.5 | 4.0 | 4.8 | - | - | 0.7 | 0.9 | 1.2 | 0.7 | - |
| Pointers as they relate to arrays | - | 3.5 | 2.9 | 2.4 | 3.5 | 3.8 | - | 4.1 | 4.1 | 3.9 | 4.2 | - | - | 0.5 | 1.1 | 1.7 | 0.7 | - |
| Format specifiers | - | 3.3 | 2.8 | 2.5 | 3.2 | 3.4 | - | 4.1 | 3.9 | 3.8 | 4.0 | - | - | 0.7 | 1.1 | 1.6 | 0.8 | - |
| Role of #include and #define directives | - | 4.0 | 3.4 | 2.8 | 4.1 | 3.9 | - | 4.6 | 4.2 | 3.8 | 4.5 | - | - | 0.5 | 0.7 | 1.0 | 0.5 | - |
| Dynamic memory allocation | 2.9 | 3.0 | 2.8 | 2.1 | 3.4 | 3.7 | 3.9 | 4.1 | 3.5 | 3.0 | 3.8 | - | 0.9 | 1.1 | 0.6 | 1.0 | 0.4 | - |
| Creating, filling, and accessing structures | 2.7 | 3.3 | 2.8 | 2.6 | 3.1 | 3.4 | 4.1 | 4.3 | 3.9 | 3.7 | 4.1 | - | 1.4 | 1.0 | 1.0 | 1.1 | 1.0 | - |
| Structure/array references as function parameters | 3.0 | 3.0 | 2.8 | 2.5 | 3.1 | 3.3 | 3.9 | 4.2 | 3.9 | 3.4 | 4.3 | - | 1.0 | 1.1 | 1.1 | 1.0 | 1.2 | - |
| Function prototypes | 2.7 | 3.1 | 3.0 | 2.6 | 3.4 | 3.6 | 3.7 | 3.9 | 3.9 | 3.4 | 4.2 | - | 1.0 | 0.9 | 0.8 | 0.9 | 0.8 | - |
| Header/source file pairs | 2.4 | 3.0 | 3.0 | 2.7 | 3.3 | 3.4 | 3.8 | 4.4 | 4.1 | 3.7 | 4.3 | - | 1.4 | 1.5 | 1.0 | 1.0 | 1.0 | - |
| Conceptual difference between compiling and linking | 2.1 | 2.6 | 2.3 | 2.2 | 2.5 | 2.6 | 3.0 | 3.3 | 3.2 | 2.6 | 3.6 | - | 0.8 | 0.7 | 0.8 | 0.6 | 1.0 | - |
| Creation of another file (e.g., a MATLAB script) using a C program | 2.0 | 2.3 | 2.0 | 1.8 | 2.4 | 2.1 | 4.3 | 4.5 | 4.3 | 3.8 | 4.7 | - | 2.3 | 2.1 | 2.2 | 2.1 | 2.3 | - |
| Solutions/projects in MSVS .NET | 2.6 | 3.2 | 2.2 | 1.9 | 2.6 | 3.0 | 3.6 | 4.4 | 3.7 | 3.3 | 4.0 | - | 1.0 | 1.2 | 1.5 | 1.7 | 1.3 | - |
| Arranging source code to promote reuse and protect proprietary information | - | 3.1 | 2.6 | 2.4 | 2.8 | 2.8 | - | 4.1 | 3.5 | 3.3 | 3.7 | - | - | 0.9 | 0.9 | 1.0 | 0.8 | - |
| | | | | | | | | | | | | | | | | | | |
| Column Sum | - | 53.0 | 47.0 | 41.5 | 53.8 | 55.7 | - | 68.5 | 63.9 | 57.8 | 68.2 | - | - | 15.3 | 15.8 | 17.9 | 14.4 | - |
| Avg | 2.9 | 3.3 | 2.9 | 2.6 | 3.4 | 3.5 | 3.9 | 4.3 | 4.0 | 3.6 | 4.3 | - | 1.0 | 1.0 | 1.0 | 1.1 | 0.9 | - |
| Stdev | 0.68 | 0.51 | 0.55 | 0.52 | 0.59 | 0.63 | 0.38 | 0.37 | 0.39 | 0.42 | 0.4 | - | 0.58 | 0.43 | 0.4 | 0.43 | 0.45 | - |

Figure 2. Results summary for the pre- and post-project student self-assessment surveys.

mathematical expressions,” the average pre-project response from the Spring 2007 class was 4.1 out of 5. For that same class, the post-project response was 4.3 out of 5, on average. On average, the pre/post difference (post response minus pre response) for that category was 0.1 for the S07 semester. Note that post-project averages and difference averages do not exist for Spring 2012 – those surveys have not been completed to date. Underneath the primary tabular layout, one will note the rows that contain the column sums, averages, and standard deviations. These were seen as a way to aggregate numbers for a given semester.

For starters, note that confidence levels of incoming students vary from semester to semester. The time span for this table is relatively broad, and the prerequisite courses that represent early programming instruction in these areas can change quite a lot depending on the assigned instructor and the goals of the departments teaching these service courses. The most interesting set of pre-project data relate to the Fall 2011 semester, where 10 of the 23 students had not taken ECE 540 prior to enrolling in ECE 512. The overall pre-project scores of the class were low in most categories relatively to prior semesters. However, when the data are pulled apart to represent ECE 540 (ASC) participation, the numbers are striking: incoming confidence ratings for the students without ECE 540 experience are lower in every category; the difference is as low as 0.3 and as high as 1.3.

The first question is whether the two columns (F11 w/o 540; F11 w/ 540) represent equivalent student groups. If the students’ final ECE 512 course scores for the respective

groups are averaged, the group w/o 540 has a percentage that is 4% less than the group that had taken 540. This is not a particularly substantive difference (less than half of a letter grade) and may represent the fact that (a) those with ECE 540 experience received higher project scores because they had more familiarity with C or (b) the idea that the students with the ECE 540 prerequisite were more responsible and had therefore managed their curriculum in such a way that their retention was better. Nonetheless, roughly speaking, these students were all at the same point in their curricula, so it is reasonable to compare the two columns of numbers relative to one another.

With that in mind, one first notes that pre-project confidence in some areas of C programming was quite different. Areas with differences greater than 0.5 include standard I/O, array manipulation, pointers, format specifiers, preprocessor directives, dynamic memory allocation, structure references, function prototypes, header/source files, file creation, and .NET usage. All of these areas are emphasized in ECE 540 as the students complete their numerical analysis assignments. These kinds of numbers are mirrored in the ‘Column Sum’ row at the bottom, where scores of 53.8 and 55.7 (for F11 w/ 540 and S12, respectively) are much higher than the number posted by the ‘F11 w/o ECE 540’ group (41.5).

Further, the post-project averages are higher as well for the F11 w/ 540 group, yielding difference averages that are actually *smaller* for the group that had taken ECE 540. This is reasonable when one considers that the group with better

prior C training likely did not have to learn as much new C material in order to perform as desired on the course projects. For the F11 group that did not have prior ECE 540 experience, they would have to work harder on C programming constructs in order to complete the projects to the same level. On the other hand, note that a disparity does still exist in the post-project scores (e.g., a disparity of 4.0 versus 4.8 for file I/O and a disparity of 3.0 versus 3.8 for dynamic memory allocation). This may simply support the assertion that one needs to spend significant time with C programming before it becomes natural. That notion is consistent with studies performed in other areas such as music, where the ability to play at a given level depends mostly on the number of hours invested in the training [13].

B. Rubric-Based Assessments

Early in the assessment process, the author surmised that a correlation would exist between pre/post survey scores, project scores, and overall scores in ECE 512. However, those correlations are not telling. One explanation would be as implied in the previous paragraph, where students will invest more time to receive the desired grade on a project because that grade will provide scaffolding for the overall grade. In these studies, we did not have a mechanism in place to measure overall effort and time invested. Such a metric would provide a good means to answer the question, "Did they feel prepared?" versus "Were they prepared?"

C. Survey Comments

Comments to open-ended survey questions potentially provide the richest source of data for post-processing analyses. Such data were quantifiably important when originally deciding whether to update the curriculum with the ECE 540 course. For example, in the Spring 2007 post-project survey, students were asked, "What was your least favorite part of this project experience?" Of the 36 separate responses, 23 responses were comments that addressed being forced to use C, debugging C code, memory allocation, and other C-like constructs that over time become easier to use and therefore make for a more reasonable programming experience.

In contrast, responses to open-ended questions on the Fall 2011 post-project survey were overall more positive. In that survey, the question was "What thoughts would you be willing to share regarding the C language and its role or placement in our curriculum?" Of the 34 responses, 14 related to the idea that C programming is a useful and important part of the domain. 19 of the remaining responses noted themes such as the idea that C takes a long time to learn and needs to be emphasized in more KSU classes, or that students often lack confidence in C. Only two comments were decidedly negative. In that same survey, 16 of 28 responses noted that C would be an important part of their career employment, whereas only 7 respondents stated that they would not use C after graduating because of their degree area. Overall, these responses are much more positive than responses to surveys from previous years, and it is not unreasonable to attribute that change in attitude, at least partially, to the addition of this new course.

D. Anecdotal Observations

After the realization of the ECE 540 course, the ECE 512 instructor fields relatively few questions about the Microsoft Visual Studio .NET development environment and the C language itself. (For example, most questions in the Spring 2012 semester related to the use of the command line arguments in a console program, a technique that is rapidly becoming outdated due to the proliferation of window-based interfaces. Most college students today have no experience with, or knowledge of, the DOS prompt in Windows. Students that work more with Linux have a better knowledge of such a construct.) The lack of confusion about these items therefore gives the ECE 512 instructor the impression that addressing these items in class is largely a poor use of the students' time. As recently as a year ago, in-class discussions regarding the development environment and the C language were mandatory in order to avoid student onslaughts during office hours.

While the level of "hand holding" has recently decreased for the better, it is clear that students still generally need better training regarding the thought processes required to debug code and to solve algorithmic problems. Arguably a trait of this generation, many students that are faced with a debugging problem that starts to cost them time are more likely to seek help from the Internet or from a group of friends than to logically fight through a problem on their own, which is an excellent learning experience. This issue is exacerbated by many students' preferences to write code in groups, assuming it is even allowed (in ECE 512 and ECE 540, it is not), which (a) muddies the line between group work and outright plagiarism and (b) makes it difficult to surmise which students might be able to write programs independently as a professional engineer.

E. Future Work

The analyses presented in this paper can clearly be supplemented with future endeavors that address further analyses based on the present data as well as new assessments related to programming-centric teaching and learning. The initial update of this material will consist of adding Spring 2012 ECE 512 post-project assessment data (and ideally Fall 2012 ECE 512 data) to the current data set in order to get a more informed picture of the benefits of this new scientific computing class. Given the nature of these data, which are in spirit a comparison of means, this analyses will likely involve paired t tests to ascertain whether these performance data can be reasonably distinguished from one another. Further, the authors are interested in investigating this notion of whether the actual time invested in C programming (as it relates, e.g., to the music illustration earlier) is the driving factor in student proficiency with C. Finally, the authors see value in performing an introspective analysis of the ECE 540 course itself, with the goal of evaluating the effectiveness of different methods for teaching programming-intensive subject areas.

IV. CONCLUSIONS

This paper presented early assessments of student preparedness for C programming projects in *ECE 512 – Linear Systems* following a curricular modification to make *ECE 540 – Applied Scientific Computing* a required prerequisite for ECE 512. Pre- and post-project surveys in ECE 512 from Fall 2001 and Spring 2012 (semesters when the course prerequisite was in place) were compared to similar surveys from Spring 2007 and Spring 2009 (semesters prior to the new mandate). These data indicate greater overall confidence in C programming, a better understanding of the associated development environments, a better attitude toward Linear Systems programming projects, and a better sense of C programming as it relates to follow-on career choices. Efforts are underway to corroborate these initial findings with new offerings of similar programming projects addressed by new groups of students that have met the ECE 540 prerequisite requirement.

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Integrating Developmental Instruction in Four Sustainability Contexts into an Undergraduate Engineering Design Curriculum: Level Three

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Abstract - Developmental instruction in four sustainability contexts (*environmental, social, economic, technical*) in an engineering design curriculum offers a strong foundation and framework upon which to build an engineering program that teaches students the necessary methodologies for designing for sustainability. Instruction in sustainability contexts described in the current paper employs a developmental approach using Bloom's *Taxonomy of Educational Objectives*, which is a way to classify instructional activities or questions as they progress in cognitive difficulty. Our objective in this paper and presentation is to detail an instructional methodology (and results of a case study and focused group assessment) that integrates sustainability instruction in four contexts into the fifth and sixth classes in our six-course design curriculum using a developmental approach.

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Index Terms: Engineering Design, Sustainability, Developmental Instruction

Note: Because of the developmental nature of this three-stage project—this paper describes the third stage—portions of the Introduction and Literature Review are excerpted from our FIE 2011 paper and presentation: Pappas, E. and Pierrakos, O. “Integrating Developmental Instruction in Sustainability Contexts into an Undergraduate Engineering Design Curriculum: Level Two.” *Proceedings of the Frontiers in Education National Conference*, October 2011.

I. INTRODUCTION

Declining environmental, economic, and social conditions world-wide require a response from the engineering community, especially in higher education, since many of the solutions to these problems are related to the discipline, particularly engineering design for

sustainability. We have come to understand well that the greatest and most immediate *sustainability problems* humans face are related to our relationship with the natural world and the populations occupying the planet. This fact places a great deal of responsibility on a discipline that must now move beyond its historical sphere of technical influence and embrace the wide variety of disciplines with which it shares influence. We define sustainability as follows:

A sustainable society possesses the ability to continue to survive and prosper, not just with respect to environmental resources and economic development, but also with respect to quality of life as it pertains to conditions that promote sustainable human prosperity and growth (e.g., opportunity, economy, privacy, community, the arts, education, and health). A sustainable society meets these needs simultaneously, and in the context of human respect and the ability to negotiate differences without violence.

The James Madison University School of Engineering teaches sustainability in the following four contexts:

A) Environmental Sustainability

Briefly stated, designing for environmental sustainability is an approach to the engineering of processes, products, and structures which has, indefinitely, a less negative, a neutral, or a benign effect on all environmental systems. Sustainable engineering design tends to produce products and processes in which nature is not subject to continual 1) increases in the use of natural resources, 2) increases in goods produced by society, and 3) increases in waste products and the effects of their degradation.

B) Economic Sustainability

Beyond the efficiencies of economic policies and manufacturing processes directly related to the efficient, profitable, and sustainable development of a process or product, economic factors in sustainability influence the

economic health and profile of communities, including the standard of living, the existing business climate, employment, and the productive role of the corporation in the life of its employees (e.g., individual well-being, opportunity, productivity).

C) Social Sustainability

Social sustainability includes the role of individuals, relationships among social groups, the family, collective behavior, social class, race and ethnicity, medicine, education, and the role of institutions in society. This includes cultural factors related to the shared values, attitudes, beliefs, behaviors, and social practices that characterize human knowledge and action (e.g., fine arts, humanities, the transmission of knowledge, shared everyday way of life).

D) Technical Sustainability

Technical sustainability addresses a wide variety of factors related to the design and manufacture of products, especially the 1) scientific research and appropriate technology (compared to alternatives) supporting product function and development; 2) ease and efficiency of durable construction and use; 3) maintenance and functioning capabilities that meet the objective for which a product is designed; 4) material selection; and 5) reduction, recovery, reuse, or disposal of parts.

Factors in all sustainability contexts are mutually dependent upon each other in complex ways, and a change in one factor is likely to result in an unpredictable change in the others. *Little work has been done to understand and assess the reciprocal influences (that is, how sustainability in one context influences sustainability in other contexts) this complex system creates.* For example, efforts to promote environmental sustainability have traditionally required trade-offs among resource availability, market forces, and technology—and may include the consideration of *some* human factors—but may ignore or deemphasize issues related to the economic, social, and cultural well-being of a population (community sustainability).

It would appear that determining the sustainability of a product, process, or human community depends upon the careful and complete *assessment and evaluation* [1] of a range of technical and human factors that may (or may not) be influenced by a particular assessment effort, noted in *The Engineer of 2020* as “the core analysis activities of engineering design” [2]. This approach is central to our efforts, but it is a methodology about which little has been written or practiced.

Our overall program objective is to provide a design course sequence that integrates sustainability instruction in four contexts (environmental, social, economic, technical) into our six-course design curriculum using a developmental approach.

Instruction in sustainability contexts described in this paper employs a developmental approach using Bloom’s *Taxonomy of Educational Objectives*, which is a way to classify instructional activities or questions as they progress in cognitive difficulty. Our objective in this paper and presentation is to detail an instructional methodology (and results of a case study) that integrates sustainability instruction in four contexts into the fifth and sixth classes in our six-course design curriculum using a developmental approach.

II. LITERATURE REVIEW

Sustainability in engineering has its roots in two engineering sub-disciplines: green engineering and environmental engineering. In general, green engineering has focused on design that is in greater long-term harmony with the environment while environmental engineering has addressed the deleterious effects engineering design (or, sadly, lack of design) has had on the environment [3]. Sustainable engineering is, in many ways, more related to green engineering as it focuses on design that requires fewer natural resources, produces less (or no) waste, and reduces, reuses, or recycles waste products.

The Brundtland Report of the United Nations World Commission on Environment and Development first expressed concern over sustainable engineering at its 96th plenary meeting (December 11, 1987), noting a concern “about the accelerating deterioration of the human environment and natural resources, and the consequences of that deterioration for economic and social development...” [4]. What is, perhaps, most notable about the Report is a definition of sustainability that includes more than environmental sustainability and the opinion that the environment, the economy, and society compose a *complex system*, and that a change in one factor in sustainability will likely cause change in others.

Other definitions of sustainability often mirror the Commission’s Report. McDonough and Braungart view sustainability from the point of view of balancing environmental, social, and cultural concerns through a “triple bottom line” based on balancing the “tripod” of ecology, economy, and equity [5]. Charles L. Redman, director of Arizona State University’s School of Sustainability defines sustainability as “...an awareness of the connectivity of the world and the implications of our actions” [6]. The University of California Los Angeles Anderson School of Management offers a multidisciplinary approach to sustainability from an economic point of view: “‘Sustainability’ (loosely defined as the simultaneous consideration of economic, environmental, and social factors) has become a key element in decision making in many areas of business and public policy. By definition, sustainability requires a multi-disciplinary perspective” [7]. Roseland focuses on

a variety of issues related to sustainable community development, such as integrating environmental, economic, and social objectives, and concepts of “natural capital and social capital, whether (and if so, how) they are linked, and explores their implications for sustainable development at the community level” [8, p. 89].

Bras-Klapwijk notes the value of integrating instruction in environmental and social sustainability into engineering design curricula using problem solving methodologies. He suggests, as well, that factors related to sustainability have significant influences on each other [9]. Interactions among contexts in environmental and social sustainability can be evaluated, according to Chapin, through a series of “feedback” systems [10]. Expanding the notion of “reciprocal influences” among sustainability contexts, Thom takes a “holistic approach with a clear vision of systems functioning” [11, p. 91]. Crofton developed a curriculum that focuses on the interactions among sustainability contexts she considers central to all engineering instruction [12].

Unfortunately, efforts to integrate sustainability into engineering curricula have met with some resistance, especially problems related to 1) adding courses or integrating instruction in sustainability contexts into already tight engineering curricula, 2) the faculty interdisciplinary expertise necessary to teach new sustainability topics, and 3) the resistance from faculty to revising existing courses [13].

Methodologies for teaching sustainability have taken a largely traditional form, apart from some efforts teaching problem-based learning [14], hands-on approaches [15]-[17] and creativity skills [18]. Teaching critical thinking developmentally, especially using Bloom’s *Taxonomy of Educational Objectives* [19], is well-represented in higher education across the disciplines, and increasing efforts in science and engineering disciplines have met with success [20]-[23] as have methods of teaching creative problem solving in engineering design [24,25].

III. CURRICULUM MODEL

We teach students problem solving in four sustainability contexts (environmental, social, economic, technical) using an integrated and developmental methodology employing Bloom’s *Taxonomy of Educational Objectives* [26], which is a way to classify instructional activities or questions as they progress in cognitive difficulty. The lower two levels of the taxonomy (Knowledge, Comprehension) require basic thinking skills; as one moves from the lowest levels (on the left, below), the activities require higher level thinking skills. As students become adept at analyzing sustainability case studies, developing and building sustainable designs, and assessing products and processes for sustainability at these two levels, they move on to the next Bloom stages. In short:

Knowledge → *Comprehension* → *Application* → *Analysis* → *Synthesis* → *Evaluation*

While stand-alone courses in design are more typical in engineering programs [27], our approach integrates instruction into a six-course, three-year design curriculum which is the “spine” for our instruction in sustainability. Our instructional approach to teaching sustainability is 1) developmental, 2) integrated, 3) interdisciplinary, and 4) hands-on (design-to-build).

Our developmental approach allows students to slowly grasp, understand, and apply increasingly sophisticated thinking and problem solving throughout the conception, design, building, and evaluation of their own designs and redesigns. Students apply the criteria to their own projects *iteratively* to determine how a design can be improved related to sustainability. Our curriculum model provides an effective workplace-modeled approach [28].

Our courses present sustainability problems in the context in which students will encounter them in their professional lives, in the present study, in the form of sustainability case studies. Course instruction and assignments present problems that direct students to confront the *reciprocal influences among sustainability contexts* and design trade-offs necessary to develop workable and creative design solutions.

The effort described in this paper encompasses instruction and assessment of *sustainability case studies* in Stage Three—the third two levels of Bloom’s Taxonomy: *Synthesis* (Descriptors: create, design, integrate, construct) and *Evaluation* (Descriptors: choose, evaluate, prioritize, predict, justify). These final two design courses apply thinking and reasoning challenges for students that fall into the two highest levels of Bloom’s Taxonomy. This is our final of three reports on this project.

IV. ASSESSMENT METHODOLOGY AND RESULTS

In this assessment, the last of three of its kind in our rather extensive mixed-methods assessment of our design sequence, first-semester senior design students (n=44) were given the following sustainability case study at the end of the fall semester. The assessment was a written take-home assignment, limited to two hours, and low stakes (full credit was given for simple completion of the assignment).

Impact of Global Warming in the U.K.

The United Kingdom (U.K.) has recently experienced an upsurge in extreme weather such as storms, floods, heat waves, and droughts. The Climate Change Committee issued a warning

this year of more frequent extreme weather changes throughout the U.K.

The first national assessment of the country's readiness for the impacts of global warming found the UK was very poorly prepared for the changes, with fewer than one in 15 companies, local authorities, and other public bodies taking action to tackle the issue.

A report by the Climate Change Committee calls for speedy action by the government to introduce regulations and funding before it is too late. Recommendations include ensuring new buildings have better insulation and protection against heat waves and flooding, consideration of compulsory water metering to conserve water, "grey" water systems for homes to replace purified tap water with recycled water for gardens and toilets, and better emergency plans to protect vulnerable groups such as the elderly. The report suggests five "priority areas" for action: land-use planning, such as not building homes on flood plains and better surface water drainage; infrastructure, such as building roads to cope with "typical Mediterranean" summers; buildings, including the construction of new homes and retrofitting old housing stock to be better insulated cool in hotter summers; natural resources, such as setting up "wildlife corridors" so species can migrate to more suitable habitats as conditions change and "making space for water" when there is flooding along coasts and rivers; and better emergency planning.

Some changes would mean spending money "smarter" rather than increased funding; others would require up-front spending for longer term savings, reported Lord John Krebs, chairman of the group. Government could also take action by introducing regulations to force higher standards, such as tougher building regulations and more water meters to encourage homeowners to be more careful with their water use, he said. Another potentially controversial suggestion was that industry regulators, such as the water and electricity sectors, should be given powers to make lower bills less of a top priority and more weight to other considerations such as adaptation, said Krebs.

Source: The Guardian, Sept 2010, www.guardian.co.uk

In this third stage, students were instructed to *synthesize* and *evaluate* the sustainability problems at stake in each of the four contexts we have been studying (environmental, social, economic, technical). Each student submitted a maximum one-page written response for each of the sustainability contexts.

Responses were scored as following: a score of 0-3 was given to each of the four written responses submitted by each student and was determined by how many valid issues a student identified, synthesized and evaluated in each of the four contexts, so that synthesizing and evaluating one valid environmental issue in the case study would yield a score of "1" for the environmental sustainability response. In the same manner, if the same student addressed three valid social issues in the case study, she or he would score a "3" for the social sustainability response. Each student, then, received a separate score for each sustainability context. Students were *not* asked to synthesize or evaluate issues in any *other* sustainability contexts, but the figures below show that students are beginning to integrate sustainability issues on their own. The three other bars in the figures below show how often a student *also* mentioned another sustainability context in the particular case study context. For example, Figure 1 below shows that the identification, synthesis, and evaluation of environmental issues in the above case study averages almost three per student. At the same time, the average mention of a social context (in the *environmental* response) was .32. Economic and technical sustainability issues were mentioned with some frequency in the environmental responses.

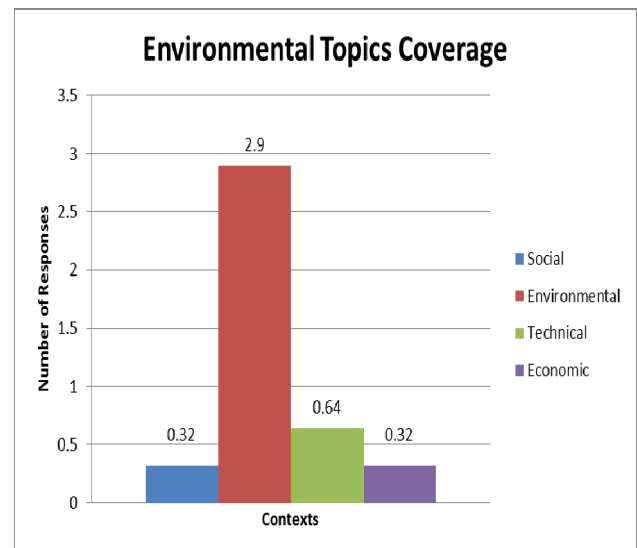


FIGURE 1:
ENVIRONMENTAL TOPICS COVERAGE

In Figure 2, it appears that students were particularly sensitive to social issues (or social justice issues) in the case study. When asked to synthesize and evaluate social

issues in their response, students noted an average of 2.7 issues per response. In this social context response, students averaged .32 environmental issues per response. Averages for technical and economic contexts were a bit stronger.

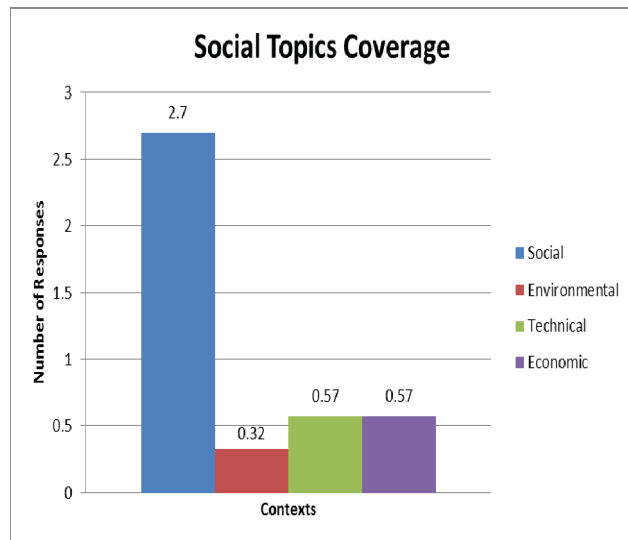


FIGURE 2:
SOCIAL TOPICS COVERAGE

In Figures 3 and 4, students demonstrated a high level of sensitivity to economic (2.7) and technical sustainability issues (2.6). Coverage of other sustainability issues in each major context was rather low but notable (see discussion).

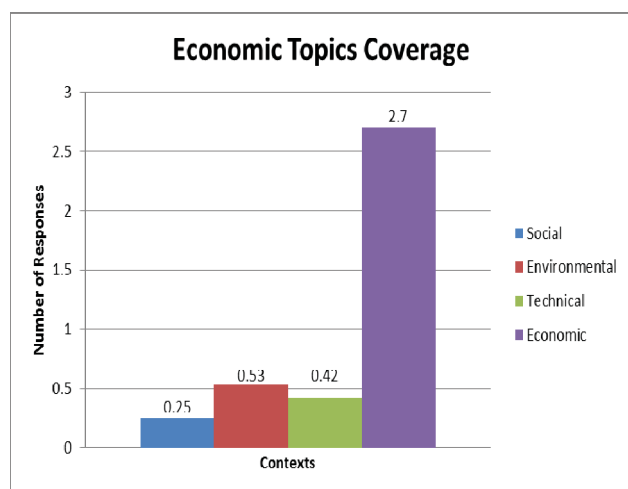


FIGURE 3:
ECONOMIC TOPICS COVERAGE

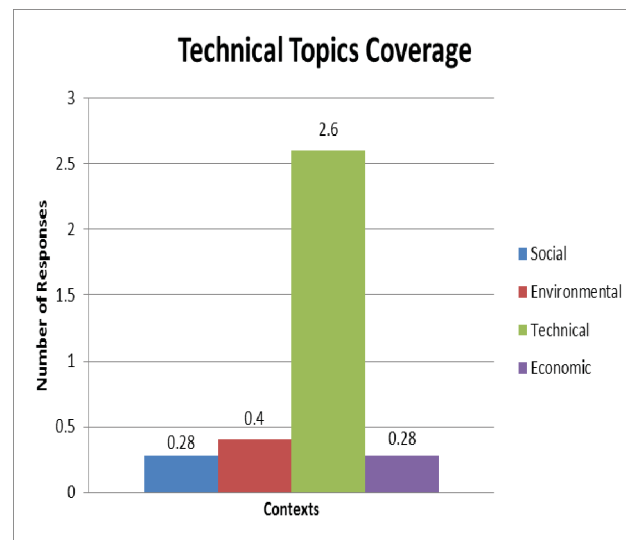


FIGURE 4:
TECHNICAL TOPICS COVERAGE

V. DISCUSSION

It is clear that even with the level of sophistication in thinking required for Stage Three of this project, students are quite easily identifying, synthesizing, and evaluating sustainability problems they found in the case study. We observe, however, that students included other sustainability contexts into their evaluation of each of the main contexts at a *higher rate* than they did for Level One (identify and describe) or Level Two (application and analysis) of Bloom as described in our FIE 2010 and 2011 papers. As noted earlier, students were *not* instructed to include in their response any other context than the main one, so that we could evaluate their “*natural* inclination to think using a systems perspective” to include other related contexts. This is challenging for undergraduate students, and we did not know what to anticipate, considering many academics and professionals in engineering do not exhibit the natural inclination to think in a systems (holistic) perspective.

Our desire here is to change how students think...that they will *naturally* link contexts using a systems perspective. (When directed to address all four contexts in a case study, our students readily do so, and with some skill.)

This effect is natural, perhaps, as the increasing intellectual sophistication required to employ higher levels of Bloom’s Taxonomy makes integrating other sustainability contexts into the main context more challenging.

We consider this NSF-funded effort to be highly successful and have established the approach described in the paper as a permanent component of our design sequence. We will continue to refine our efforts,

especially related to teaching students system theory and holistic thinking. We have recently received another substantial NSF sustainability instructional grant to expand our efforts.

VI. CONCLUSION

The approach to thinking detailed in this (and the two earlier papers) has applications in STEM disciplines as well as across most all academic disciplines. Students need to understand the profound connections and reciprocal influences among the biological, social, and economic factors that determine global sustainability.

We consider social sustainability the central sustainability context because it is the nature of human relations that determine our actions towards the environment. For this reason, we believe many sustainability efforts to be mis-directed in the direction of environmentalism. Social and community sustainability are contexts that need further and serious examination and research.

In particular, we are developing methods for assessing social sustainability especial related to how *individual sustainability* (how well one balances one's intellect, emotions, spirituality, relationships, and physical well-being) influences community well-being. Individual and social sustainability are the likely final determinants in all sustainability efforts. Little serious research has been conducted in these areas.

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Promoting Design Skills in Distributed Systems

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Abstract—Distributed software system design is by nature an ill-defined or wicked problem. In order to learn to design them, the student must be presented with complex, open-ended problems for which there may be more than one correct solution. The decision-making strategies students acquired in previous courses are not effective when applied to large, complex problems of distributed systems. Students (novice designers) tend to think linearly and focus only on the problem at hand. They also tend to use trial-and-error strategies and they lack confidence in their design decisions. The purpose of the distributed systems' course is to create a learning approach that helps students to adopt and to apply expert design decision-making strategies. We use a case-based learning approach with classroom assessment techniques and rubrics to identify the critical weaknesses in the approaches that novices typically use when attempting to solve difficult design-oriented problems. The novice-oriented knowledge-based learning and application environment is supported by scaffoldings to incorporate expert strategies. In this paper, we describe the experience and the learning environment that provides the opportunities for professional development. We present and analyze our data comparing the students' outcomes over four terms, the time it takes to develop our students' expertise and how time spent with an expert (instructor) is crucial to an overall development.

Keywords—*component: distributed systems, expertise, formative assessment, problem-based learning, scaffoldings.*

I. INTRODUCTION

Distributed systems is concerned with understanding the nature and requirements of pervasive software-based systems of systems that collaborate to provide essential services to society. Software in these systems is often required to (1) operate in distributed and embedded computing environments consisting of diverse devices (personal computers, specialized sensors and actuators), (2) communicate using a variety of interaction paradigms (messaging, media streaming), (3) dynamically adapt to changes in operating environments, and (4) behave in a dependable manner [1, 2]. Understanding and designing are the two key activities of distributed systems development. By design, we mean both the design of specific systems for specific needs, and the design of more generic toolkit environments [3].

A distributed system has design issues that arise specifically from its distributed nature. A distributed software system consists of interacting entities that work together to

perform specific tasks: (1) it provides concurrency by disbursing objects over a network of computing resources. In contrast, centralized systems can only simulate concurrency. (2) An individual computing resources in the network of the distributed system can fail or become unreachable. In centralized systems, failure is usually treated as an all-or-nothing condition. (3) It provides dynamic, incremental change. A distributed system rarely requires a complete shutdown to make changes in the way that it work is performed. Mechanisms for dynamic and incremental change are often built into the infrastructure.

Furthermore, the ideal premise of a minimum conceptual distance between analysis and a corresponding design of a centralized systems design tend to increase and complicate the design process. Some examples are: (1) many software objects distributed across the network can represent a single real-world object; (2) a software object may represent only a portion of the behavior of the entity described in the analysis; (3) the distribution of objects should consider factors like performance, reliability, security, and fault tolerance, and not only locality. Distribution can introduce a significant amount of resource sharing that did not exist in the analysis. [4]

Consequently, the distributed systems design problem can be characterized as a wicked [5] or ill-defined problem [6]. Ill-defined problems refer to the fact that the design problem is incomplete and has no one single solution, while wicked problems are progressively defined during the design process. Wicked problems are essentially unique, and each can be considered to be 'a symptom of another problem' [7]. Wicked problems require an ongoing iterative analysis between problem and solution to begin to understand either [3].

In our Distributed Systems Design course for advanced Informatics Engineering students we have combined a Problem based Learning (PBL) approach with a commitment to developing independent learners with professional (expert) design skills providing guidance through a cognitive support system.

We will describe the experience and the learning environment that provides the opportunities for professional development. We will present and analyze our data comparing the students' outcomes over four terms and the time it takes to develop our students' expertise and how time spent with an expert (instructor) is crucial to an overall development.

II. WICKED PROBLEMS

Rittel and Webber [5] describe two classes of problems: tame problems and wicked problems. A tame problem is one for which the traditional linear process is sufficient to produce a workable solution in an acceptable time frame. Many traditional exercises in Concurrency and Introductory Software Engineering courses fall into the category of tame problems.

Wicked problems are ill-defined problem sets that are too complex to be solved by rational systematic processes. Key properties of wicked problems include the following:

There is no definitive formulation of a wicked problem. Problem definition and solution co-evolve because there is no optimal solution. Solutions to wicked problems are never true or false but instead are qualitatively judged as better or worse. A 'satisficing' (combining satisfy with suffice) [9] or 'good enough' solution is the realistic goal.

The process of solving a wicked problem is inherently non-linear. Progress is defined qualitatively in terms of how much more is understood about the problem rather than distance from the solution.

III. DESIGN EXPERTISE IN WICKED PROBLEMS

The first step in coping with a wicked problem is to recognize its nature and their properties. There is a tendency to treat all problems as tame, perhaps because these problems are easier to solve, reinforced by the lack of understanding about wicked problem dynamics and the tools and approach they require [8]. Rowland [10] found that novices do not see the problem as being ill-structured and thus assume that the information and variables are clearly specified. They do not think beyond the written description of the problem. They shift rapidly from problem analysis to solution generation and failed to elaborate solution alternatives. Therefore, simply engaging students (novice designers) in problem solving does not ensure the development of expertise [11] and get a satisfactory solution for the distributed system.

Experts are able to active mental models that connect relevant previous experiences with domain specific knowledge and skills. They activate a mental framework for representing the problem and seek solutions. Experts integrate given information with prior knowledge and experiences to make inferences that go beyond the state information [10]. Design activities would more or less creative according to conceptual domains evoked sources. Experts can refer to intra-domain or inter-domain sources in order to engage in analogy making for solving the design problem. [12].

Experts delimit the space of research to understand the problem on the basis of different kinds of constraints; in order to quickly reach in depth levels of understanding. Constraints are propagated during design problem solving orienting the designer's reasoning towards the most appropriate decision-making and design choices [12]. Experts usually pursue predominantly breadth-first and top-down strategies.

In contrast, novice designers have only a few reference cases to deal with new design problems, which may restrict their space of research of innovative ideas. The suggestion of sources, whatever they are, either intra- or inter-domain, did

not appear to enhance the production of new creative ideas. Novice designers can often become bogged down in attempts to understand the problem before they start generating solutions. For them, gathering data about the problem is sometimes just a substitute activity for actually doing any design work.

Experts spend more time analyzing the problem and only move to solution generation after ensuring that they have understood the situation completely [10]. Experts usually pursue predominantly breadth-first and top-down strategies.

Novice designers are also frequently found to become fixated on particular solution concepts. Early solution concepts are often found to be less than satisfactory, as problem exploration continues. Instead of searching for a better alternative, novice designers try laboriously to design-out the imperfections in the concept, producing slight improvements until something workable but perhaps far from ideal is attained.[13].

Another difference is that novices will often pursue a depth-first approach to a problem. They sequentially identify and explore sub-solutions in depth, and amass a number of partial sub-solutions that then somehow have to be amalgamated and reconciled, in a bottom-up process.

Researchers [12, 14] suggested that in order to enhance novices' analogical thinking, it appears necessary to go further than simply suggesting intra- or inter-domain sources. Novices would benefit from pedagogical actions during design education in order to show them how and why to use analogies for successful design problem solving [14]. In particular, a specific guidance should lead them to adopt various points of view on the suggested sources, as well as to connect these sources with the object to design. For instance, novices could get specific questions related to aspects that they do not spontaneously consider [12], in order to benefit more from the presentation of inter-domain sources.

Experts make designing seem easy and intuitive. Skilled design in practice therefore often appears to proceed in a rather ad hoc and unsystematic way. However, a study by Radcliffe and Lee [15] did show that a systematic approach could be helpful to students. They found that the use of design processes closer to an ideal sequence correlated positively with both the quantity and the quality of the students' design results. Other studies have tended to confirm this [13].

IV. OUR DESIGN PROCESS

PBL presents a challenge to novice designers. When students explore complex problems in a PBL environment, the problems may generate a heavy load on students' working memory due to their lack of proper schemas to integrate new information with their prior knowledge [16]. Given the complex nature of PBL, it is critical that instructors provide guidance to learners through each of the PBL activities while providing "direct instruction on a just-in-time basis" [17].

Instructors can support students' problem-solving activities with strategies such as providing hints and cues, asking question to direct student's attention, eliciting their causal explanations, and elaborating their thinking [18]. According to

the notion of cognitive apprenticeship [18], while the mentor and novices engage in the same problem-solving experience, the mentor makes his or her thinking visible to novices through social dialogues and scaffolds their problem-solving activities. The literature provides a theoretical framework for designing technology scaffolds to support students' problem-solving processes through the following strategies: question prompting, peer reviewing, expert modeling, and reflective thinking [19].

Our PBL focused on a design project, from the initial statement of the problem to a working prototype. We gave twenty students (our novices) the problem statement and material to work with. Students must follow a systemic approach for solving the problem. To address the demand for providing guidance to support students PBL experience, we designed a cognitive support system or scaffoldings.

V. THE REAL-WORLD CASE STUDY

We match the form and complexity of the problem to a real distributed problem to contribute to the realism of the experience. The problem statement was "Follow a Truck down the assembly line" from GM [20]. It had a decentralized nature to introduce the concepts of decentralized control.

The problem description stated the assembly process through one GM plant, which makes GM's full size pickup trucks. The assembly line had five production stations (Body shop, Paint shop, Trim, Chassis, and Final Assembly). The supplies for the assembly line arrive "Just in Time" (JIT). The JIT logistic is the Toyota Production System using the electronic Pull scheduling (e-Kanban) technique [21]. It is a standard of the Inventory Visibility and Interoperability (IV&V) project of the Automotive Industry Action Group (AIAG) [22].

In addition to the problem statement, we gave students a set of resource material such as videos, pictures and notes describing the different assembly line shops hardware and procedures, standards, papers about e-Kanban specifications, and Internet links. We encouraged students to search for more sources.

VI. SYSTEMATIC APPROACH FOR SOLVING THE PROBLEM

Software design consists of an ongoing series of decisions, from the problem statement and the elicitation of requirements to the initial system architecture sketches to a designer's choices of suitable models, algorithms, data structures, and user interfaces.

The design approach was based on the Rational Unified Process Software Development Process (RUP) [23]. RUP provides an iterative and incremental development process divided in phases. At the end of the design of each phase, students documented the formal solutions using UML (Unified Modeling Language) diagrams. The implemented solutions were tested in the lab. The phases are Requirements Specification, Analysis, Design, Code, Test and Integration.

The project had two RUP iterations. The first iteration was the development of the application's prototype and its API (Application Programming Interface) over raw networking support (TCP connections). Students use an object-oriented

approach and the base constructs of the Integrated Enterprise Modeling method [24].

The second iteration was the development of a middleware for the first iteration's prototype and API. The middleware system was organized into several service layers adapted from Schantz's et al. middleware [25]. The first service layer and API was the domain-specific middleware services layer. The next layers were the common middleware services layer with domain-independent services, the distribution layer providing high-level distribution, and the host infrastructure layer hiding differences between operating systems by providing common abstractions for communication primitives and other resources.

VII. THE COGNITIVE SUPPORT SYSTEM

The cognitive support system consisted of a suite of support mechanism characterized by mentorship and social interactions: question prompt, peer review, expert modeling and self-reflection [19]. Our design process consisted of a real-world case study, an outline of the design process steps using a Software Development Process, CATs (Classroom Assessment Techniques: Assessing skills in Problem Solving) [26], and scaffoldings: questions prompts, peer-review, expert modeling, and self-reflection. Sketches, related information, meeting decisions and formal documentation were shared through a yahoo group.

The Assessing Skill in Problem Solving CATs allow faculty to assess and promote problem-solving skills of various kinds [26]. The assessment techniques in this group are: Problem Recognition Tasks, What's the principle?, and Documented Problem Solution. CATs were mandatory homework for reflective writing activities. Students must write their arguments and the collected evidence for their positions in argumentative essays (reports) for the in-class meetings. The purpose of the reports and collaborative in-class sessions was to create an ongoing process of discovery. The CATs activities were based on Quellmalz's [27] key strategies of critical thinking.

Software design is collaborative. Developers work in face-to-face settings and CATs act as the coordination mechanism to support the design dialogue during the meetings. CATs and rubrics also act as formative assessment tools to give feedback and "just in time" mentoring during the meetings for reflection, in the sense of thinking about something again [28, 29].

Rubrics assessment purposes are to improve the reliability of scoring written assignments and active participation during meetings. Rubrics convey goals and performance expectations of students in an unambiguous way, convey "point values" and relate them to performance goals, and engage students in critical evaluation of their own performance [30]. Rubrics are also a guide of how to do the work.

VIII. SCAFFOLDINGS.

Scaffolds were introduced to support the learning environment. Scaffolds were combination of question prompts, peer-review and expert modeling, to improve novices' problem-solving skills [11, 19].

A. Question prompts.

In addition to the problem-solving outline, the students received prompts consisting of elaboration and metacognitive questions with each problem-solving step [19]. For instance, the following questions were presented among others for the JIT design: How will you manage the concurrent use of the forklifts with the other stations? How will you manage the different types of material (big pieces or parts of the truck, bullets and nuts, raw material, etc.)?

B. Peer review.

The peer review mechanism was designed to enable students to see multiple perspectives from peers' reports and help them notice things they might not have thought about previously. By reviewing their peers' thinking, students were supposedly compelled not only to attend more closely to their peers' ideas, rationales, plans and solutions, but also to their own for self-reflection [19].

C. Expert modeling.

Expert modeling was provided by presenting students with expert's reasoning during in-class meetings. This support mechanism was expected to offer students an opportunity to observe the expert's (instructor) reasoning, which they would compare with their own reasoning. It was assumed that the comparison would result in disequilibrium [19].

When team members are immersed in a design activity, they are often unable (or unwilling) to acquire knowledge that cannot be immediately put to use. If students do not see the need for help, it is unlikely they will ask questions. Experts notice features and meaningful patterns of problem solving that are often not noticed by novices [19]. Walz [31] recommends that formal training activities, when appropriate, be integrated into project activities rather than remain independent. One way to achieve this might be to have an instructor participate in a few design meetings so the training can be custom-tailored to the project.

In the last semester, we included the expert-modeling scaffold and help, as expert designers and mentors, novices to focus on hidden relational properties of the problem during the in-class meetings. We introduced them in practices of reasoning about systematic exploration of possibilities (finding gaps, or finding unexplored relationships between problems and potential approaches) and scenario-based reasoning to explore assumptions and consequences.

D. Self-reflection

A meeting ended with a self-reflection writing activity with a few reflective questions. Self-reflection was an important mechanism to supplement the expert modeling mechanism and allowed students to observe an expert's reasoning facilitating students' reflection on the gaps between student's and the expert's reasoning [19].

E. Agenda and goals

A collaborative design session is more likely to succeed when designers agree on ground rules for conducting the session. By setting time limits and achievement goals, designers can force themselves to focus on the fundamental problems. We scheduled the agenda and goals for the meetings.

For instance, we scheduled three brainstorming meetings for the problem understanding and first design decisions: (1) business process modeling (JIT), (2) production processes and JIT model without faults, and (3) the whole model including faults and defective material handling.

The scaffolds help students to focus on target users, reframing of requirements and sketching before formalizing their notation using UML. Informal diagrams and sketches offer a great way to examine the relationships among objects in the different problem domains, as well as their interactions. Sketches hide students from making premature design decisions because the UML notation pushes them to think of abstractions and focus on understanding the problem space.

IX. A RUP ITERATION

A. Problem Scoping and Information Gathering.

Problem scoping and information gathering are aspects of design activity that involve identifying criteria, constraints, and requirements; framing the problem goals or essential issues; gathering information; and, stating assumptions about information gathered.

A nontrivial portion of a software team's work for the initial stage involves improving their understanding of the problem domain from a succinct problem statement (design brief) and a vague set of requirements to produce a design that addresses users' needs. More than half the cost of the development of complex software systems is attributable to decisions made in this initial phase. [31]

Many students find it difficult to cope with the wicked nature of the problem at the initial stage of the design. Instructor's guidance and scaffolding can facilitate the problem solving process and enables students to bridge the gap between their current abilities and the intended goals of expertise.

Students like to have formal processes or procedures to use for problem solving, but as we have seen and is reported by research [32], the UML formal procedures they learned to use in former subjects do not work well with ill-formed problems. Experts use UML diagrams only after they make the final design decisions for the RUP phase. A flexible and adaptable "design thinking" process for guiding design decision-making would provide an alternative to these formal procedures. This process could explicitly incorporate steps for looking at the big picture of the system, the use of rules, principles, and/or practices for examining the design and generating solution alternatives, selecting and evaluating candidate alternatives, and reflecting on what has been accomplished in an iterative approach.

We supported this design thinking process by "The Problem Recognition Tasks" CAT. The CAT assesses students' skill at determining what kind of problem they are faced with, so they can choose the appropriate solution [26].

Reflective writing and sketching supported the CATs activities.. Student sketched diagrams, and other informal representations of the problem domains and constraints, use UML formal diagrams, annotations (textual and graphical), corrections, alternatives, etc. to communicate ideas.

Cross [13] calls sketching an “intelligence amplifier” and enumerates how sketching helps design thinking. It enables designers to handle different levels of abstraction simultaneously, enables identification and recall of relevant knowledge, assists in problem structuring through solution attempts, and promotes recognition of emergent features and properties.

For the next steps of the iteration, we divided up the class into five groups. Groups were in charge of the design and prototype of the assembly line station (a subsystem) and the exchange of information between stations and other enterprises. We use the same cognitive support system. CATs writing activities and their scaffoldings supported the intra-team problem solving activity and the inter-team decisions to reach consensus on protocols, formats of information exchange, paradigms, models, etc. Inter-team meetings were held in class.

New levels of abstractions and key concepts about distribution’s complexity were introduced after the need to learn them has been established in the context of observed phenomena or unexpected system behaviors.

B. Multiple Solutions Generation

Another aspect of design behavior often thought to be important is the generation and consideration of alternative solutions. However, research results suggest that the role of alternative solutions is not clear. Students tended to focus on one design and tried to make it work.

This activity was supported by the “What’s the Principle?” CAT to assess students’ ability to associate a specific problem with general principles used to solve them [26].

Students’ teams use their CATs to analyze the interrelations and connections of the complex system and generated alternatives for the integration of business processes (e-Kanban cross-enterprise data exchange) with product and service oriented processes of the assembly line.

C. Analysis and Selection of the Solution

Once students have conceived alternative solutions to the design problem, they need to analyze those solutions and then decide which solution is best suited for implementation. Analysis is the evaluation of the proposed designs.

Experiments and programming exercises in the lab were introduced to check and exhibit distributed systems complex behavior against student’s expectations and to show how a population of asynchronously executing processes without central top-down control can exhibit unexpected or “emergent” behavior at the system level.

Students must apply their technical knowledge to the proposed solutions and use the results to decide which solution to carry out. They validated system goals, constraints and connections/interrelations. They documented the solution using a reduced set of the UML diagrams. These are the tasks of the Documented Problem Solutions CAT. This CAT assesses how well students solve problems and how well they understand and can describe their problem-solving methods [26].

D. Prototype Implementation.

A prototype is the first fully operational production of the complete design solution. It is not fully tested and may not work or operate as intended. The purpose of the prototype is to test the design solution under real conditions.

Teams implemented the subsystems. For the individual testing of a subsystem, they programmed simple stubs that emulate the interacting subsystems. For the integration of the prototype, the stubs were replaced by the real subsystems and the whole prototype was tested under normal conditions and in presence of failures.

The next iteration focus was on middleware issues to address “possible repairs” of the unexpected behavior of the prototype in presence of failures of the first prototype.

X. RESULTS AND DISCUSSION

Our course goal is that students master distributed systems design issues. The only way to achieve this goal is that students develop critical thinking and reasoning skills. When we designed our first PBL course, we acknowledged that we would find some hurdles, because students’ interaction with others is not only guided by the learning task, it is also shaped by their emotions, perceptions, and attitudes. Some social-emotional processes are beneficial for learning others are not [19]. Therefore, the relationships between motivation, peer interactions, and wicked problem solving are worth further attention to answer the questions: How much time would it take to develop expertise in our students? How can we improve the process? The successful guidance of PBL is largely dependent on the availability and skills of instructors who can scaffold students’ problem-solving activities. [17].

Having a small number of students in each semester, we had the opportunity to use the PBL processes exhaustively in order to have a close observation of our students’ learning process. We arranged extra out-of-class meeting to help students to develop common positions on relevant issues when they did not meet the in-class meeting goals. We were there for office hours, kept scheduled appointments, and made time for students/teams when they need additional help. We arrived at class early and stayed after class.

After each semester we review literature and transform our cognitive support system for using the in-class time more efficiently. Our support system in 2008 included CATs with report feedback, meetings and peer-review with a facilitator and feedback, in-class experiments. In 2009, we added the self-reflection writing activity and rubrics. In 2010, we included question prompts and in 2011, the expert modeling scaffold.

We use a standards-based grading system where every student, as shown in Table I must meet a determinate level of performance. Each step is evaluated in points from 1 to 10 following a set of rubrics. These are formative assessment earned points; they do not weigh for the final grade but are very useful as feedback.

In the four terms, the points’ statistics are similar, meaning that the performance level from the student remained reasonably high. The difference appears in the Out of Class time and extra meetings we held with the students/teams.

TABLE I. STUDENTS PERFORMANCE AND EXTRA TIME

| ITERATION No. 1 | 2008 Students = 8 | | | | 2009 Students = 6 | | | | 2010 Students = 6 | | | | 2011 Students = 20 | | | |
|-----------------|-------------------|------|--------------------------|----------------|-------------------|------|--------------------------|----------------|-------------------|------|--------------------------|----------------|--------------------|------|--------------------------|----------------|
| | Average | SD | Out-of-class time h/week | Extra Meetings | Average | SD | Out-of-class time h/week | Extra Meetings | Average | SD | Out-of-class time h/week | Extra Meetings | Average | SD | Out-of-class time h/week | Extra Meetings |
| Design | 8.92 | 0.67 | 6 | 4 | 9.62 | 0.32 | 6 | 3 | 9.87 | 0.10 | 3 | 2 | 9.37 | 0.65 | 2 | 1 |
| Implementation | 9.64 | 0.48 | 4 | 2 | 9.86 | 0.21 | 4 | 1 | 9.86 | 0.21 | 3 | 0 | 9.62 | 0.35 | 3 | 0 |
| Total Scores | 9.17 | 0.60 | 10 | 6 | 9.70 | 0.26 | 10 | 4 | 9.87 | 0.12 | 6 | 2 | 9.46 | 0.50 | 6 | 1 |
| ITERATION No. 2 | | | | | | | | | | | | | | | | |
| | Average | SD | Out-of-class time h/week | Extra Meetings | Average | SD | Out-of-class time h/week | Extra Meetings | Average | SD | Out-of-class time h/week | Extra Meetings | Average | SD | Out-of-class time h/week | Extra Meetings |
| Design | 9.91 | 0.18 | 6 | 1 | 9.88 | 0.19 | 4 | 1 | 9.88 | 0.19 | 2 | 0 | 9.88 | 0.11 | 2 | 0 |
| Implementation | 9.89 | 0.19 | 4 | 1 | 9.85 | 0.21 | 4 | 1 | 9.85 | 0.19 | 4 | 1 | 9.83 | 0.17 | 4 | 0 |
| Total Scores | 9.90 | 0.17 | 10 | 2 | 9.87 | 0.19 | 8 | 2 | 9.87 | 0.19 | 6 | 1 | 9.87 | 0.11 | 6 | 0 |

As we included new items in the cognitive support system, fewer meetings and few extra-time were needed to obtain the same result.

As shown in the 2011 cohort with 20 students, an increase in the number of students did not represent an increase in the extra support time. Without the whole scaffolds managing 20 students would have taken all of our office hours and perhaps more.

The use of deliverables in the cognitive support system allowed us to adapt our teaching to the current cohort. These documents also made a good base for reflecting on and pinpointing difficulties.

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Work in Progress: Making Room: Creating Design Spaces for Design Practice

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Abstract—This work investigates affordances of co-working, collaboratory spaces in support of engineering design student design teams. A framework for establishing such spaces is presented adapting a set of design axioms: design is a social activity, preserve ambiguity and all design is redesign. Student reflections are used to illustrate these design principles and example spaces are described in brief.

Keywords—engineering design; creativity; workspaces; design thinking; collaboration

I. INTRODUCTION

Design as a driver for project-based learning [1] and capstone engineering experiences is well established in engineering programs [2, 3]. Having dedicated physical space for these design project teams available outside engineering lab and machine space, however, is not. While there are engineering design programs that do make available some shared design co-working space [4, 5], this paper uses an array of design spaces for different engineering design and design programs primarily at a one, single institution, Stanford University, to illustrate what a co-working space can be and what affordances are useful in such a space.

This paper will outline a framework for creating such collaboratory spaces using Leifer's axioms for design [6] that design is a socio-technically mediated activity, designers must preserve ambiguity and all design is re-designing.

These design axioms will be defined in the context of the created design space and the affordances of digital and analog tools available. A set of spaces will be described and reflections and feedback from users and alterations made in response to one particular space will be highlighted.

A brief description of the conceptualization, design and implementation of just such a conceptual design space for teams engaged in design project work at Arizona State University will be shared. The selection and visioning of the space, how it complements existing student fabrication faculties as well as the array of expectations of various stakeholders (students, administrators, faculty) will be mentioned.

A metric for assessing current design spaces will be introduced and presented as basis for future work.

II. AXIOMS FOR DESIGN ACTIVITY

In Reference [6], Leifer captures learnings from decades of teaching engineering design students at Stanford University. Primarily developed from annual cycles of the ME310 Global New Product Development course [7, 8], he highlights for teams of engineering designers design as a socio-technically mediated activity, that designers must preserve ambiguity and all design is re-designing [6].

A. Design is a Socio-Technically Mediated Activity

Engineering design is an activity that often is done in groups or teams of engineers or engineering students. Many interactions among teammates is informal, towards building a high-performing team – a “community of practice” [9] that has shared norms for working in a situated learning environment. The “learning ecology” [10] may extend past the immediate team to include formal and informal advisors [11], in the classroom introducing informal and formal learning loops [12].

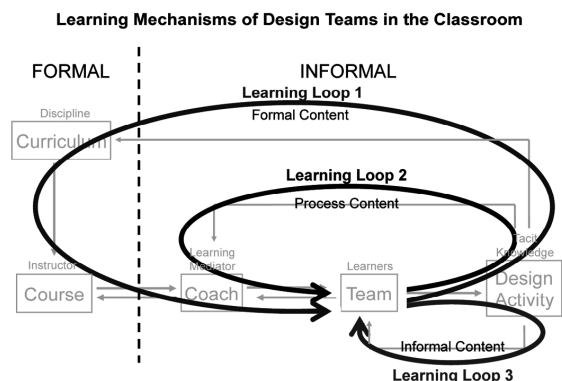


Figure 1. Formal and informal learning loops in the classroom [12]. Learning loop 3 can include the informal, situative learning in a design space. The totality of the 3 learning loops can describe its “learning ecology” [10].

Particularly with a human-centered design process [13, 14, 15, 16, 17], engineering design work increasingly includes a person in the system if not systems of people. At the heart of human-centered design is a motivation to make the resulting design better for those users and stakeholders. Understanding their social and technical needs within their frames of reference also makes it a social endeavor.

B. Designers Must Preserve Ambiguity

Design thinking is a balancing act between divergent and convergent thinking [13, 17]. In the same manner “defer judgment” and “encourage wild ideas” are tenets of the creative brainstorming practice [15], innovative ideas can come from extending the problem and solution area past what is first expected. Reference [17], as seen in Fig. 2, deconstructs the design thinking approach as going from concrete to abstract thinking to be able to break new ground.

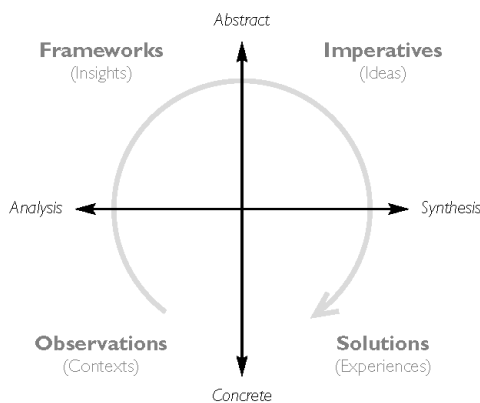


Figure 2. Design thinking approach showing concrete to abstract thinking framework [17].

C. All Design is Re-Designing

Building on these initial axioms, all design activities are acts of re-design. Reference [18], illustrated in Fig. 3, highlights the “comprehensive design engineering approach.” In this model, the fields of engineering approach problem solving through a lens of technical feasibility. Business uses a lens of business viability. Attacking the same problems through the designer’s lens of human values and desirability can result in a much different and differentiated result. It might be that there is not a completely new problem to address but rather a new way to approach solving it.

There are many instances in which previous attempts have been made to create a better artifact, interaction or experience. By acknowledging those and learning from apparent or latent deficiencies, the act of re-design can start from a place further forward than the origin. It’s not reinventing the wheel. Rather by advancing the design is social axiom in concert, one can come to rely on peer designers or users and stakeholders in the value chain to provide insight.

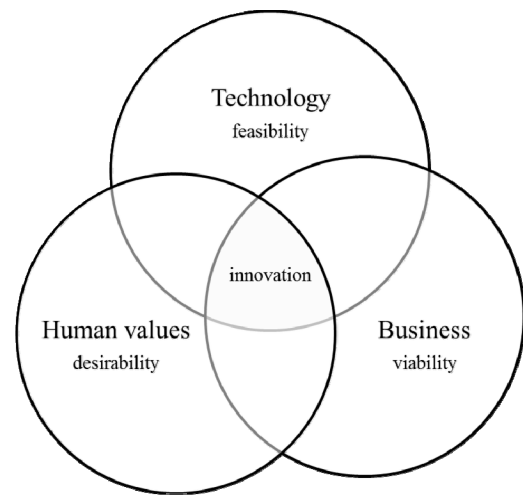


Figure 3. The comprehensive design engineering approach [16].

III. EXAMPLE DESIGN SPACES

A. Global Design and Innovation Studio

The Global Design and Innovation Studio space, shown in Fig. 4, is used as a dedicated workspace assigned to approximately 10 student teams engaged in solving problems posed by industry in the ME310 Global New Product Development class at Stanford University [7]. Each student team is assigned a work table, whiteboard and storage cubby set around a one room studio. There is a small rudimentary shop available to fabricate and tinker.

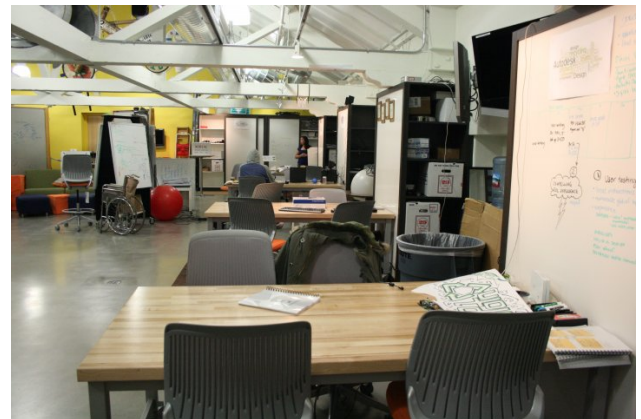


Figure 4. Global Design and Innovation Studio space

B. Mechatronics Technical Lab

The Mechatronics Technical Lab space, shown in Fig. 5, is used by 25-40 students in a 3-quarter ME218 graduate mechatronics course sequence at Stanford University [19, 20, 21]. Students work in teams, are assigned to a computer and technical workbench. Teams share common resources such as soldering stations.

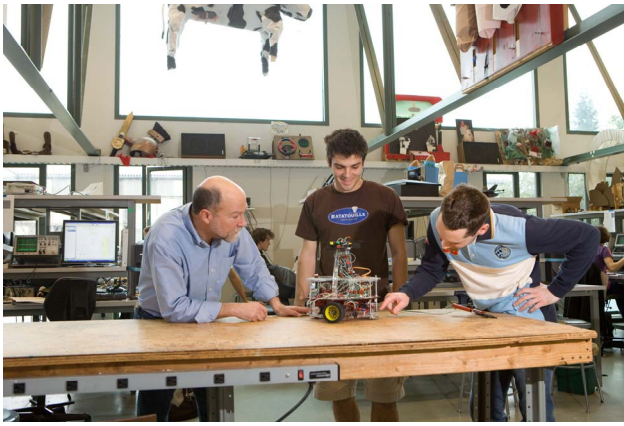


Figure 5. Mechatronics Technical Lab space

C. Design Thinking Studio

The Hasso Plattner Institute of Design at Stanford (the “d.school”) [22] hosts quite a number of hoteling, or temporary spaces, for an array of students teams to use. An example collaborative space in shown in Fig. 6. Reference [23] details the space development and design for furniture and artifacts included therein. There are many student teams from quite an array of classes in the space during any one week so accommodations are always temporary and project boards and technology are employed to help make the use of the collaborative spaces scale. Student teams do belong to classes offered so there is accountability and affinity for those using the space. Reset configurations for each space are posted to aid in managing the use and expectations of returning furniture, tools and materials to a common configuration.



Figure 6. Design Thinking Studio space

IV. IN ACTION REFLECTIONS

A. Reflections on the Global Design and Innovation Studio

The ME310 course resides in a collaborative working loft area that fosters implicit learning in a community of practice [9]. The array of people and affordances in the space allow for close work and peer support in building skills, experiences and developing towards being a future engineer.

As graduate students working on a core class in their design theory and methodology concentration, the loft becomes a popular place to hang out, whether working on their project or other activities. It becomes central to their experience, as one student contributes:

I can't wait to see next year's group of 310er's walk into the loft and have NO idea what lies ahead. They will walk in the door looking at 310 like a regular course, but be confused by the crazy contraptions hanging from the ceiling. In this crazy place called "the loft," they will learn how to really work with other people for the first time. The students will be amazed at how technically involved building a bike out of paper can be [an introductory engineering design activity]. They will read the corporate sponsor prompts, and be both excited and intimidated by the ambiguity of some of the projects. They will form teams, and try to find a balance of both talent and mutual interest with a group of individuals as talented and intelligent as them. They will learn how to rapidly prototype something, and learn that the message conveyed by the prototype is more important than the finished look of the prototype. They will learn how easy it is to become emotionally involved in a project, and will learn how to manage these emotions so that they are always constructive to the project. They will learn how to "embrace ambiguity," and they will learn how some of the best ideas for the project come out with a little (lot) of Jaloviina [brandy] and a late night in Finland. They will learn to leverage the technical skill of each member of the team, and that anything imaginable can be made in the loft. They will spend late nights [there], and come to think of getting to bed by 3am as an early night. They will learn that 501 [a small office] is actually a really nice space to sleep, and that the design group office has some damn good coffee. They will experience the reward and excitement of EXPE [year-end project fair] on no sleep, and be more proud of their project than almost anything else that they have ever been a part of. And, lastly, they will feel a deep nostalgia as the year comes to a close.

Another student quantifies those long hours,

I think success was inevitable, provided most of us put our all in to whatever it is we decided on. And that is exactly what we did. 100hr weeks for a month straight? At least one person in the loft [from our team] from 7:30am till 2am almost every day?

Students in the Mechanical Engineering 310 Global New Product Development course, regardless of their particular project, have some difficulties in approaching and managing their design projects [24]. The constellation of the course affords a strong support structure. Students work in teams of 3-4 students locally at Stanford and are matched up with similar teams of students at globally distributed university partner sites. They are provided with a sizeable project budget and a physical working space in a project loft. Students have regular weekly meetings with the teaching team consisting of Professors, Teaching Assistants and Consulting Professors with technical expertise. Student teams also have a coach from industry to consult on technical and team dynamics issues.

Working together in close collaboration with others is also somewhat of a challenge. Students are in the first year of their graduate program, in their early twenties, without project experience; issues with project management, planning and communication are always learning experiences for student teams. A student reflects on the team experience and lists a few of the bumps along the way:

... We were lucky. The team is effective and our efforts are often well-orchestrated (despite a lack of planning, lapses in communication, and ballooning stress levels)...

Students are introduced to a human centered design process with emphasis given to rapid prototyping and iteration. Moving from planning to doing so rapidly is often a switch in their usual practice for students.

The environment and the people help form strong bonds. The experience has been likened to a start-up environment. A student reflected on that aspect as well:

After completing my undergrad degree I wasn't quite ready to go to the real world. I enjoyed learning, I loved [being here], and I wasn't sure if I was mentally or emotionally ready for a full time job. Well, ME310 fixed all of that in the best ways possible. It perfectly bridges the gap between school and work, functioning as an 8-person startup where you have help and guidance along the way. You make close friends, you stay up late, you wake up early, you work with awesome teammates from around the world, and you solve real problems. I couldn't have asked for a better experience. From the outsourcing to the deadlines to the project management to the travel to the budget to the personalities to the assignment to the pressure to the fun I feel like ME310 did a fantastic job of prepping me for life beyond [here], and I look forward to maintaining many of the friendships I've developed this year.

And another student reiterates the job-like experience,

For me, it has been much like working a full-time job at a typical Silicon Valley startup, sans pay and sans risk of losing your job if you fail miserably. This is the beauty of [class] to me – it allows you to take risks, to really go out on a branch with innovative ideas, without this fear of risking anything more than a hyphen behind your letter grade. It is precisely this type of environment that fosters creative design thinking and innovation that defines [this course].

B. Other Stakeholder Valuation

Design is an active and messy proposition. The workspaces described above all serve as showcases for innovation and innovative work. Potential partners, students and sponsors are regularly toured through all of these spaces to demonstrate the innovative ethos that is inherent in each program. Ironically, with students' schedules, most tours during normal business hours reflect a less than full student engagement. The materials and artifacts left behind, however, demonstrate the type of innovative work they are engaged in. All are useful to instructors, administrators and other visitors to highlight using creative and different working space, whether as a benchmark or the basis on requesting development dollars.

V. MAKING ROOM

A. Developing an Innovation Commons

Another collaborative space is the Startup Labs innovation commons space at Arizona State University's College of Technology and Innovation, pictured in Fig. 7. This space was recently configured based on experiences and applied design axioms previously described. Housed in a converted clean room teaching area, the space is replete with white boards and glass walls for writing as well as flexible and moveable tables, chairs and other furniture. The space is available to engineering students, business students and human factors students throughout the college and space is used in an ad-hoc, as needed basis

The Startup Labs innovation commons adds a co-working space to the resources available to students. It is a collaborative space that is more flexible than the nearby library, allowing for noise and ready reconfiguration of the available furniture to meet immediate student team needs. It augments physical prototyping spaces such as a nearby student machine shop and sophisticated fabrication facilities. The space also serves as an overflow workspace from engineering studio spaces for project work.

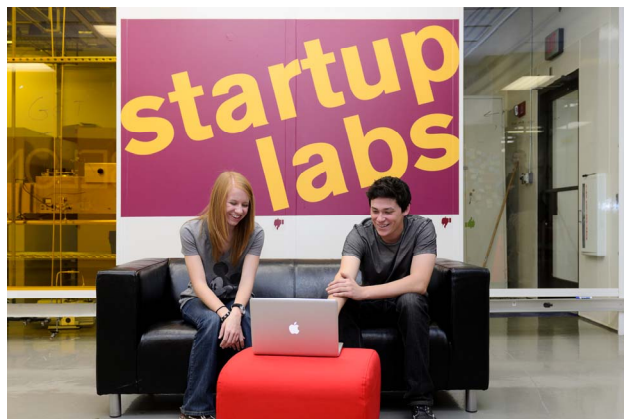


Figure 7. Innovation Commons space

VI. DISCUSSION: METRICS FOR ASSESSING SPACE

The three design axioms introduced above can be the basis for cataloging, comparing and assessing the utility of such collaborative engineering design spaces. In development is a tool specific to highlighting and making visible those distinctions. Already, with brief descriptions and vibrant pictures of a small number of spaces, one can see an array of possible affordances, features and use.

A. Design is a Socio-Technically Mediated Activity

A space can be evaluated based on how well it can accommodate a team of designers as well as the duration of time a team inhabits and owns a space. The array of spaces described above all include meeting space with tables and chairs, whiteboarding areas and storage. Depending on the throughput and number of dedicated users groups or hoteling

teams, the amount of time duration ranges from a whole academic year, quarter to by the day or hour.

B. *Designers Must Preserve Ambiguity*

The simplest means to have a space that affords preserving ambiguity is one that hosts flexible parts that can be easily moved around to suit an immediate need or fashion. Most spaces described have wheeled tables, chairs and carts to do so. Additionally, whiteboarding surfaces in such quantity that most readily available surfaces are writeable allows student teams to create ideas and experiences without bounds, to think and do outside the box. Both the flexibility of the artifacts in the space and the affordances of the room spaces help to create an environment that serves to preserve ambiguity.

C. *All Designing is Re-Designing*

Each space has a means to collect, display and inform of work done previous. It ranges from championed artifacts hung from the ceiling or preserved on shelves to libraries of previous reports and work available for immediate reference. Some are kept as exemplars of project outcomes and some remain as emblematic trophies of particularly wacky or memorable design attempts.

D. *Making Qualitative Measures Quantitative*

The next steps for this work is to codify means to assess design space based on this framework and be able to make qualitative measures quantitative. There is an opportunity to imagine and design work space for design teams and then be able to assess its utility, impact and use to inform redesign and improvement.

ACKNOWLEDGMENTS

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Integrating International Students' Contests with Computer Science Capstone: Lessons Learned and Best Practices

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Abstract—Microsoft Imagine Cup is the world's premier student technology competition. Every year students from all over the world compete to solve the world toughest problems in different categories. In ten years, the Imagine Cup has grown to be a truly global competition focused on finding solutions to real-world problems. Since 2003, over 1.4 million students have participated in the Imagine Cup with 358,000 students representing 183 countries and regions registering for the Imagine Cup 2011 competition [7].

In this paper, we present our experience in integrating imagine cup (IC) with computer science (CS) capstone courses at the American University of Kuwait (AUK). In the past four years, we coached four different teams in three consecutive years (2009-2012) to win Microsoft Imagine cup in the Gulf region (GCC region includes Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and UAE) and qualify to the world finals. We present our best practices and three case studies of winning projects in the region (one of the three teams was totally formed of girls). We will also present the lessons learned and guidelines on how to integrate such design competitions with computer science capstone.

Keywords- *Software Engineering, Collaborative learning, software engineering education.*

I. INTRODUCTION

A. Education in Kuwait

Kuwait is a small country situated in the Persian Gulf and is part of the Gulf Cooperation Council [GCC] that incorporates: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and UAE. With crude oil reserves of about 102 billion barrels, oil production represents the main pillar of Kuwait's economy and accounts for nearly half of GDP, 95% of Export revenues, and 95% of government income [3].

Today, Kuwait's education system is larger than ever. There are currently close to 500,000 students enrolled in Kuwaiti schools, constituting approximately 30 percent of the entire population. There are three basic levels of education in Kuwait – elementary, intermediate, and secondary. All stages of state education, including higher education, are free. Students in all Kuwaiti schools study English starting the second grade.

According to the most recent release by the UNESCO Institute for Statistics in 2009, the percentage of female graduates in tertiary education in Kuwait have reached 69% while the female tertiary graduates, as percentage of all graduates in science in Kuwait, has reached 80% [5].

B. Typical problems in traditional capstone class

Traditional teacher-assigned-project capstone classes have many potential problems:

- Maintaining Student Interest

Pre-defined projects by professors may lead to students losing interest in class and project. In this approach, students may be forced to work on a project that does not match their interests and skills. Students mainly focus on obtaining passing grades rather than enjoying the learning process [6]. In other cases, the projects professors assign to students may be too theoretical to be applied out of the classroom, which also affects students' interest in the project in a negative way.

- Interpersonal Skills and Communications

It is widely agreed that most computer science students have problems with interpersonal and communication skills [8]. This is due to the technical nature of the field. Average class size at AUK is 28. Students in capstone class present their projects in front of their class mates only, which may not be challenging enough to prepare them for real life technical presentations and conferences.

- Business and Entrepreneurship Skills

In some technical programs, computer science students do not get enough general education courses in business and entrepreneurship. Adding such dimension to CS students is pretty important; however, it is difficult to incorporate it in the capstone course due to time limitation.

The rest of this paper is organized as follows:

- Section 2 presents an overview of the environment where the research was conducted.

- Section 3 includes how to associate the Microsoft Imagine Cup competition with the capstone course.
- Section 4 includes the hypotheses and findings.
- Section 5 contains main challenges, how to overcome them and how IC addressed some problems.
- Section 6 includes samples of projects.
- Section 7 includes assessments of professors and students.
- Section 8 points to future research directions and concludes the papers.

II. BACKGROUND AND LITERATURE REVIEW

A. Environment

We conducted our research throughout the capstone course offered by the computer science program at the American University of Kuwait (AUK). The American University of Kuwait (AUK) is an independent, private, equal opportunity, and co-educational liberal arts institution of higher education. The educational, cultural, and administrative structure, methods and standards of AUK are based on the American model of higher learning. The language of instruction is English. Established by Amiri Decree 139 in 2003, AUK was accredited in 2006 and re-accredited in 2008, by the Council for Private Universities, Ministry of Higher Education - State of Kuwait. AUK was established by as a Kuwaiti University but with an American name. This necessarily makes it bi-cultural. So while the educational system is American, it exists in a very different cultural environment which provides both challenges and opportunities.

1) Course Description

CSIS-490 (Capstone course) integrates core topics of the computer science body of knowledge, teamwork, and professional practices through the implementation of a large scale project.

2) Intended Learning Outcomes

On completion of Capstone course the student should:

1. Apply the concepts learned in various courses taught in computer science curriculum.
2. Acquire technical information and background on subjects not studied in courses.
3. Develop the ability to work in a team and to give technical presentations.
4. Develop the ability to work under stress and meet deadlines.
5. Develop skills in writing technical reports and manuals.
6. Develop project planning and management skills.

B. About Microsoft Imagine Cup

Microsoft Imagine Cup (software design category) has three main rounds. Round 1 starts by students submitting their proposals using a template provided by Microsoft. The template includes: problem, solution, architecture, business

viability and technologies to be used. Participants have to submit a 15 minute narrated video that includes a demo or a prototype of the proposed solution. Problems have to contribute to solving one of the eight millennium development goals (MDGs) defined by the United Nations Development Program (UNDP). The areas are:

- End poverty and hunger
- Universal education
- Gender equality
- Child health
- Maternal health
- Combat HIV
- Environmental sustainability
- Global partnership

A limited number of proposals advance to round 2: the country's finals. Normally, in Kuwait there are between 2 to 5 teams in the country's final round. The country's final round is a public event where students have to present their projects in front of a panel of 4-5 judges. Each team presents for 15 minutes followed by a 5-minute question session. The winning team advances to the world finals.

The world finals have one team from each country. The world finals are composed of three main rounds:

- Round 1 has around 68 teams and it takes place on day one. Each team presents for 20 minutes, followed by questions from the judges for 15 minutes. Each presentation has to include a live demo for the project. The panel of judges consists of 5 judges. Presentations are not public. Attendance is granted by permission from the team mentor. At the end of the day, the top 12 teams qualify to the second round. The grading criteria for Imagine Cup is included in the following table:

TABLE 1

| |
|---|
| 10% - Problem Definition (How are you making a difference?) |
| 35% - Solution Design & Innovation (What does your solution do?) |
| 30% - Technical Architecture & User Experience (How does your solution work?) |
| 15% - Business Viability (How will your solution become a reality?) |
| 10% - Presentation (How well have you explained your solution?) |

- Round 2 is more technical and it takes place on day 2. More judges sit with the 12 teams and evaluate thoroughly the technical side of their projects. Presentations are not public. Attendance is by permission from the team mentor. At the end of the day, 6 teams qualify to the final round.
- In Round 3 (day 3), the top 6 teams present in public in front of a new panel of judges (mostly judges who have not judged the team in previous rounds). The top 3 teams are awarded [7].

III. HOW TO ASSOCIATE THE MICROSOFT IMAGINE CUP COMPETITION WITH THE CAPSTONE COURSE.

Imagine cup has three main milestones over the duration of a year: The proposal deadline, the country's final and the world finals. Table-2 shows the timeline for the activities

TABLE 2

| Stage | Requirement | Time |
|------------------------|------------------------------|------------|
| Call for participation | Proposal and video | Early Fall |
| Local Finals | Presentation and Demo | April |
| World Finals | Presentation, Demo and Video | July |

CS Capstone is offered twice a year (once in the Fall and once in the Spring semester). Fall semester starts early September and ends mid-January, while Spring semester starts in February and ends around the beginning of June. Table 3 shows the activities of capstone course with the estimated timeline (for both semesters). The percentage of the grade of each activity is shown as well in table-3.

Table-4 shows the timeline of both capstone (CS) and Imagine Cup (IC). We aimed at the following goals:

- We use the same template of Microsoft imagine cup to propose projects in the capstone course. In that case, all of the capstone projects can be eligible and ready to apply for the first round if students are interested.
- Students have to implement a prototype before the country's final. To do so we aligned, the design presentation to be before the country's finals (in

TABLE 3 Timeline for capstone with marking scheme

| Stage | Requirement | Percentage | Time |
|---------------------------|--|------------|--------------------------|
| Finding an idea | Proposal Document and presentation | 5% 5% | October, February |
| Requirements Presentation | Requirements (RS) Document and presentation | 10% 10% | November, March |
| Design Presentation | Design Document (DD) and Presentation, prototype | 15% 10% | Early December, April |
| Final Presentation | Demo and full presentation | 25% | End of December, Mid May |
| Oral Exam | Committee oral exam | 20% | January, End of May |

TABLE 4 Timeline of both Capstone and Imagine Cup.

| | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|----|------------------------|----------|----|----|------|-----------------|----|--------------|------|---|----|
| | Fall Semester | | | | | Spring Semester | | | | | |
| CS | | Proposal | RS | DD | Demo | Proposal | RS | DD | Demo | | |
| IC | Call for Participation | | | | | | | Local Finals | | | WF |

December and in April). The presentation covers solution design and architecture.

- The world finals (WF) are after the end of Spring semester. The practice is that we work to enhance the project after the end of the semester (based on the comments we receive in the country's final and committee exam of the capstone course).

IV. HYPOTHESES AND FINDINGS

A. Hypotheses

The following are the two hypotheses we aimed to verify:

1. Communication skills and performance will improve if students participate in IC
2. The quality of the final products of the capstone course will improve if students participate in IC.

In order to verify hypothesis 1, we mainly collected grades for public presentation before and after participation in IC. Grades of presentations are calculated based on the average of panel of 5 judges. The average GPA of students was the same over the span of the 4 years of the study. Number of students in class ranged from 15 to 23.

In order to verify hypothesis 2, the number of resulted publications out of the capstone class was traced before and after participation in IC as an indicator of quality.

B. Findings

Table-5 shows the results of students' participation in IC and the outcomes. We can notice a steady increase in the number of resulted academic publications after participation in IC. Also, there is increase in course presentation grades.

As shown in Figure-1, the academic publications out of the capstone class increased with the increase of number of participating teams. In addition, the second graph shows how the performance in class presentations improved.

V. MAIN CHALLENGES AND BEST PRACTICES

In this section, we introduce the main challenges we face and how to handle each situation. We also mention how some of these issues fulfill the learning outcomes of the course. As for, learning outcomes 5 and 6 (writing technical reports and planning) participating in Imagine Cup improves both outcomes as participants have to submit reports and videos that are evaluated by external entities.

A. Coaching more than one team in the same year

Aligning IC with the capstone course may result in instructors coaching and mentoring many teams for the same contest. This could be a challenge as classmates compete against each other for the qualifying ticket to the world finals. Confidentiality of ideas, projects, meetings, and rehearsals are

essential in such situations. Other considerations include maintaining an unbiased coaching approach, and equal dedication of time and effort to all competing teams. This builds a trustful relationship between the teams and the coach, essential to keep up the moral. Applying these methods, we could get over the problems arising between the competing groups. In previous years, we managed to coach up to 4 teams simultaneously, all competing against each other in the regional contest. The experience was exhausting for the coach yet very rewarding. In the latest experience in 2012, three teams mentored by the same coach ranked 1, 2, and 3 in the country's finals.

B. Funding

If a team qualifies to the world finals, funds should be obtained for the following items: Publicity material (brochures, posters), Hardware, Software, Video for the demo, Per-diem for team.

In order to produce the best possible product for the world finals, we apply for external grants and sponsorship directly after the country's finals. In the past two years, we managed to get support from Kuwait Foundation for Advancement of Sciences (KFAS). KFAS is the main Public organization funding scientific activities and research in Kuwait.

TABLE 5 Results of Students participation in IC and outcomes.

| Year | Number of teams who submitted proposals | Team formation | Qualified to Kuwait Finals | Kuwait Finals | Regional Finals | Publications | Presentation grades |
|------|---|--------------------------|----------------------------|---------------|-----------------|--------------|---------------------|
| 2008 | 0 | N/A | N/A | N/A | N/A | 0 | 55 |
| 2009 | 1 | All Male | 1 | Ranked 1 | Ranked 1 | 2 | 62 |
| 2010 | 3 | 1 All Female, 2 All Male | 1 (All Female) | Ranked 1 | Ranked 1 | 3 | 68 |
| 2011 | 5 | 4 All Male, 1 All Female | 3 (All Male) | Ranked 1 | Ranked 2 | 4 | 72 |
| 2012 | 4 | 2 All Male 2 Mixed | 4 | Ranked 1,2,3 | N/A | In progress | 76 |

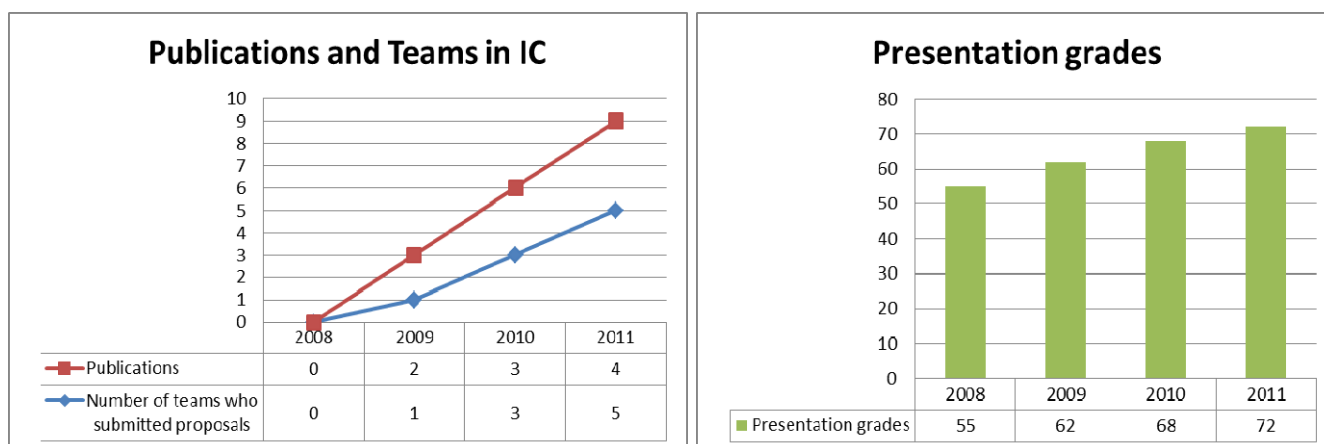


Figure 1 Relation between participation in IC and Presentation grades, Publications

C. Cultural Barriers

Recently, the gender segregation law has been amended to include also private and public higher education institutes, like the American University of Kuwait. By means of Law no. 34 for 2000 for Establishment of Private Universities, Private universities/colleges and branches of foreign universities shall enforce gender segregation [4].

This resulted mostly in single gender grouping in the contest as well as the capstone class. In 2010, we coached an all-female team for the first time. The experience was challenging due to cultural barriers between the male coach and female team. However, the team won on both local and regional levels, advancing to the 2010 world finals. The presence of a female team representing Kuwait in the world finals was a media scoop for the following few weeks. In the current academic year, mixed-gender teams were allowed, so we had two mixed-gender teams for the first time. This issue addresses learning outcomes number 3 and 4.

D. Technology Limitations Using Microsoft Technology

Contestants in Imagine cup have to use Microsoft technology since the competition is a Microsoft initiative. Other tools may be allowed in situations where Microsoft does not have similar tools to support. This limits the technological choices in some projects. It creates a challenge since at AUK we do not use Microsoft technologies throughout our curriculum. We mainly support open source products and languages like Java. In previous years, students had to learn C# and programming for windows phones on their own to be able to compete. This adds an overhead for learning the new tools, yet it is a real life challenge. This also helps to fulfill learning outcomes number 1 and 2.

In order to get over this issue, we organize a set of workshops in collaboration with Microsoft to teach our students how to use Microsoft tools. The workshops are done as an extra-curricular activity where attendance is free for all those who are participating in Imagine cup.

E. Failure to Qualify to Next IC Rounds

In some cases, teams fail to qualify to the next round in Imagine Cup which could be very frustrating for them. Yet, they still have to finish the project for their capstone class. Typically teams exposed to this situation would stop working on the project for one week.

In order to get over this issue and keep students motivated, I created a mini contest in the capstone course where all students in class compete using a more comprehensive criterion than that of Imagine Cup. We have a final public event that is juried and attended by almost 200 people every year [9]. The panel of 5 judges that includes a combination of professors, alumni, and industry experts. The following is the assessment criteria we use: problem definition and innovation, effectiveness and extensibility, functional completeness, Answering questions and creativity.

F. Grading

Students get individual grades in the capstone course depending on their role and the quality of their project. They have to attend an individual oral exam after their final demo and presentation. Imagine Cup does not require all team members to talk during presentations. So, a team may choose to present using two team members only. In class presentations all team members have to present as a requirement for assessment. It is becoming common that students who compete in Imagine Cup present better in class activities since they have better training.

G. Business Case

Imagine Cup assessment criteria includes 15 percent on the business feasibility of the solution. CS students do not necessarily have business background to complete this part of the project successfully. To get over this issue, we integrate the course with other courses offered at AUK. Entrepreneurship courses like ENTR-201 and ENTR-301 are good candidates. The two courses give guidelines on how to operate a business from an entrepreneur's point of view. They

do not have any special emphasis to software projects though. We are currently investigating if this could be added, or if other new courses should be offered. This issue addresses learning outcome number 1.

VI. SAMPLES OF PROJECTS & TEAM STRUCTURES

The following are three samples of projects in different formations:

A. All Male team

ElectReduce is a mobile application that aims at reducing electricity consumption by providing live feedback through mobile phones [1]. ElectReduce was the winner of Gulf-Imagine cup (mobile category) 2009. The product led to a publication in an international conference as well [1]. The team who developed the project went on to start their business and applied for a patent in Kuwait.

B. All Female Team

They Want They Do (TWTD) is multi-touch educational software that aims at teaching physically challenged students basic skills (English, Mathematics, colors, science) using computers. The application uses a combination of technologies in an economically feasible way. TWTD was tested in public schools for the physically challenged students in Kuwait [2]. TWTD is the winner of Gulf-Imagine Cup (software design on 2010). The team went to represent the region in the world finals in Poland (July 2010).

C. Mixed Team

Phyzio is a Kinect-based health software that connects pregnant women with their doctors. The main idea is that pregnant women perform the physical exercises in the form of a computer game using the Kinect sensor. The results are then forwarded to the appropriate doctor who in return advises the patients how to proceed. The project was among the best 5 projects in the Kuwait finals of Imagine cup, April 2012.

VII. ASSESSMENTS

A. Instructors' Assessment

- Culture plays an important role in team management activities. Since Kuwait is a conservative, traditional Muslim country, students tend to pick same gender team members. In a group of 40 students, only two groups had mixed-gender members.
- Competing in Imagine cup raised the quality and motivation level of students. This resulted in raising the average grade in the capstone class. The more teams in the class competing in the Imagine Cup, the higher the average class grade.
- Students definitely learn more and get more experience in handling real time problems as they have to set up their projects in 5 minutes (during presentations). Working under stress is the norm in software industry and competing in Imagine cup definitely prepares students to handle such situations professionally.

B. Students' Assessment

Numerical evaluation was around 4.6 out of 5 (based on anonymous survey that students have to fill around the end of the semester). Students' comments were very encouraging. For most of them, it was a life changing experience. Here are samples of students' evaluations collected anonymously at the end of each semester:

- "This course was the highlight of my senior years. I gained an experience in this course as i am taking whole semesters that i spent together to reach this level"
- "I believe the achievements of Dr. Amir Zeid this semester speaks for his evaluation. Taking 3 teams into the Microsoft Imagine Cup, and at the same time mentoring the rest of the teams in the class. He was able to take his team into the finals of Imagine Cup for the second year in a row"

VIII. CONCLUSION

In this paper, we introduced our experiences about integrating Imagine cup and capstone in Computer Science course. Participation in Imagine Cup has positive impact on capstone course. The contest helps solving typical capstone problems. The nature of the competition raises the level of interest for students in implementing their solutions. Once students start collecting requirements from real stakeholders the understanding of the life cycle process becomes much clearer. Students get trained to present their projects in front of panel of judges in a huge public event. The number of attendees is about 200 compared to the 25-30 normal audience in class room. Students develop the ability to stand, present and answer questions in a more confident manner. We used Imagine Cup as a case study for students design contests.

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Work in Progress: The Integration of Human Performance Considerations within Aerospace Engineering Design Education

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Abstract—Humans play a vital role in the operation of aerospace engineering systems, whether in the cockpit of a spacecraft or in the control center for unmanned air vehicles. Current research in aerospace engineering design education is limited in defining ways to incorporate the performance considerations of the operator within an undergraduate design experience. In addition, few studies examine the effects of these design experiences on the industry preparedness of aerospace engineering graduates. This research aims to fill this gap by reviewing the design processes, learning outcomes, and pedagogical techniques related to human performance that are currently embedded in aerospace courses and curricula. A brief syllabi review found that aerospace capstone courses are generally comprised of a large-scale design project with requirements dictated by industry, NASA, or a professional society. The students follow a design process commonly defined by a classic aircraft or spacecraft design text. These techniques typically do not address design considerations which affect the operator's performance. This work-in-progress discusses these findings as well as proposed future work regarding (1) how to assess the effectiveness of these different techniques and (2) the development of an appropriate educational intervention to address human performance within capstone courses.

Keywords - Aerospace Engineering, Engineering Design Education, Aircraft Design Curricula, Human Performance

BACKGROUND AND MOTIVATION

Humans play a vital role in the operation of aerospace systems, whether in the cockpit of an aircraft or the control station for unmanned air vehicles. These systems operators interact with on-board automation, monitor system components, and control all or part of the system's dynamics. Due to the context in which aerospace vehicles function, system operators have been labeled as hazards or causes of error and, in some cases, accidents [1]. In addition, the defining characteristics of an aerospace vehicle and its subsystems can affect the operator's ability to complete his or her role effectively [2-4]. Thus, in the design of aerospace systems, it is critical to consider the performance of these human operators and the environmental context in which they operate.

However, current aerospace engineering education curricula emphasize quantitative methods and design processes to assess, for example, aerodynamics, mass sizing, and propulsion concepts. This contrasts with the qualitative

analyses and categorical descriptions used to define estimates of human performance, such as workload [5-7]. While many studies discuss ways to teach aircraft and space system design [7-12], few studies examine the effects of these design experiences on the industry preparedness of aerospace engineering graduates [13, 14]. This research aims to fill this gap by (1) reviewing the design processes, learning outcomes, and pedagogical techniques that are currently embedded in aerospace engineering design curricula and (2) identifying where education regarding human performance considerations could be better integrated into the curricula.

REVIEW OF CURRENT TECHNIQUES

Undergraduate aerospace students typically enroll in a capstone aerospace engineering design course during their final year of study. This course may be focused on aircraft, spacecraft, or another technical component (e.g. engine design). While course outlines vary from program to program, these design experiences generally include a large-scale team project accompanied by course content on the aerospace design process. The most variability among courses and programs comes from the required texts, the instructional approaches, and the requirements of the large-scale project. The subsequent sections describe three trends found in a review of publicly-available aerospace engineering senior design course syllabi from several universities, including MIT, Georgia Tech, Virginia Tech, University of Texas-Austin, Iowa State University, and Purdue University.

A. Human Performance Within Isolated Courses

Both MIT and Georgia Tech offer elective courses which focus on human performance within an aerospace system. These courses introduce students to factors which affect a human's performance, such as perception, attention and decision-making [15, 16]. Students also begin to examine effect of interactions between the human and automation on total system performance [15, 16]. These courses, however, are taught in isolation from the required courses in aerospace engineering fundamentals. By the time of a student's senior capstone design course, he or she may be unaware of the connections between their human performance-related elective and aerospace design.

B. Human Performance Within Design Textbooks

The aircraft design courses mention using one of three classic aircraft design texts [17-19], while space system design courses require *Space Mission Analysis and Design* [20]. In the aircraft design texts, the human component of aerospace systems is emphasized in chapters about sizing the fuselage, estimating the weight of flight deck avionics, and assessing the handling qualities of the aircraft [17-19]. The space systems text goes beyond the discussion of size and weight of the passengers and provides information about the physiological effects of space travel and human safety [20]. While these texts include important components relative to human performance, critical decisions about trade studies involving human performance metrics or where to consider human performance within the design process are not included.

C. Human Performance Within Design Competitions

Each year NASA and the American Institute of Aeronautics and Astronautics, along with industry and other organizations, publish design competitions for undergraduates to design an assortment of aerospace systems. These design tasks range from unmanned aircraft systems to air racers to deep space habitation modules [21, 22]. Each competition provides students with a Request for Proposals that dictates the requirements for the aerospace system they will design. Some past design competitions have focused on an array of human-related design requirements, including cargo handling system with time constraints for loading and unloading and the environmental effect of the reduction of the number of pilots in the cockpit [23, 24]. While this is not the case for all the projects and competitions, the inclusion of human-related requirements may facilitate the focus on human performance considerations within an aerospace design curriculum.

PROPOSED FUTURE WORK

Current aerospace engineering design curricula account for human performance considerations most commonly in the discussion of handling qualities or the size of the fuselage. These approaches forsake discussions about, for example, the implications of a design on the number of pilot training hours and the cost of training. Design curricula could, alternatively, examine the design problem from a holistic systems perspective by integrating the human component.

To further this idea, our future work will begin with a review of the learning outcomes and major concepts in capstone courses from other engineering disciplines and more human-centered design disciplines (e.g. industrial design, human-computer interaction). This will be followed by semi-structured interviews of systems design engineers from a large aerospace engineering company. These interviews will allow the researchers to engage in conversations about the major challenges faced by entry-level engineers on design teams.

The second phase of the research will incorporate an examination of the extent to which aerospace engineering students currently understand how human performance considerations can be integrated into the design process. Small assessments [25] will be used to determine how students' understanding and awareness develop over the course of a capstone design course, based on the current pedagogical

techniques employed (e.g. individual projects versus team projects, simulation-focused versus textbook-focused).

The final phase will be to implement an educational intervention into one section of an aerospace engineering capstone course at a large, research-intensive university and to evaluate its effect on students' understanding of human performance. The researchers will examine learning theories and pedagogies (e.g. situated learning theory and simulation based learning [13], expectancy-value theory [26, 27]) that have been used within the development of other capstone courses [28] to account for the complexities of engineering design education. The results of each phase and the appropriate learning theory will then be used in the design of this intervention which will introduce students to the integration of human performance within the aerospace design process.

EXPECTED OUTCOMES

The future work outlined in this paper will help define human performance-related learning outcomes for senior aerospace design capstone courses. The evaluation instrument will be designed with these learning outcomes in mind to examine students' understanding and perceptions of human performance considerations within the aerospace design process. The development and implementation of an educational intervention will serve as a starting point for future research in pedagogical techniques, integrating human performance considerations into engineering design education. In the design of the evaluation and the intervention, the researchers plan to permit future implementations within any aerospace design capstone course, regardless of the structure.

Over the next few decades, advanced aerospace designs will require engineers to consider critical design issues, such as the implications of fully automated commercial aircraft or long space missions on human performance. By incorporating the human performance component of design into aerospace engineering design education, we hope to assist faculty in preparing their students to respond to these and other future challenges in the aerospace industry.

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Collaborating Interaction Design into Engineering Projects in Community Service (EPICS)

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Abstract— This paper investigates the design collaboration process between the Interaction Design (IXD) program and Engineering Projects in Community Service (EPICS) program at Purdue University. There have been quite a few recent research focused on analyzing the collaboration between Industrial Design students and Engineering students. However, little in the literature has been dedicated to discuss the education of Interaction Design and its collaboration with engineering programs. In this research, we tried to identify characteristics that differentiate IXD and EPICS students by focusing on the experiences of the IXD students. Some characteristics made the collaboration successful, but other created frustrations. In order to understand, explore, and evaluate the collaboration process, we collected the data during and after the collaboration and qualitatively analyzed it using a design collaboration model. This analysis identified several interesting features of this interdisciplinary collaboration. The collaboration between two programs benefited both sides and will be conducted regularly. The understanding gained from this study helps to understand and manage the discourse during the interdisciplinary collaboration, which will benefit our future education and inspire better interdisciplinary education and collaboration.

Keywords - service-learning, community engagement, interaction design, interdisciplinary collaboration

I. INTRODUCTION

The new generation of innovative technologies blurs the boundaries between objects and services causing an increased need of interaction design in engineering projects to improve users' experience. In response to such needs, we created the Interaction Design (IXD) program in Purdue University's Industrial Design (ID) program. Different from traditional Human-computer interaction courses in the computer science, this program tries to weave real-world projects into the courses, study related cognitive and social systems, employ research methodologies to evaluate and improve the industrial design, and adopt innovative technologies to better accommodate human experience [1].

EPICS is a recognized model for service-learning and design education where teams of students design projects serving to meet needs of local and global communities. Started at Purdue University in 1995 as an undergraduate program, it has grown to over 400 students per year [2]. Partnerships with community organizations provide benefits to both the community and to the students. Having real customers is very

motivating for the students and provides a compelling learning environment, while the community organizations benefit from access to knowledge and skills that the students and their team mentors utilize in the projects they deliver.

Professors of IXD and EPICS saw that the collaboration between two programs had great potential to benefit students from both programs and improve the deliverables to the community. In 2011, the IXD and EPICS programs collaborated by linking sixteen IXD students in eight pairs with eight EPICS teams. The collaborative projects range from science installations in Children's museums, iPad applications, interactive recycle devices, to project management systems. Overall, the collaborations were successful and received some positive feedback from the faculty advisors and the participants themselves. However, there were a variety of issues in the process. In order to understand and evaluate the collaboration, and improve the education experience, we collected the data from the IXD students during the design process through weekly progress blogs and end of the semester reflection. The purpose of this paper is to review and analyze the collected data and report this collaboration process from the IXD students' perspective. The sample of data analyzed in this paper represents one set of promising practices for supporting students' engagement around interdisciplinary development in a collaborative design process, while it also affords a glimpse into IXD students' understanding and process of meaning-making at a specific moment in time.

II. THEORETICAL FOUNDATIONS OF THE STUDY

A. Design Collaboration Models

Mattessich and Monsey's survey in collaboration literature [3] has drawn a clear distinction among cooperation, coordination, and collaboration. *Cooperation* is the informal relationship without a commonly defined mission, structure or effort. *Coordination* shares the understanding of compatible missions, but authority still rests with the individual organization. *Collaboration* connotes a more durable and pervasive relationship, and the authority is determined by the collaborative structure. To judge the collaboration type of a design, it is important to identify its mission, authority, and relationship.

Gero and McNeill [4] have shown that design is a process that consists of a series of distinct events that occupy discrete

and measurable periods of time. Most significantly, the temporal span of these design events is remarkably short (15 to 30 seconds). As collaborators come together in design, Kvan [5] suggested that collaboration is also episodic and cyclical. This means that design remains a series of discrete steps. Collaborators work together for moments, then divide up and go their separate ways. Gasson [6] proposed that collaborative design consists of parallel expert actions, each of short duration, bracketed by joint activity of negotiation and evaluation. Thus the design activity itself is discrete, individual and parallel, not intimately linked. This theory strengthened Kvan's model demonstrated by **Error! Reference source not found..**

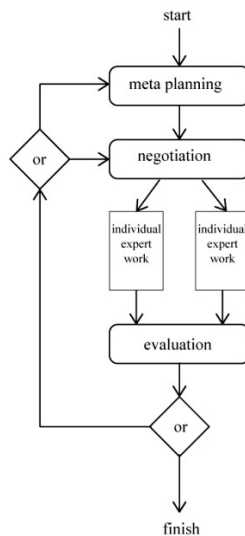


Figure 1. Kvan's model of Design Collaboration [5]

B. Design Collaboration between ID and Engineering

Employing Industrial Design (ID) collaborators to enhance Engineering Education have been studied for more than three decades [7], [8]. There are studies on the educational perspective[9], [10], and design methodology [11]. Esko Kurvinen [12] outlined critical settings and situations that should be taken into account when industrial design is introduced to engineering-oriented product development. In biomedical engineering, Jay Goldberg [13] argued that engineers and industrial designers tend to emphasize different aspects of design. Engineering students tend to focus on the technical aspects of design while industrial design students focus on usability, safety, quality, and the aesthetics of products. Both disciplines place heavy emphasis on identification of customer needs, manufacturing methods, and prototyping. A number of recent research efforts [9], [10], [14] focused on analyzing the collaboration between Industrial Design students and Engineering students in various projects.

C. Design Collaboration between IxD and Engineering

In recent years, researchers interested in studying problems involving complex interactions on human-machine system have risen. Numerous researchers highlighted the importance of user interface features in design as the design will help users

to predict what will happen towards the system [15] [16]. Despite the fact that there are many research studies related to Interaction Design and complex technology products have occurred, still there are limited literature reviews highlight on the emerging themes in Interaction Design, such as the role of methods and theories, interaction design processes and design criteria [17]. Even little in the literature has been dedicated to discussing the education of IxD and its collaboration with engineering programs.

According to the literature review, currently there is no established collaboration framework of Engineering and IxD for us to refer. However, different design collaboration models reviewed are helpful for us to understand and analyze the process. Furthermore, the different aspects of ID designers and engineers are informative to explore the differences between IxD and EPICS students.

III. THE CONTEXT OF THE STUDY

The context for the study was the EPICS Program at Purdue University. EPICS is a multi-disciplinary, engineering-centered design program that teaches human-centered design within a service-learning context. EPICS projects have significant impact on both community and students. Projects can extend to multiple semesters to allow students to see the entire design cycle. The maturity of different projects varies at any point within the semester. Students can enroll in EPICS multiple semesters for one or two credits per semester. While the majority of students are from engineering, the project teams are multi-disciplinary with over 70 majors represented throughout the program last academic year. The teams are also multi-level with first year through senior students. EPICS counts as a technical or lab elective in several engineering departments and as a senior capstone design in Electrical, Computer Multidisciplinary and Environmental Engineering as well as Computer Science. Outside of engineering it counts as various electives, options and selectives. EPICS teams use a human centered design process to address diverse needs within the community through the application of technology [17][18]. Within the teams there are specific roles such as team leader, project leaders, community liaison and financial officer [19]. To collaborate with IxD course, EPICS directors Oakes and Zoltowski selected eleven projects that would benefit from the collaboration with interaction design. Considering the nature of projects and availability of collaborators, we narrowed them down to eight design projects:

- Wireless power (Imagination Station (IS), partner with the Children's Museum in Lafayette)
- Laser harp (IS team)
- Wind tunnel (IS team)
- Cell model (Cellular Engineering Demonstrations (CED), partner with Biotechnology Center in the Children's Museum in Indianapolis)
- Gene Expression (CED team)
- iPad application development for students with special needs (Greater Lafayette Area Special Services/GLASS team)

- myEPICS production system (Information Management System (IMS) team)
- Interaction recycling disposal unit (Boil Green Initiative/BGI team, Purdue EPICS teams [20])

These eight projects range from physical museum installation to digital interface design, from mobile application to strict system development, and their users range from museum visitors, students with special needs, sport fans to EPICS students themselves. These projects are supervised by Supervised by five different EPICS instructors. Professor Qian led sixteen design students in an IxD course. These students range from sophomores to first-year graduate students. Although they have different proficiency in IxD, all of them have received solid design training from industrial design program.

During the first class, EPICS instructors introduced these projects to all the IxD students. Each student was able to rank the projects into his/her own favorite list. After a little bit adjustment, all the students were able to join either the first or the second of their most favorite projects. For each of EPICS projects, there were two IxD students as interface design collaborators. Every week, apart from attending one hour lecture and three hour software workshop in Qian's class, IxD students went to join the EPICS classes to collaborate with their team members.

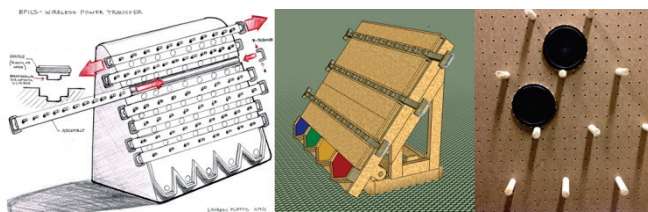


Figure 2. Sketch, digital model, and physical model of Wireless Energy Transfer Project (IS team)



Figure 3. Interactive recycling bin designed for the 2012 Super Bowl in Indianapolis (BGI team)

At the end of 2011 fall semester, eight projects all achieved different stages of success. For example, the interface of wireless power installation was re-modeled and enhanced (Figure 2). The interactive recycling bin (Figure 3) has entered the usability testing stage in the events of Purdue football and basketball games. The iPad application for students with Autism with improved interface and interaction design (Figure 4) has entered the iTunes Apple store.

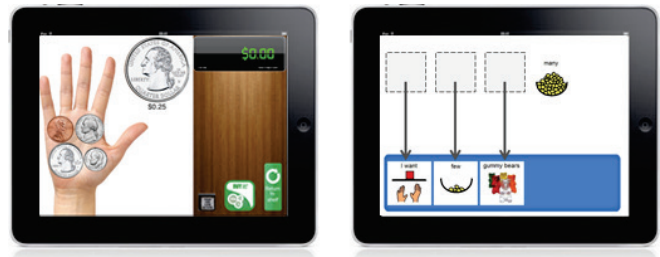


Figure 4. Interface of iPad application for Autism students (GLASS team)

IV. DATA COLLECTION AND ANALYSIS

These design collaborations lasted for a full semester (16 weeks). We received some very positive feedbacks from students, instructors, and external industry reviewers. However, there are a variety of issues existing in different teams. To understand and evaluate the design collaboration process from the IxD student's perspective, we collected the data of their progress through the whole design process, asking each IxD team to blog their weekly progress, and recorded their collaboration reflections at the end of the semester. Apart from this information from IxD students, we also collected external reviewers' notes and reactions from EPICS instructors and team leaders to gain an overview of the whole scope.

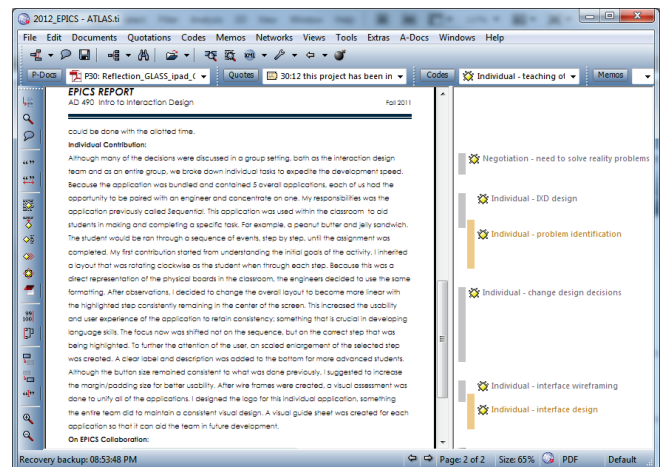


Figure 5. Coding IxD students' blogs and reflection reports in ATLAS.ti

We used ATLAS.ti [20] to analyze IxD students' blogs and reflection notes. In order to code these data, we adopted Kvan's design collaboration model [5] to divide the collaboration process into four stages: meta planning, negotiation, individual expert work and evaluation. After coding 39 documents (Figure 5), we generated 74 codes to identify different issues in the collaborative process. Some sample codes are like: "meta planning – wait for industrial partner's response", "negotiation – narrow down brainstorming ideas", "individual work – interface wire framing", and "evaluation – unsolvable technical problems". Through judging code relationships and connecting them through different logic links (be associated with, be part of, etc.), we created the code networks (Figure 6) to understand the problem scope.

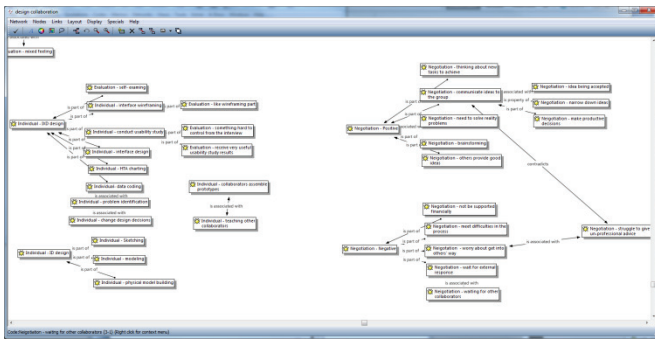


Figure 6. Part of the network view in ATLAS.ti

A. Meta Planning Stage

The stage of meta planning took place after student collaborators have got familiar with each other and started to explore their design problems and assign tasks. Some teams were well-organized, starting from designing the procedure of usability studies and discussing details of interviews. Some team decided to develop a new visual language in order to create continuity between the different games and tie the application together as a logical whole. Some problems started to emerge during this early stage:

- Schedule problem: e.g. Collaborators' course schedules conflicted and hard to find meeting time outside of class. Students were unclear about the project's milestone by the end of semester.
"I had thought at first that this project would be wrapped up by the end of the semester, but it is nowhere near completion."
- Communication problem: e.g. long waiting time for external response from community partners.
- Emotional problem: e.g. there is a tension existed between old participants and new participants.
"Members who were previously on the team seemed to be reluctant to move forward and change some components of the design. The new members would come up with improvements and suggest them, but it seemed as though the older members would disregard them."

Overall, most of the IxD students were "excited" and self-motivated to develop good design since it was their "first time" to collaborate with engineering students and they were going to work on their most favorite projects.

B. Negotiation Stage

The negotiation stage is the period when most main decisions were made. According to the data, the condition split to two parts.

- From the positive aspect, some students were able to communicate their ideas smoothly to the group and got accepted. The whole team brainstormed together in an active way or narrow down to some really cool ideas effectively. From the reflection reports, some students confirmed that other collaborators provided really good

ideas. Some were motivated to propose new design directions:

"I'm feeling the need to regroup myself and create more in terms of output".

- From the negative aspect, different issues showed up such as: the expense of IxD students was not financially supported in some teams, some students felt themselves got into other engineers' way, waited for a long time to get their collaborators' updates, or struggled whether their design would satisfy their collaborators.

"I'm still struggling to have some visual output. So far, all I have are my Persona pages, which really don't have much to do with the operations of the system".

C. Individual Expert Work Stage

Most of the sixteen IxD students have received Industrial Design training since Purdue's IxD program is a branch of its ID Major. While working the EPICS projects, they were able to practice their different design skills:

- IxD design skills: Some students focused on interface design in their teams. They started from drawing the Hierarchical Task Analysis (HTA) charts to understand the current interaction problem, used wire framing to build the interface structure, and then applied graphic design to the interface. Some students adopted user experience study methods to design, implement, code, and analyze usability issues. Though conducting such studies, they were able to receive very useful results.
"As it turned out, we had a good group who not only left good feedback on the paper survey, but were also quite vocal during the focus group."
- ID design skills: In some teams, IxD students were involved in drawing sketches, creating computer models, and building physical models. These students were confident and proud of their quick prototyping skills: "I created the organelles and other CATIA files that are used for 3D printing and cutting out the placement of the organelles in the big Cell."
- Some of them were quite happy that they could teach their engineering partners something – "advising the engineers on options for materials and processes for manufacturing our receiver coil casings, and actually building receiver coils".
- Sometimes, they were also frustrated with their engineering collaborators' productivity: "Even though working on a team was fun, there were times that made things difficult while working with EPICS. At times it seemed like that unless XX and I were there, nothing really got done".

D. Evaluation Stage

As with the other collaboration stages, the IxD students reported having both positive and negative experiences in the design evaluation stage. Shown by Figure 6, the code amounts of two different groups are about the similar size.

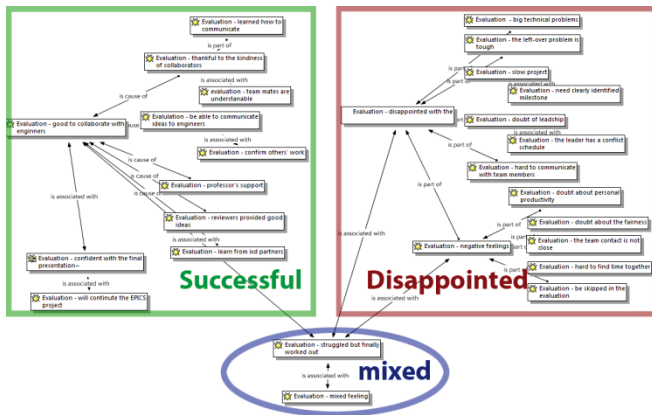


Figure 7. Code network view of Evaluation in ATLAS.ti

From the positive perspective, lots of students were thankful to the kindness of their engineering collaborators.

- They felt they were “welcomed” by the teams, they can communicate ideas with engineers, and their contributions were “confirmed” and “appreciated”. “It was a great pleasure to be welcomed and engaged in a dynamic team of different major, to be able to draw from one another’s skill sets, learn from each other’s experiences, and grow as an individual and as a designer.”
- They confirmed the skills of their collaborators: “My closest project partner (my programmer) XX, was an extremely talented computer science major with a very advanced knowledge of the coding language we were using for the application. This made it easy to refine and implement new changes to our game throughout the semester.”
- They also stated that they learned a lot from their engineering collaborators and the collaborative experience itself: “I learned a lot about collaborating with other groups, especially engineering departments that are really the rhyme and reason to the design groups.”
- They appreciated the good ideas contributed by the external reviewers, and acknowledged some instructors’ kindly support: “I really enjoyed meeting everyone on my team and Professor XX. He was like the second voice for us when we felt like things weren’t getting done. He was able to talk to the other team members and express our frustration without putting us on the spot with the other members of our group.”

These positive attitudes lead to their confidence with the final presentation of project. Four of these sixteen students mentioned that they would take EPICS courses to continue their projects in the future semesters.

However, our coding result also demonstrates a negative aspect. There were mainly two types of problems: the structure of collaborative project and social issues.

- In the collaboration, IXD students were used to defined schedules and wanted clearly identified milestones of the projects. They found the developments of some projects were too “slow”, or the left-over problem of previous semester is so “tough” that their engineering collaborators were not able to solve the technical problems as they expected. Apart from the class time, it was difficult to find time to work together.
- From the social communication aspect, some students did not trust their leaders’ capability or responsibilities. Because of the limited presentation time during the project reviews, lots of their slides were skipped. Without the opportunity to present their contribution, they started to doubt the fairness in the collaboration and suspected their contributions were “ignored”.

In Figure 7, there are two codes, “struggled but finally worked out” and “mixed feelings”, bridging the left “successful” scope and right “disappointed” scope. These two codes were shared by lots of reflections and described a fact in this design collaboration experiment: the interdisciplinary collaboration is challenging and even frustrating, but it is still possible to work out with a successful ending. Students in this category carried on a mixed feeling upon this experience: unsatisfied with some issues but still felt engaged in the teams and expected to see the success of project. This small “mixed” scope is an important and honest portion to present the reality.

E. Feedback from EPICS Instructors and Reviewers

The reaction from the instructors was overall positive. The collaboration provided valuable perspectives on the project with a greater emphasis on the users. EPICS teaches a human-centered design process and the addition of the IXD students brought more students with the user focus into the teams more explicitly. The IXD students not only had a focus on the user, but they had tools to bring to the teams to implement the human-centered design steps. Interestingly, one manifestation of these tools was the increase in prototypes. The IXD students were very comfortable working in the lab making prototypes and often pushed the engineering students to build simple prototypes more quickly. There were tangible benefits to the quality of the end project with the additional features and attention to users from the collaboration. Students on the EPICS teams wanted the collaborations to continue and in a couple of cases talked the IXD students into continuing into the next semester as part of the regular EPICS team.

Some of the challenges included the fact that it was difficult to monitor the collaborations of the teams that did not meet at the same time as the IXD course. These teams often met in the evenings or during the day when the instructor was not present. Some EPICS students were taking it for only one credit hour and the participation in the collaborative sessions left little time to implement suggested solutions. While most teams integrated well, a few struggled to find a complimentary set of roles for their project.

V. DISCUSSION

We employed Kvan’s design collaboration model [5] to catalog the data into four stages, in reality these stages were

implicitly mixed up. In a blog, a student started from evaluating a problem he met, then discussed his work in that week and then described how he negotiated with his collaborators. There was no clear sequence for these events at all. This fact actually matches well with Gasson's theory [6]: the design activity is discrete, individual and parallel, not intimately linked.

Considering Mattessich and Monsey's distinction structure [3], this collaborative experience was actually a mixture of coordination and collaboration. Although students of both sides carried the same mission, they were judged by different instructors in different courses and the duration of collaboration is comparably short. Luckily, students contributed sincerely in the projects and didn't make that issue serious.

According to Jay Goldberg [13], engineering students tend to focus on different aspects of the projects. From the observation, we found that IxD students shared some characteristics with ID students (such as ergonomics and aesthetics), they tended to be more interested in sketching and wire framing user interaction and conducting usability studies to understand the problems. Furthermore, they cared a lot about the milestone of projects and socially they wanted their ideas to be accepted, implemented, and presented. More importantly, since some design decision were implicit in the final outcome; they wanted their contribution to be recognized and confirmed by their engineering collaborators.

For an interaction designer, there is a strict process to go through: identifying the design problems, brainstorming the ideas, selecting the alternatives, and prototyping the solution. EPICS students are taught a similar human-centered design process that involves iteration, prototyping, testing and evaluation and ultimately delivery of a working design to the community. However, since the EPICS projects span multiple semesters and all of the selected projects were in on-going stages, it was impossible to run a complete process of interaction design in one semester. This may model well industrial teams where team members are often brought into on-going projects. Most of students adapted to the context quickly and figured out a way to contribute their design ideas. This collaboration process also demonstrated the flexible potential of interaction design.

VI. CONCLUSION

The collaboration of IxD and EPICS was successful and benefited both sides. Feedback from the instructors and design reviewers were positive and encouraging. We plan to continue the collaboration with the insights gained from this research to help us manage the process. This paper focused on the IxD students' perspective. Unavoidably, some opinions were biased. In the future, we plan to collect more rigorous data from the EPICS students and understand to capture the whole collaborative experience from all perspectives.

Like any collaborations, there were lessons learned and areas to improve. The next iteration will include more preparation before the collaboration starts, set clearer goals motivate and help them throughout the process with more successful outcomes. Scheduling of team meetings will be more explicitly discussed and be a more prominent factor in matching the teams. In the long run, the information gathered

will enrich our understanding of interdisciplinary collaboration format and improve how we implement such experiences to the benefit of the students and the communities we serve.

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Work in Progress: Integrating Computation Across Engineering Curricula: Preliminary Impact on Students

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Abstract—The Collaborative Process to Align Computing Education with Engineering Workforce Needs (CPACE) team developed a partnership among various stakeholders to identify the computational skills that are essential for a globally competitive engineering workforce. Our goal is to redesign the role of computing within the engineering programs at Michigan State University (MSU) and Lansing Community College (LCC) to develop computational competencies – informed by industry needs – by infusing computational learning opportunities into the undergraduate engineering curriculum. In this paper we summarize the process that we used to translate our research findings about the computational competencies needs in the engineering workplace into fundamental computer science (CS) concepts that can be used in curricular implementation. We also discuss the initial phase of our curricular implementation strategy in two disciplinary engineering programs at MSU and transfer programs at LCC.

Keywords—component; Computational thinking in engineering; industry to academia; curricular reform

I. PROJECT IMPLEMENTATION STRATEGY

The CPACE project is divided in two phases: During the initial phase we: a) identified the computational competencies needed in the engineering workplace; b) developed a ‘data-to-computer science (CS)-concept map’ to translate our research findings into CS concepts that can be used in curricular implementation. In the second phase we are using this concept map as a framework to guide the implementation of curricular revisions in Chemical and Civil Engineering at MSU and pre-engineering courses at LCC.

A. Workforce Computing Needs

Based interview and survey analyses, we developed an understanding of industry needs with regard to computational competencies both at the practical-tool level and at the computational problem-solving level. Our findings [1, 2] are consistent with other research on engineering education [3, 4] and indicate that employers: (a) value interpersonal skills, ability to organize and present data, and the ability to function in a team; (b) value critical and innovative thinking, and problem solving; (c) see trends towards computational globalization, which translates to the need for engineers to understand business practices and the importance of integrating engineering data across larger systems; (d) value the ability to

understand both engineering and computational principles that allow them to select and use computational tools to solve engineering problems by moving between physical systems and abstractions in software. Excel, CAD, modeling software, and data and project management software were identified as very important to the engineering practice.

B. A Framework to Align Workforce Computing Needs to Computer Science (CS) Concepts

To translate our interview and survey data into CS concepts that can be integrated in the curricula we evaluated three different frameworks: 1) *Great Principles of Computing* [5]; 2) *Computational Thinking* (CT) [6]; 3) *Being Fluent with Information Technology Report* [7]. The CS concepts enumerated in the latter are instantiated in practical technologies and applications that allowed us to move from the computational competencies identified in our industrial data to CS concepts that can be integrated in the curricula and offered the best framework to complete our alignment. Detailed discussion of the alignment process and findings are presented elsewhere [2].

The chart in Figure 1 shows the distribution of the computational competencies—required in the engineering workplace—mapped to CS concepts. We are using this CS concept distribution as a framework to guide the design and implementation of the curricular reform.

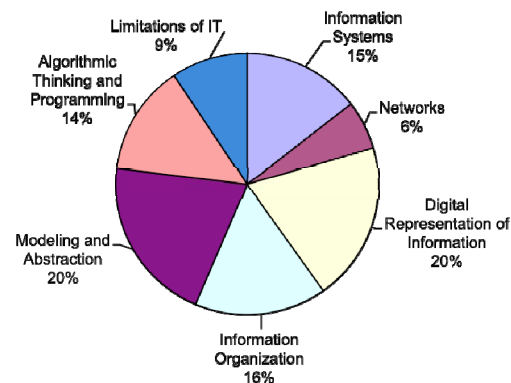


Figure 1. Distribution of engineering workplace computational competencies aligned to computer science concepts.

II. CURRICULAR IMPLEMENTATION

The learning sciences have influenced repeated calls for improving engineering education that focus on providing students with the opportunities to integrate their knowledge across disciplines through authentic problem solving [3].

To accomplish an integrated computing experience our goal is to infuse computational competencies throughout all four years of the engineering curricula [8] and use problems derived from contemporary industrial engineering practice. These problems provide a context where students are required to apply the various computational concepts (Figure 1) for their solution. To collect and develop these problems we have a collaborative team of industrial partners, disciplinary and CS faculty. Key courses are addressed throughout the degree programs on ChE and CE at MSU and pre-engineering transfer courses at LCC.

A. Data Collection and Analyses

Following a mixed methods approach, quantitative and qualitative data are collected through faculty, student, and other stakeholder surveys at the beginning and end of the target courses. The goals of the surveys are: (a) to measure attitudes towards engineering in general and (b) to measure attitudes towards computational problem solving in particular. Other types of data collection include: Systematic observation of selected project and classroom activities; standard class data on learning outcomes and sample course work e.g. final project reports and homework assignments; and faculty and student interviews. We use SPSS V 19 for all analyses.

B. Survey Results

Preliminary results indicate that participation in the course project is helping students feel more confident with respect to their computational skills and competencies. Table I presents a subset of data comparing a freshman course at MSU with the equivalent transfer course at LCC. In the MSU course, the self-reported gains in most computational skills are statistically significant ($p=0.001$). At LCC students report gains in algorithmic thinking and programming skills ($p=0.01$).

TABLE I. COMPUTATIONAL SKILLS RATING: FIRST YEAR (MSU) AND TRANSFER LEVEL (LCC)

| Skill | Transfer LCC* N=11 | | Freshman MSU* N=85 | |
|--|-----------------------|-------------------|-----------------------|-------------------|
| | Before | After | Before | After |
| I can move data from EXCEL into MATLAB. | 4.91 ¹ | 4.91 ¹ | 3.27 ² | 4.61 ² |
| I can check the results of running MATLAB and debug my functions. | 4.36 ¹ | 4.64 ¹ | 3.41 ² | 4.32 ² |
| I can write a correct FOR loop in MATLAB. | 2.55 ³ | 4.45 ³ | 2.08 ² | 4.55 ² |
| I can write a correct nested FOR loop in MATLAB. | 2.09 ³ | 4.36 ³ | 1.99 ² | 4.47 ² |
| I can write MATLAB code that will find the largest number in a 3D numerical array. | 2.82 ³ | 4.27 ³ | 2.78 ² | 4.61 ² |

* Mean; 1. Not significant; 2. Significant $p<0.001$; 3. Significant $p<0.01$; 4. Significant $p<0.05$

Interestingly, data comparisons between the freshman and the sophomore courses at MSU indicate a loss of confidence in the use of some skills from the time students take the freshman course to the time they enter their sophomore year. After our intervention the sophomore students regain confidence in the use of those skills and in some instances return to the initial levels of confidence shown in the freshmen year course.

III. SUMMARY AND FUTURE DIRECTIONS

The CPACE project brings together post secondary educators and industry and community leaders in a collaborative process to transform undergraduate computing education within the engineering and technology fields. Based on interview and survey data analyses we developed an understanding of industry needs with regard to computational competencies. We developed a CS concept distribution framework to guide the design and implementation of a curricular reform (Figure 1). The goal is for engineering graduates to enter the workforce with improved and practice-ready computational competencies that are aligned with industry needs and enable students to integrate conceptual knowledge, technical skills and professional practice. To accomplish this goal we are introducing a series of problems derived from engineering practice in target courses across all four years of the engineering curricula.

The data analyses presented in this paper correspond to the first year of implementation. While encouraging, these are preliminary analyses from self-reported student data and we are in the process of analyzing other data streams including more objective measures such as course and project grade, and other sample course work. Our plans for the second year of the implementation phase include: collection of engineering problems; instructional design and development of course supporting materials, and data collection and analyses.

ACKNOWLEDGMENT

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Uncovering and Repairing Crystal Structure Misconceptions in an Introductory Materials Engineering Class

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Abstract – The crystal structure of a metal plays an important role in its relationship to its macroscopic properties as well as atomic mechanisms of structural change. As such, students need to have an ability to visualize planar crystal atomic packing features, but often find it difficult. Thus, the research question here is, "How can a student's baseline knowledge and misconceptions of planar atomic packing features for different metal structures be measured and how well can instruction promote conceptual change and misconception repair." Answering this question will provide insight for developing more effective pedagogy for crystal structures. A multiple-choice survey with six items was developed using misconceptions from students' pencil and paper sketches of face-centered cubic (FCC) and body-centered cubic (BCC) atoms on (100), (110), and (111) planes. Pretests and posttests of the survey were administered to students in a Spring 2012 introductory materials engineering course. Misconceptions that were revealed included: missing atoms, extra atoms, misplaced atoms, "non-touching atoms where they should touch"; and "touching atoms that should not touch". Students' difficulty in solving increased from (100) to (110) to (111) planes for both BCC and FCC structures. Details of the survey instrument and results are described in the paper.

Keywords–*crystal structure; visualization; misconceptions; conceptual change; assessment*

I. INTRODUCTION

The book, *How People Learn* [1] states that, one of the most important principles for more effective teaching and learning is that instructors should be aware of students' prior knowledge as developed from academic courses and personal experience. As such, concept tests, such as the Force Concept Inventory [2], the Statics Concept Inventory [3], and the Materials Concept Inventory [4], can reveal knowledge gaps, skill gaps, and misconceptions. Knowledge of such issues can then inform classroom practice and instructional materials. In introductory materials engineering courses, one of the key topics that students need to understand as part of the underlying microstructural basis for properties of materials, is the topic of crystal structures. An important aspect of instruction on crystal

structures is that students need to develop an ability to visualize two-dimensional projections of atom locations on differently oriented planes for different crystal structures. Such understanding will help students describe relationships between a material's crystal structure and its macroscopic properties, such as elastic modulus, and atomic-level mechanisms that play a role in determining the yield and tensile strength of a material. As such, a method is needed for characterizing a student's misconceptions and baseline knowledge of crystal structures, as well as the effectiveness of instruction designed to promote knowledge and understanding of crystal structures. Thus, the research question for this paper is, "How can a student's baseline knowledge and misconceptions of planar atomic packing features for different metal structures be measured and how well can instruction repair misconceptions and promote conceptual change."

II. BACKGROUND

A. Spatial Visualization

There is a strong relationship between spatial ability and success in science and engineering that is well documented. In engineering, Hsi, Linn, and Bell found that spatial ability predicted course grades and strong spatial skills were necessary for success on course exams [5]. In addition, instruction in spatial strategies improved problem solving and contributed to confidence in engineering, especially for women. Peters, Chisholm, and Laeng also found that initial gender differences favoring males were reduced with practice [6]. No gender differences were found for performance in the associated course. It was found by Piburn, et. al. there was a relationship between visualization skills and success in geology. Moreover, they found that spatial visualization scores were as strong a predictor of success on a geology test as was prior knowledge [7]. They also found that practice on spatial tasks eliminated gender differences. Additionally, Sorby & Baartmans found that a course that was developed specifically to strengthen the visualization skills of engineering students led to greater

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persistence in engineering, higher grade point average (GPAs) upon graduation, and better spatial skills for students who took the course than for students who did not take the course [8]. Thus, it can be seen that spatial visualization ability plays an important role in learning engineering, which may be influenced by group dynamics and may also be related to problem solving, retention, and GPAs. The work in this research is intended to contribute to this body of knowledge on the impact of spatial visualization ability on engineering success.

B. Assessment of Knowledge with Pre-Post Topical Quizzes

Constructivist pedagogy is now being applied to teach some introductory materials science and engineering courses [9]. Students' conceptual knowledge baseline and conceptual knowledge gain have been assessed across a semester with the Materials Concept Inventory (MCI). This assessment tool is a 30-item, multiple-choice, pre-post course instrument [4, 10, 11]. This summative instrument measures a student's baseline conceptual knowledge of materials science topics at the beginning of a semester and conceptual knowledge gain for the entire class after it is again administered at the end of the semester. There are two questions on the MCI that are related to crystal structures. In the first question, students are asked to determine how many faces and edges are characteristic of a cube, while the second question queries about how many body diagonals are found in a cube. Surprisingly, for these two questions, students at the beginning of the course only get both items correct about 60% to 70% of the time. By the end of the course, on the exiting MCI, the scores improved to 75% to 85%, but never reached a level of 90% and higher. These results demonstrate the difficulties students have in applying spatial visual thinking skills to relatively straightforward tasks in an introductory materials science course.

In order to determine in more detail the types of misconceptions students hold about crystal structure geometry features, a Pre-Post Topic Quiz was developed for crystal structures. It was administered as a classroom activity before the topic of crystal structures was taught and again after instruction on the topic had been completed. In this test students sketched images of atom projections on different crystal planes as deduced from looking at 3-D images of face-centered cubic (FCC) and body-centered cubic (BCC) crystal structures. The goal of the sketches was to project the atom positions in those two structures onto the crystal's major crystal planes of (100), (110), and (111). The crystal structure sketching activities were used to inform instruction and measure conceptual change. A pre-topic test measures baseline conceptual knowledge and reveals misconceptions and knowledge gaps present. After instruction, the same test measures conceptual gain and remaining misconceptions which are classified as robust misconceptions. These topic pretests and posttests assess with finer granularity and greater depth a student's conceptual understanding of a given topic, as well as revealing students' misconceptions and knowledge gaps for that topic. These are summative across a given topic but, in a sense, they are also formative assessments because they assess a small segment of content within the course. Such formative

assessments can immediately inform the instructor of student understanding of the current content. Formative feedback at this stage of instruction has been shown to be very effective when carried out in real time. This was also true in the materials class when sketched crystal structure atom projection results were given to students.

III. METHODS

A. Development of a Crystal Spatial Visualization Survey

A paper and pencil assessment was created to test students' crystal structure spatial visualization skills and administered before the topic was presented. It was given the past four semesters to 30 to 40 students per class. The types and frequencies of misconceptions were compiled from looking at the frequencies of the misconceptions in the quizzes. The misconceptions from the sketched concept tests were used as the basis for incorrect answers in a multiple choice test, the Crystal Spatial Visualization Survey (CSVS), developed and used for the first time in the Spring 2012 term. A typical sketched pretest is shown in Figure 1 in which a number of misconceptions can be seen. For example, the FCC (110) shows two extra atoms inside the (110) plane. Next, the FCC (111) plane shows two misconceptions; one is the extra atom in the center of the triangular boundary and the other is the fact that atoms should be touching but are not. This is a particularly important misconception because the student does not see that the FCC (111) is a close packed plane on which dislocations would glide. For the BCC (111) there is also a misconception which occurs frequently. There is an extra atom in the center of the plane which represents the body-centered atom. However, for an atom to be on a plane, the atom center must lie on the plane, which students often forget.

Misconceptions like the ones just discussed were used for incorrect answers in multiple choice questions. For any given question, four of five multiple-choice incorrect answers (distractors) were generated from misconceptions from pre- and post topic sketched topic quizzes. Overall, six major types of misconceptions were revealed in the sketched topic quizzes which were incorporated into the multiple choice topic quiz. Figures 2 and 3 show new multiple choice question sets for FCC and BCC crystal structures with the intersecting planes being the (100), (110), and (111) planes. In the next section on results, a comparison of the results of a set of 2009 sketched atom projections are compared to the results of the 2012 multiple choice exam.

IV. RESULTS AND DISCUSSION

The new 2012 multiple choice topic test was compared with the 2009 sketched topic test. The most frequent misconceptions from the 2009 test and the 2012 test are shown in Table I. An overall comparison of those results is found in Tables II and III. Table II summarizes the percentages of pretest answers for all choices for the sketched images in 2009 and, in parentheses, the percentages of pretest answers for the 2012 multiple choice test. Similarly, in Table III there is a corresponding set of results for the posttest results.

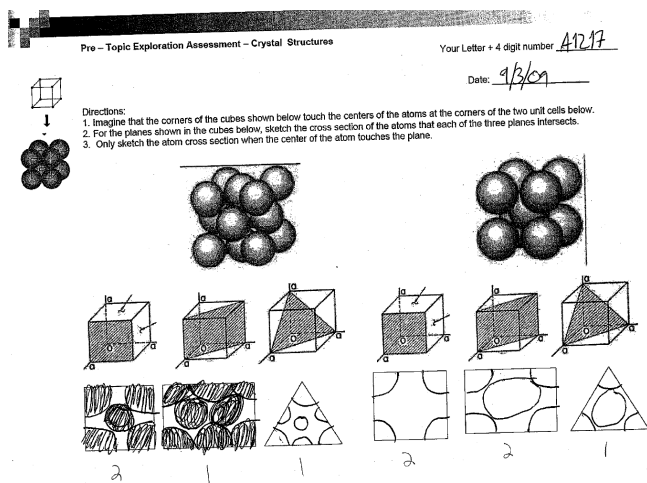


Figure 1. Student Pre-Topic Quiz for FCC and BCC crystal structures for the (100), (110), and (111) planes.

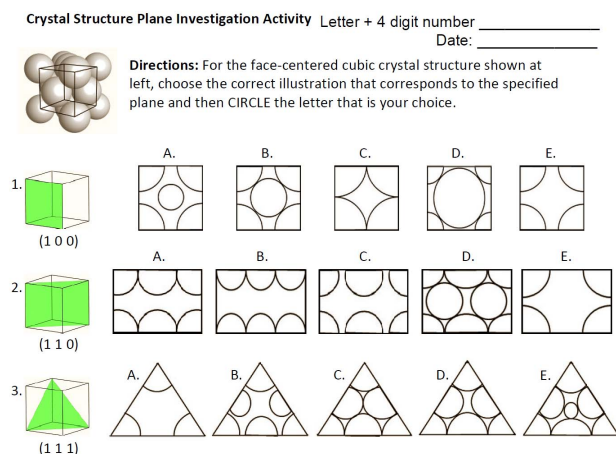


Figure 2. Student Pre-Topic Quiz for an FCC crystal structure for the (100), (110), and (111) planes.

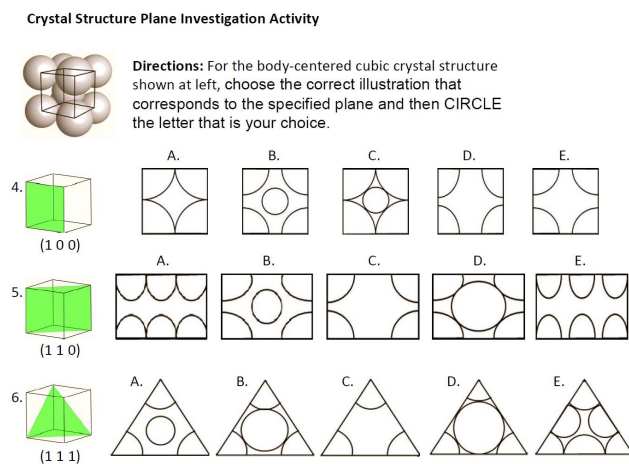



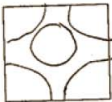

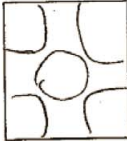


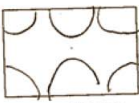
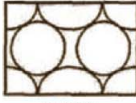

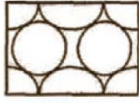
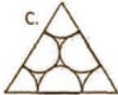
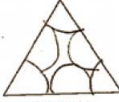
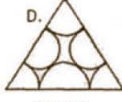

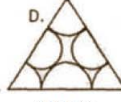

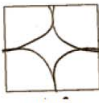



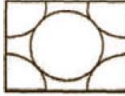

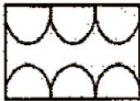
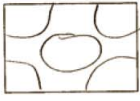
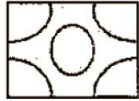
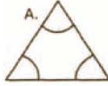

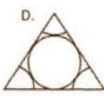

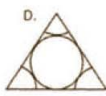
Figure 3. Student Pre-Topic Quiz for a BCC crystal structure for the (100), (110), and (111) planes

In general, it was found that there were six main types of misconceptions that occurred with different frequencies. The most frequent misconceptions are shown in Table I for the 2009 and the 2012 FCC and BCC crystal structures for the (100), (110), and (111) planes. The most frequent misconception was "atoms correctly located, but not touching where they should", with 12 times. This is seen for both the 2009 sketched pretest and also posttest: FCC (100); FCC (110), FCC (111), and BCC (110). It was also seen for the 2012 multiple choice test: pretest FCC (100) ; pretest and posttest FCC (111) ; and posttest BCC (110). The next most common misconception, seven times, was "extra atom(s)" as seen for: pretest and posttest 2012 FCC (110) ; pretest 2012 BCC (100); and all pretest and posttest 2009 and 2012 BCC (111). The next most common misconception is "atoms touching but should not" which occurs for all four pretests and posttests 2009 and 2012 BCC (100). Other less frequently occurring misconceptions included: "missing atom", posttest 2012 FCC (100); "displaced atoms", pretest 2009 BCC (110); and "differently sized atoms", pretest 2012 FCC (100) and pretest 2012 BCC (100).

The summary comparison for percentage of correct pretest and posttest responses for the 2009 sketched test compared to the 2012 multiple choice test is given in Table IV. The average percentage correct for the six items for the pretest in 2009 is 35% and for 2012 is 43%. These values are generally similar for some individual items, but the types of misconceptions sometimes differ. In the posttest there are definitely some anomalies. The average percentage correct for the six items for the posttest in the 2009 sketched test is 37%, a gain of 2%, and for the 2012 multiple choice test result is 72%, a gain of 29%. Additionally, for the 2009 sketched pretest and posttest, some scores actually went down; FCC (100) decreased from 65% to 47% correct and BCC (110) decreased from 41% to 18% correct. In re-examining the data, what had happened was that, in the pretest, many students who had correct answers with atoms touching at correct positions changed to an incorrect answer, atoms at correct positions that *were not touching*. In the 2012 posttest, students after instruction selected the correct answer from five choices and recognized when atoms were touching. In 2009, students did not have a correct answer as a possible choice (while the 2012 students did), but sketched what they thought was the correct answer, but often forgot to show atoms touching, which accounts for lower scores.

In order to see if this hypothesis was true, the answers with the misconception of "atoms not touching" was added to correct answers for both 2009 and 2012 pretests and posttests as shown in Table V. For the 2009 results, the average pretest result (correct + not touching misconception) to posttest result showed a gain from 66% to 79%. The 2012 multiple choice pretest to posttest results showed an average gain from 59% to 78%. The 2009 and 2012 pretest to posttest results for the combined "correct + not-touching misconception" are quite similar. Thus, it seems that one major difference between the 2009 sketched test and the 2012 multiple choice test is that the

TABLE I. CORRECT ANSWER AND MOST FREQUENT MISCONCEPTIONS FOR CRYSTAL STRUCTURE
PRE AND POST TESTS FOR 2009 HAND DRAWN IMAGES AND FOR 2012 MULTIPLE CHOICE SELECTIONS

| Correct Answer | Pre-Tests | | Post-Tests | |
|---|--|--|--|---|
| | 2009 Hand Drawn Sketches | 2012 Multiple Choice Selection | 2009 Hand Drawn Sketches | 2012 Multiple Choice Selection |
|  FCC (1 0 0) |  (35%) Atoms not touching where they should. |  (12%) Atoms not touching where they should |  (47%) Atoms not touching where they should |  (5%) Missing center atom |
|  FCC (1 1 0) |  (29%) Atoms not touching where they should |  (70%) Extra atoms in the center. |  (41%) Atoms not touching where they should |  (15%) Extra atoms in the center. |
|  FCC (1 1 1) |  (41%) Center atoms not touching where they should. |  (37%) Center atoms not touching where they should |  (65%) Center atoms not touching where they should |  (28%) Center atoms not touching where they should |
|  BCC (1 0 0) |  (29%) Atoms touching where they should not |  (26%) Extra atoms and atoms touching where they should not |  (24%) Atoms touching where they should not |  (10%) Atoms touching where they should not |
|  BCC (1 1 0) |  (53%) Atoms not touching where they should |  (14%) Extra atoms and missing center atom |  (65%) Atoms not touching where they should |  (3%) Atoms not touching where they should |
|  BCC (1 1 1) |  (41%) Extra atom |  (47%) Extra atom |  (35%) Extra atom |  (45%) Extra atom |

*Frequency of misconceptions in parentheses

TABLE II. 2009 AND 2012 CRYSTAL STRUCTURE PERCENTAGE OF PRETEST ANSWERS

| Questions | Crystal Structure | A | B | C | D | E |
|-----------|-------------------|------------------|------------------|-----------------|------------------|------------------|
| 1 | FCC (1 0 0) | 35% (12%) | 65% (70%) | 0% (5%) | 0% (9%) | 5% (5%) |
| 2 | FCC (1 1 0) | 41% (23%) | 0% (5%) | 29% (0%) | 25% (70%) | 5% (2%) |
| 3 | FCC (1 1 1) | 18% (9%) | 29% (7%) | 5% (47%) | 41% (37%) | 5% (0%) |
| 4 | BCC (1 0 0) | 29% (14%) | 12% (14%) | 0% (26%) | 5% (7%) | 53% (40%) |
| 5 | BCC (1 1 0) | 0% (14%) | 53% (9%) | 5% (7%) | 41% (67%) | 0% (2%) |
| 6 | BCC (1 1 1) | 0% (23%) | 18% (47%) | 5% (9%) | 41% (14%) | 35% (7%) |

*Note: 2012 data are in parentheses

TABLE III. 2009 AND 2012 CRYSTAL STRUCTURE PERCENTAGE OF POSTTEST ANSWERS

| Questions | Crystal Structure | A | B | C | D | E |
|-----------|-------------------|------------------|------------------|------------------|------------------|------------------|
| 1 | FCC (1 0 0) | 47% (0%) | 47% (95%) | 0% (0%) | 5% (5%) | 0% (0%) |
| 2 | FCC (1 1 0) | 59% (75%) | 41% (3%) | 41% (0%) | 0% (15%) | 0% (8%) |
| 3 | FCC (1 1 1) | 5% (15%) | 12% (8%) | 12% (48%) | 65% (28%) | 5% (0%) |
| 4 | BCC (1 0 0) | 24% (10%) | 12% (3%) | 5% (5%) | 5% (0%) | 53% (83%) |
| 5 | BCC (1 1 0) | 5% (3%) | 65% (3%) | 5% (0%) | 18% (95%) | 5% (0%) |
| 6 | BCC (1 1 1) | 5% (13%) | 5% (45%) | 35% (35%) | 18% (5%) | 35% (3%) |

*Note: 2012 data are in parentheses

TABLE IV. PERCENTAGES OF CORRECT ANSWERS ON 2009 AND 2012 CRYSTAL STRUCTURE PRETEST

| Question's Number | Description | Pretests | | Posttests | |
|-------------------|--------------|----------|------|-----------|------|
| | | 2009 | 2012 | 2009 | 2012 |
| 1 | FCC (1 0 0) | 65% | 70% | 47% | 95% |
| 2 | FCC (1 1 0) | 41% | 23% | 59% | 75% |
| 3 | FCC (1 1 1) | 5% | 47% | 12% | 48% |
| 4 | BCC (1 0 0) | 53% | 40% | 53% | 83% |
| 5 | BCC (1 1 0) | 41% | 67% | 18% | 95% |
| 6 | BCC (1 1 1) | 5% | 9% | 35% | 35% |

TABLE V SUMMATION OF PERCENT CORRECT ANSWERS PLUS ATOMS NOT TOUCHING MISCONCEPTION.

| Question's Number | Description | Pretests | | Posttests | |
|-------------------|--------------|----------|------|-----------|------|
| | | 2009 | 2012 | 2009 | 2012 |
| 1 | FCC (1 0 0) | 100% | 82% | 94% | 95% |
| 2 | FCC (1 1 0) | 70% | 52% | 100% | 75% |
| 3 | FCC (1 1 1) | 75% | 81% | 89% | 84% |
| 4 | BCC (1 0 0) | 53% | 40% | 53% | 83% |
| 5 | BCC (1 1 0) | 94% | 76% | 83% | 98% |
| 6 | BCC (1 1 1) | 5% | 9% | 35% | 35% |

presence of the correct answer with "atoms touching" significantly increases performance of students on the posttest. The lack of a correct answer on the 2009 posttest actually created an increase of the "atoms not touching" misconception for the posttest. Although speculative, it is suggested that students may have learned what correct answers look like from the 2012 multiple choice topic test, so the presence of the correct answer in the multiple choice set may have repaired the "atoms not touching" misconception. This is in contrast to 2009 results where the "atoms not touching" misconception actually was more prevalent *after instruction*.

Overall, for the 2012 test, the greatest percent correct after instruction was for the (100) planes, with FCC increasing from 70% to 90% and BCC increasing from 40% to 83%. The second largest percent correct (but the largest gains) were for the (110) planes with FCC at 23% to 75% and BCC at 67% to 95%. The lowest percent correct (and the lowest gains) were for the (111) planes with FCC increasing from 47% to 48% and BCC increasing from 9% to 35%. The reason gains were so low for the BCC (111) was that the students did not adhere to the rule that, for an atom to be considered as on a plane, the atom center must lie on the plane. As such, the majority of students included the body-centered atom on the (111) BCC plane, even though the atom center did not lie on the plane.

V. SUMMARY AND CONCLUSIONS

Overall, for the pretest, there was reasonable registry between the results of the 2009 sketched and 2012 multiple choice images for 2-D representations of atom positions on (100), (110), and (111) planes for FCC and BCC structures. However, for the posttest, a major difference was that the "atoms not touching" misconception decreased significantly on the multiple choice 2012 posttest because the five multiple choice selections for any given question included the correct answer where "atoms should be and are touching". In contrast, the percentage of students creating the "atoms not touching" misconception during their sketching actually increased on the posttest for the 2009 posttests. It then seems likely that, when students see the correct answer on the multiple choice question sets (as in the 2012), or at least see answers that show atoms are touching, they understand which is the correct answer. For instructors, the overall impact of having the CSVS available to identify the major misconceptions for each of the six items could be the potential for encouraging development of more effective teaching strategies for crystal structures.

Thus, a new survey, the CSVS, has been created which can assess students' crystal spatial visualization skills and understanding before and after instruction. It can be used as a topic pretest to uncover student misconceptions about crystal structures and planes and also establish a baseline of conceptual knowledge about crystal structures. Given as a post-topic test it can measure conceptual gain which should reflect the effectiveness of instruction on crystal structures. More effective instructional methods can be devised to improve student visual spatial skills and understanding of crystal

structures. Results from a larger and more varied population of students will be needed to establish the psychometrics of the instrument. It would be interesting to find out what other instructors might find in other settings to see where differences might arise from course prerequisites, gender, or ethnicity. In order to promote broader usage and testing of the survey it has been loaded on to a web enabled testing site AICHE Concept Warehouse, where it can be administered and graded via computer. The results are immediately available for the instructor so that he/she could use them in their classroom in real time. Presently, the Crystal Structure Visualization Survey is a useful tool that has been tested for a limited population, but has the potential to be a catalyst to motivate more development of more effective instructional strategies on the topic of crystal structures. It could be used not only in materials engineering classes, but in any other discipline where crystal structures are studied, such as chemical and electrical engineering, physics, chemistry, geology, and mineralogy. There is the hope that, in a way that the Force Concept Inventory helped transform pedagogy in the teaching of physics, that the CSVS would, in a more focused way, encourage instructors to develop innovative approaches for teaching the topic of crystal structure.

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Development of an Augmented Reality Based Remedial Course to Improve the Spatial Ability of Engineering Students

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Abstract—This paper presents the results of a pilot study designed to evaluate the effect of attending an intensive remedial course (8 hours worth of work during one week) based on desktop augmented reality exercises to improve the spatial ability of freshman engineering students. Activities based on practice with an augmented reality enhanced exercise book had a positive effect on students' spatial ability, measured by both MRT and DAT:SR tests. To promote students' autonomy, a YouTube tutorial for each type of exercise was developed. This allowed greater freedom for students to advance at their own pace during the training sessions. An evaluation and satisfaction questionnaire based on a five level Likert scale was submitted by participants. The experience was considered very positive by students.

Augmented reality; spatial skills; remedial course (key words)

I. INTRODUCTION

Spatial ability is a key element to students' success in science, technology, engineering, and mathematics (STEM) disciplines [1],[3]. Although some students are better at spatial thinking than others, everyone can improve with appropriate training. Development of students' spatial thinking is currently not widely covered by the educational system, although there are many studies that justify that spatial ability plays a critical role in developing expertise in STEM [2]. Spatial skills are usually developed indirectly. Onyancha & Kinsey report that those students in engineering majors which rely more heavily on these skills (e.g. mechanical engineering) increase them more than other engineering majors [6] from freshman to senior years due to their exposure to an engineering curriculum.

In the context of the Spanish educational system, many students enroll in engineering undergraduate degree programs without proper spatial skills. This paper presents the results of a pilot study designed to evaluate the effect of attending an intensive remedial course based on desktop augmented reality exercises to improve spatial ability of freshman engineering students. Many of these students have problems in managing visual information or in creating mental models of objects represented by their orthographic projections. Due to this fact,

the School of Industrial Engineering at Universitat Politècnica de València (UPV) in Spain provides a series of remedial courses at the beginning of each academic semester to give support to those students that need extra help to follow the regular courses. However, in recent years, some of these remedial courses have been suffering a growing lack of interest and motivation in students. This was the case of the "Introduction to Graphical Expression" remedial course based on classical paper and pencil exercises. The growing gap between the teaching procedures and the technological way of life of students [7] requires bringing new resources to the teaching/learning process. Besides, true learning is experiential. The more senses that are involved (sound, sight, touch, emotions, etc.), the more powerful the learning experience is [8]. In this context, augmented reality (AR) can play an important role supporting experiential learning and giving the students an appealing technological tool to support their learning activity. This has been the approach followed to improve the remedial course "Introduction to Graphical Expression".

In the next section, previous experiences using AR for spatial skills improvement are analyzed. Then the didactic contents used for the development of the remedial course are presented, with all the details about the experimental design. Section IV reflects the results obtained. Discussion and conclusions are presented in the last section of the paper.

II. RELATED WORK

Although spatial ability has been studied using Virtual Reality technology [10],[13] there is a very small number of studies about the application of AR to train spatial ability. In 2006 Dünser et al. [9] presented the first large-scale study (215 students) that analyzed whether spatial ability can be trained using an AR application. They used their collaborative augmented reality system Construct3D. This system employed see-through head-mounted displays (HMD) for the visualization of three dimensional objects that students usually calculate and construct with paper and pen methods. Training groups were composed of two students and a tutor, that attended six 45 minute training sessions (once a week).

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Participants worked on the post-test 10 weeks after completing the pre-test. The training was centered on the use of combinations of Boolean operations and transformations in space to model objects. This study could not find a clear advantage for AR-based geometry training in improving spatial ability.

Do & Lee [12] developed a desktop augmented reality 3D LEGO game as a tool to develop spatial ability. The game allows practicing different spatial skills such as analyzing a 3D model's structure, figuring out what to do to make a primitive geometry become a component of a 3D model and assembling components to create a complex model. Physical markers are used by players to control the game. The main limitation of this study is that the authors did not employ any spatial ability test to verify the effect of playing the AR game on players' skills. They concluded that the 3D LEGO game improved players' skills using a questionnaire where users evaluated the game. One of the questions was if the user considered that the game was able to improve spatial abilities. This question received an average score of 6.8 out of 7 from the 67 participants.

Chen et al. [14] developed two teaching aids for the explanation of the relationship between three-dimensional (3D) objects and their projections. These aids were tangible models (physical objects) comprised of a set of differently shaped pieces and augmented reality models. The authors conducted a user test on 35 engineering-major students. However, they did not apply any standardized spatial ability tests to measure the impact of their intervention on participants' skills. They concluded that tangible models significantly increased the learning performance of students in their abilities to transfer 3D objects onto two-dimensional (2D) projections. Students also demonstrated higher engagement with the AR models during the learning process, although the augmented reality model had little effect on the capability for the transformation of 2D images into 3D objects.

III. MATERIALS AND METHODS

The "Introduction to Graphical Expression" remedial course is short and intensive (16 hours of work, during 2 weeks) and it is offered as an elective course to those students enrolled in the first-year "Graphical Expression" course with a poor technical drawing background. Its general learning objectives are to promote the learning of the systems of representation and the knowledge of the common geometric shapes used in engineering. The course is arranged in two blocks.

The first block (four 2-hour sessions in a week) is based on classical paper and pencil exercises where a basic review of metric geometry, the foundations of graphical representation and multiview and axonometric representation systems are provided to participant students. In this part, students are provided with wooden models to support the execution of some exercises.

The second block (four 2-hour sessions in a week) is based on an augmented reality application that uses virtual 3D models to help students to realize a series of activities designed to exercise their spatial skills. Each student is provided with an "augmented book" [17]. There is an exercise in each book's

page that is coded using a couple of small fiducial marks embedded in the book layout. The student uses another fiducial mark (printed on cardboard or loaded in their mobile phone, as seen in Fig. 1) to manipulate and interact with the virtual model linked to that specific exercise.

To promote students' autonomy, a YouTube tutorial [18] for each type of exercise has been developed. This allows greater freedom for each student to advance at their own pace, as to advance, they do not need to wait for the teachers explanation or to adapt to the speed of the rest of the class. This option has been positively valued by the participating students.

A. Description of augmented reality contents

The second block of the remedial course is based on the resolution of a series of exercises organized in level of increasing difficulty.

Level I exercises require the identification on the projected views of the surfaces marked on the AR model (Fig. 1 & 2).

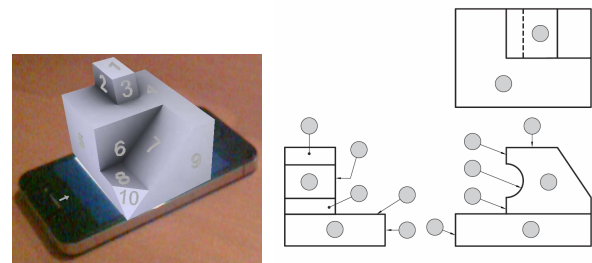


Figure 1. Using a mobile phone to manipulate the fiducial marker.

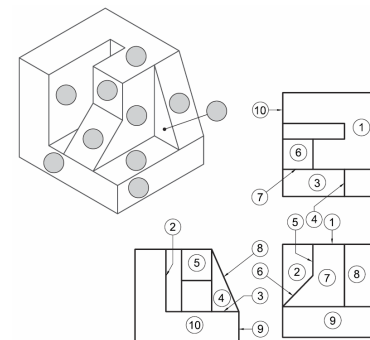


Figure 2. Write in the perspective view the number that corresponds to the surfaces marked on each view

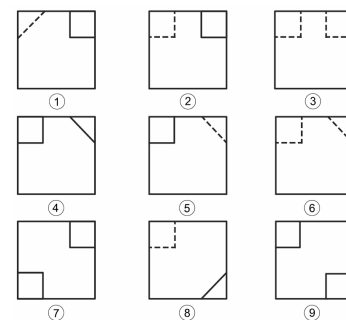


Figure 3. Identify the views that correspond to the virtual object

The second level consists of a series of exercises where students have to select the correct projection view for the representation of a virtual model manipulated through the AR application (See Fig. 3 for an example).

The third level is devoted to prism identification exercises (Fig. 4), and the election of the minimum number of views for the representation of a virtual object (Fig. 5). The fourth level consists of an initial set of exercises where the students have to solve missing view problems (Fig. 6) and draw the normalized views of a virtual object.

The last level does not employ a virtual object. The input for students is a set of views, and they have to sketch a perspective drawing of the corresponding part.

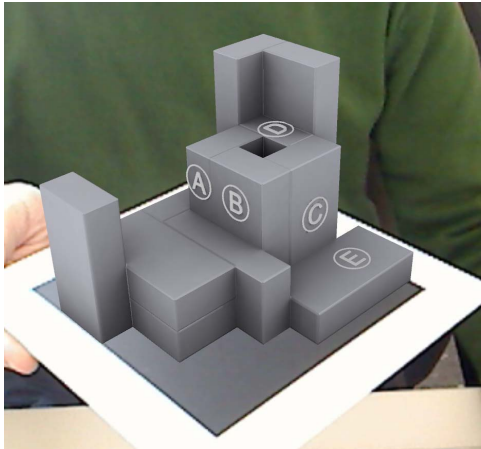


Figure 4. Prism identification exercises.

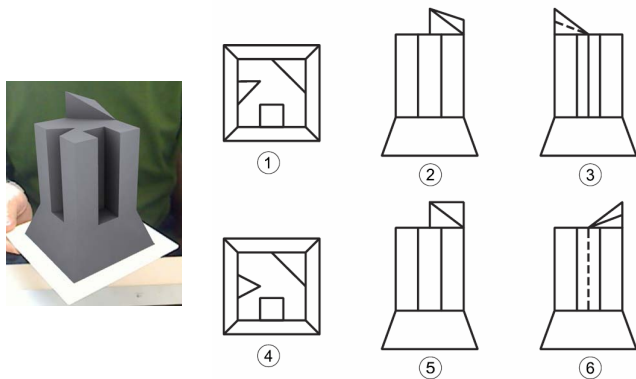


Figure 5. Minimum views exercises

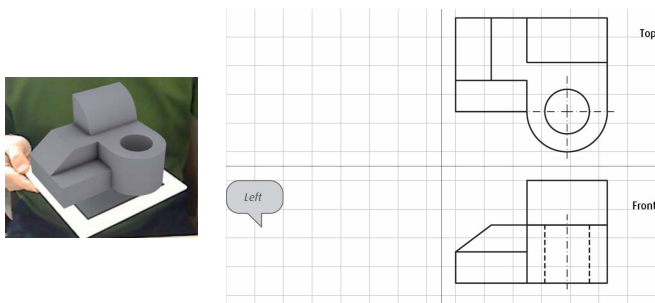


Figure 6. Missing view exercises

B. Participants

This remedial course was offered to freshman engineering students that were enrolled in the “Graphical Expression” course of the Bachelor’s Degree in Industrial Technologies Engineering offered by the School of Industrial Engineering from UPV. 27 students participated in this elective course during the first two weeks of February 2012 and formed the experimental group. A control group of 15 students was selected from one of the regular groups of the “Graphical Expression” course. The control group does not perform any activity related to spatial skills training during the period of realization of the remedial course.

C. Instruments

Although spatial ability is a complex topic, where several subcomponents are identified, for this work only two categories have been considered, firstly “spatial relations” related to tasks that require the mental rotation of simple two-dimensional or three-dimensional objects. Secondly “spatial visualization” that requires the mental manipulation and integration of stimuli consisting of more than one part or movable parts, where usually there is movement among the internal parts of a complex configuration and/or the folding and unfolding of flat patterns. Two tests have been chosen to quantify the values of the spatial ability of participants:

- Mental Rotation Test (MRT) [3] (20 items) for the “spatial relation” subcomponent.
- Differential Aptitude Test (DAT-5:SR level 2) [5] (50 items) for the “spatial visualization” component.

Both experimental and control groups were pre-tested the week before starting the augmented reality based training (second block of the remedial course). Both groups were post-tested the week after they ended the training.

IV. RESULTS

In Table I, MRT (spatial relations) and DAT-5:SR (spatial visualization) values can be found before and after training for both experimental and control groups. As a null hypothesis H_0 , it is considered a fact that there is no statistical difference between average values of both groups. The result of comparing both average values using a “*t*-student in independent series” analysis shows there were no significant differences between groups prior to spatial training, so the null hypothesis H_0 is rejected ($t = -1.557$, p -value = 0.127 on DAT-5:SR and $t = -1.836$, p -value = 0.073 on MRT). In this case p -values are over 5%, so both groups were statistically equivalent in spatial visualization and spatial relation at the outset of this study.

TABLE I. MEAN AND (STD. DEV.) SCORES FOR PRE & POST TESTS

| | Pre- test | | Post- Test | | Gain MRT | Gain DAT |
|----------------------------------|-----------------|-----------------|------------------|-----------------|----------------|----------------|
| | MRT | DAT | MRT | DAT | | |
| Experimental Group n = 27 | 17,04 (6,66) | 34,66 (9,42) | 25,81 (7,83) | 41,11 (7,71) | 8,77 (5,54) | 6,44 (5,44) |
| Control Group n=15 | 21,4 (8,55) | 39,26 (8,68) | 28,26 (10,56) | 41,26 (7,77) | 6,86 (5,75) | 2,00 (5,01) |

In Table II results corresponding to the comparison of the mean scores obtained in pre and post tests using the t-Student paired series test are shown.

TABLE II. RESULTS OF COMPARISON OF AVERAGE SCORES

| | | | |
|----------------|--------------------|------------|-----------------|
| Training Group | PreMRT vs Post MRT | t = -4.435 | p-value = 0.00 |
| | PreDAT vs Post DAT | t = -2.749 | p-value = 0.008 |
| Control Group | PreMRT vs Post MRT | t = -1.957 | p-value = 0.06 |
| | PreDAT vs Post DAT | t = -0.664 | p-value = 0.511 |

The group that underwent training shows a statistical improvement in spatial ability levels, where p -values are below 1% of statistical significance, which indicates that the students have a probability of over 99% of improving their levels of spatial ability by training as proposed by Augmented Reality. Besides this, results show there is no improvement in control group levels.

TABLE III. QUESTIONNAIRE. MEAN SCORE AND (SDT. DEV.)

| | |
|---|------------|
| Q1: The course contents look good. | 4.4 (0.84) |
| Q2: The manipulation of the virtual model with the cardboard marker is adequate. | 4.1 (0.73) |
| Q3: Course levels are well organized and the difficulty and characteristics of exercises are adequate. | 4.1 (0.85) |
| Q4: YouTube videos are a good help to resolve doubts. | 3.3 (1.03) |
| Q5: The augmented reality application worked well. | 4.1 (0.92) |
| Q6: Image quality is good. Virtual objects do not present jittering. | 3.2 (0.95) |
| Q7: The number of exercises to be solved is adequate for the available time. | 4.6 (0.78) |
| Q8: I feel confident to solve all the proposed exercises. | 4.6 (0.90) |
| Q9: The number of exercises of each work session was correct. | 4.7 (0.78) |
| Q10: The manipulation of the virtual object with the cardboard mark is easy to learn | 4.6 (0.59) |
| Q11: The concept of the augmented book is intuitive and easy to understand. | 4.6 (0.66) |
| Q12: I think that the course has improved my spatial skills. | 4.3 (0.88) |
| Q13: I think augmented reality technology is very interesting | 4.7 (0.47) |
| Q14: I think augmented reality technology is very original | 4.5 (0.67) |
| Q14: I think augmented reality technology is very useful | 4.3 (0.83) |
| Q15: I think augmented reality technology is very stimulating | 4.1 (0.87) |
| Q16: I would like to use augmented reality during the regular "Graphic Expression" course. | 4.7 (0.71) |
| Q17: I would prefer to do these kinds of exercises only with paper and pencil | 2.4 (1.38) |
| Q18: I think that the manipulation of the virtual model with the cardboard marker is easier than using the mouse. | 4.1 (1.10) |

V. DISCUSSION AND CONCLUSIONS

The results obtained agree with the previous experience of our research group [15],[16] that augmented reality based training for the development of spatial skills is a feasible approach that provides good results and offers an attractive stimulus to students to enroll in elective activities.

Low cost desktop augmented reality is very easy to implement, adding a webcam and the proper software to a regular CAD computer lab. Although the augmented reality contents presented here are relatively simple, only requiring one mark manipulation, student preferred this physical interaction to the typical mouse interaction (as can be seen in Table III, Q18). This confirms past research into the application of spatial ability in engineering education that suggested that motor activity contributes to the comprehension of the concept of space [19]

The concept of the augmented reality book was very well considered by participant students, as Q11 shows. The book layout has been designed to support a seamless integration of fiducial markers in the page layout, in such a way that they do not distract or break the point of interest centered on each exercise. Students receive the virtual content on a specific cardboard marker that they can manipulate independently of the exercise book. This tangible interaction probably gives the real added value to the experience as Q2, Q5, Q10 reflect.

Perhaps problems will appear when, in the future, students ask for more augmented reality contents to support the regular "Graphic Expression" course. The wide adoption of augmented reality requires authoring environments oriented to provide support to the teacher with a creative and active attitude towards the new technologies. However, current authoring tools are programmer oriented, and require a big effort to create the didactic contents.

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Work in Progress: What is Critical Thinking?

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Abstract—Critical thinking is generally recognized as an important skill, and one that is a primary goal of higher education. However, there is surprisingly little in the literature regarding critical thinking in engineering. This paper describes two pilot studies. A mixed methods study found that graduate engineering students performed worse than undergraduate students on a standard critical thinking instrument. This difference is explained through the two groups' familiarity with test-taking. In a qualitative study, engineering undergraduates were interviewed about how they use critical thinking. It was found that their descriptions were more complex than typical definitions in the literature. Overall, the results point to a need to further investigate what critical thinking means for engineering.

Keywords—critical thinking

I. INTRODUCTION

Development of critical thinking skills is generally recognized as an important aspect of undergraduate education. As pointed out by Mason much of the rhetoric regarding education and its reform revolves around teaching students to think and question critically [1]. Surveys show that well over 90% of faculty believe critical thinking is one of the primary goals of higher education [2]. Most definitions of critical thinking are based on identifying specific abilities that seem to be associated with critical thinkers and provide general definitions [3-5]. Less work has been done to define critical thinking specifically within the context of engineering. For the most part these studies have considered critical thinking in the context of engineering problem-solving [6, 7]. A comprehensive overview of critical thinking in engineering cannot be obtained from the available literature, which is somewhat surprising given its perceived importance. What is missing from the literature is an understanding of what critical thinking is in engineering and how students use critical thinking. This study begins to address these issues by examining how critical thinking is practiced by engineering students and how it might be measured. The specific research questions that guided this study were: 1) What are the processes students use to solve critical thinking problems? 2) What do students believe that critical thinking is? 3) Is there a difference in critical thinking skills between undergraduate and graduate engineering students? These questions were addressed through two pilot studies, one mixed methods and one qualitative.

II. METHODOLOGY

For the mixed methods study, the CCTST Form 2000 was administered to 12 graduate students in Materials Science and Engineering who had passed the PhD qualifying exam, and 13 undergraduate juniors in Materials Science and Engineering at the same institution. The CCTST is a 34 item multiple choice instrument. Questions on the instrument ask for analysis or interpretation of general topics, such as data on commuting patterns or logic puzzles; there is no specific engineering content. The CCTST was administered several different times and the test manual procedures were followed in all cases. The most important aspect of the procedure for this study is that there was a 45 minute time limit for completing the instrument. Participants were paid \$20 for participating in the study. Statistical analysis was conducted using a two-tailed t-test to compare scores between the undergraduate and graduate students. Subsequent to administering the CCTST, participants were contacted by email and asked to reflect on their experience taking the instrument. A total of 8 undergraduates and 10 graduate students responded. Codes were developed out of the responses by identifying major themes articulated by the students.

The participants in the qualitative study were undergraduate civil engineering students at a large public university. Interviews were conducted in which the students were shown four different problems taken from the California Critical Thinking Skills Test (CCTST), Form 2000. The first two problems were given exactly as on the CCTST. The second two problems were similar in nature to the first two, but they were given without the multiple choice answers. The interviews were semi-structured, with questions focused on the approaches the students used to solve the problems and general questions about how they have used critical thinking, both within and outside of engineering. The interviews lasted 40-60 minutes, and students were compensated \$20 for their participation. The interviews were recorded and transcribed verbatim. Analysis was conducted using thematic analysis. Transcripts were examined for statements that related to the research questions. These statements were then grouped into themes through a constant comparative process.

III. RESULTS

Table I shows the results from the quantitative component of the mixed methods study. As can be seen from this data, the

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Table I Results from CCTST

| | Undergraduate students | Graduate students |
|--|------------------------|-------------------|
| CCTST index ^a | 24.15 | 21.17 |
| Number of items answered ^a | 33.92 | 30.92 |
| Percentage of items correct ^b | 71.23 | 68.70 |

a: Difference between the two groups is significant at $p < 0.05$.

b: Percentage of correct answers out of the total number answered.

undergraduate students scored higher than the graduate students, which would normally indicate that the undergraduates have better critical thinking skills. However, careful examination of the data showed that the difference in scores is due to the graduate students not being able to complete the instrument in the allotted time. Thus, the qualitative study was conducted to determine the reason for the difference in completion for the two groups. Table II provides a summary of the results from the qualitative component. As can be seen from this table, the responses indicate a difference in familiarity in test-taking, suggesting that the CCTST was actually measuring test-taking ability, not critical thinking skills.

The second qualitative study was used to examine the nature of critical thinking as enacted by students. Five primary themes associated with critical thinking were identified from the qualitative study: identifying the problem and information, organizing information, using prior knowledge, using opinion, and making decisions. All students recognized the need to identify the purpose of the problem and the relevant information needed to solve the problem, develop strategies for organizing the information presented in the problems, and justify their answers. Some students expressed that they did not look solely at the information in the problem, but also looked to prior knowledge that might help them. Opinion was used in different ways, with one student stating that “you have to separate your opinion from what you’re trying to put on the paper.” In contrast, another student accepted the role of opinion in thinking critically, stating, “What’s true to you and what’s not true to you I think you think critically about those issues.”

In addition to these themes, the students discussed what constitutes critical thinking. Here the conceptualizations varied widely. One student believed that critical thinking required you to think in a new way. If you use a known algorithm to solve a problem, for her that is not critical thinking. Another student felt that critical thinking was the development of a process to solve a problem. Thus, even if you use an established algorithm, that is still critical thinking because you are using a process that had to be created. A third student had an

intermediate view, stating that a “plug and chug” problem could contain critical thinking if you thought about what the answer means and did not simply accept the answer as given.

IV. CONCLUSIONS

Taken together, the results from these two studies point to the complexity of critical thinking and the limitations of our current understanding. The mixed methods study shows that critical thinking cannot be operationalized in a simple instrument. There is also the issue of whether critical thinking is more appropriately measured through a recognition task, as in this study, or through a production task. The results from this study suggest that the CCTST, and by extension similar instruments, actually measure test-taking ability and not critical thinking. Contributing to this difficulty in measurement is the complexity of critical thinking as brought out in the qualitative study. It is clear that critical thinking as practiced is much more complex than most conceptualizations imply. Rather than a discrete list of independent skills, critical thinking includes a series of feedback and interactions among the skills. Future work is needed to more clearly understand what constitutes critical thinking in engineering. We are continuing the work described here with a qualitative study that will examine expectations for critical thinking among faculty, how critical thinking is enacted in practice, and how critical thinking in engineering differs from critical thinking in other fields such as humanities. Ultimately, our goal is to create a model for Engineering Critical Thinking.

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TABLE II: Coding of participant responses. The numbers indicate the number of each group who provided a response.

| | Undergrad | Grad |
|--|-----------|------|
| 1. Hard to choose answers, spent time deciding. | | 3 |
| 2. Questions were complicated, needed to read carefully | | 3 |
| 3. Tried not to stay with any question too long, made best educated guess. | 3 | |
| 4. Long time since I took a written test. | | 3 |
| 5. CCTST was similar to high school or undergrad experience. | 2 | |
| 6. Surprised when time was up. | | 2 |
| 7. Use of test-taking strategies. | 1 | 2 |
| 8. Different attitude towards exams or ability to think as grad vs. undergrad. | | 4 |
| 9. Hard to choose answers, no indication of strategy. | | 2 |

Work in Progress: A Generic Model for Interactivity-Intense Intelligent Tutor Authoring Tools

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Abstract — Intelligent Tutoring Systems (ITS) provide many features that improve learning and teaching experiences. ITS are usually interactivity-intense and content-specific. Interactivity-intense assignments are recommended for scaffolding learning, while content-specific systems can offer low flexibility regarding its possible pedagogical approaches and its uses by teachers. In order to overcome this limited flexibility, there are systems which let content-specific interactivity aside to provide authoring tools, with which teachers can author intelligent tutored assignments without programming. The generic model proposed herein intends to address this problem providing flexible authoring tools for interactivity-intense assignments with tutoring features, letting teachers benefit from the flexibility of content authoring tools as well as the interactivity usually restricted to content-specific ITS. We introduce an application framework which implements this model, which is available as free software.

Keywords – *Authoring Systems, Computer Assisted Instruction, Electronic Learning, Intelligent Tutoring Systems.*

I. INTRODUCTION

Intelligent Tutoring Systems (ITS) are educational software that provide intelligent feedback in order to improve learning experiences for students [1]. ITS main benefits are, for instance, recognizing misconceptions, guiding them through the study, enhancing the speed of learning procedures and helping or preventing teachers from repetitive work.

In our point of view, there are two important aspects of educational systems, including ITS: interactivity and flexibility of use. In order to guide the use of interactive mechanisms on user interfaces of software systems, some conceptual frameworks were developed [2]. Using this approach, it is possible to highlight types of interactivity that enhance learning of specific domains, such as sciences and mathematics. We define interactivity-intense assignment as the one in which user interfaces adopt different types of interactivity in order to enhance learning. Flexibility consists of allowing teachers to adapt the system behavior in order to better suit his/ her pedagogical approach [3].

Interactivity is an aspect well explored by ITS, which is not the case for flexibility of use. Most ITS provide assignments for students in a fixed set of problems or they are created automatically using templates. There are authoring tools that intend to facilitate the programming of tutored assignments [4]. Authoring tools for teachers are presented by example-tracing

tutors [6]. By analyzing existing systems, we found no ITS with interactivity-intense assignments and authoring tools for teachers, but systems with one feature or other.

Our goal is to provide means to facilitate the development of ITS that present the two features together. This paper proposes a generic model of ITS in order to develop systems with interactivity-intense assignments and authoring tools, which we call Interactivity-Intense Intelligent Tutor Authoring Tools.

II. A MODEL FOR INTERACTIVITY-INTENSE INTELLIGENT TUTOR AUTHORING TOOLS

In this section, we present the model for developing educational software with functionalities of: (i) intelligent tutoring, (ii) interactive assignments and (iii) authoring tools for teachers. The model is presented as a generic system architecture with its description and the structure for each functionality it provides. By using it, one can develop an ITS with the desired features following a cookbook and reusing the proposed architecture. Fig. 1 presents this model with four components: structural, assignment, domain and tutoring.

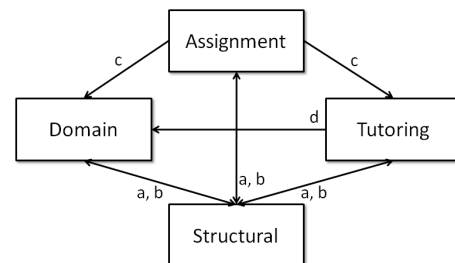


Figure 1. The model components and the communication among them.

The communication flow depicted in Fig. 1 works as follows: (a) structural component initializes other components; (b) use of domain-independent features by them; (c) assignment component integrates domain and tutoring actions to create and manage assignments; and (d) tutoring component reacts to domain actions. A system built with this model can be used in two ways, by teachers that author and edit assignments and students that solve these assignments. We describe the four components of the proposed architecture as follows.

The structural component has three goals: (i) providing basic structure to the system and (ii) to the domain-independent

features; and (iii) initializing and setting communication among other components. Its basic architecture is defined by its conditions of use and its final user, such as Web-based, mobile, or desktop applications. As these specific aspects of the system are essential to designing its architecture, the proposed model is restrained to define this component role.

The assignment component has three main goals: (i) modelling an assignment; (ii) allowing teachers to author assignments; and (iii) allowing students to solve assignments. This modeling must be respected by other components for compatibility. Fig. 2 shows how an assignment is structured: it has a proposition, a configuration, three states (current, initial and expected) composed of domain objects. Domain objects are elements specific to the educational concepts used by the system, such as points in geometry. The student starts an assignment defined by the initial state, interacts with the current state to solve it, and the system compares the solution to the expected state through automatic assessment.

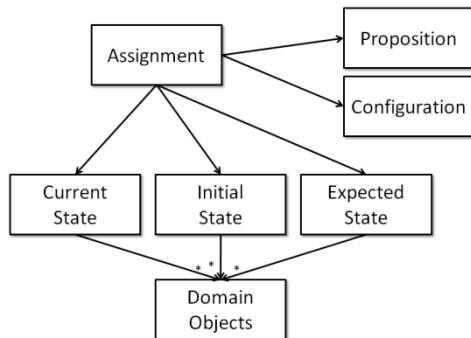


Figure 2. The internal structure of assignment component.

The domain component provides means for the domain-specific features to be compatible with other features. Domain features are functionalities that are specific to the educational domain, such as creating a line in geometry. These features are the essence of the system interactivity-intense assignments. The internal structure of this component is shown in Fig. 3. It uses the *Command* pattern [6]. On the left, the graphical user interface (GUI) has a list of domain actions, which connect an assignment state and a list of domain objects (its parameters) to the domain model, the class responsible for executing the operation.

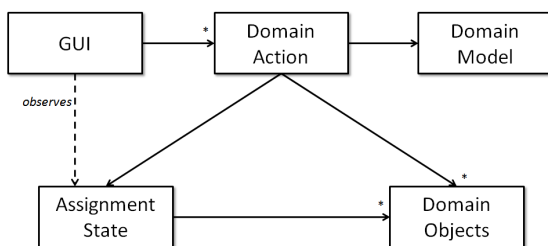


Figure 3. The internal structure for domain component.

The tutoring component provides the intelligent features for the system. Its main goals are: (i) providing intelligent tutoring actions; (ii) managing the way these actions are being accessed; and (iii) allowing the definition of the tutor behavior. Its structure is depicted in Fig. 4. On the left, domain actions are observed by a tutoring sensor, which is associated with the intelligent module, in the same way as the help button. This module has a list of tutoring actions that are selected and

executed depending on the assignment state and its behavior, defined by the authoring user interface on the right.

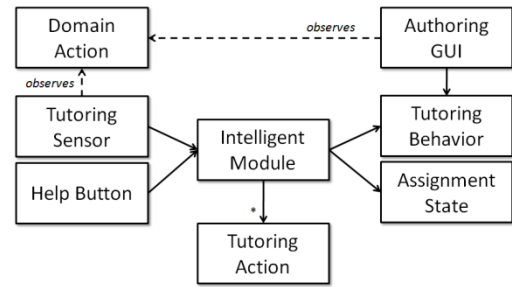


Figure 4. The internal structure of the tutoring component.

III. AN APPLICATION FRAMEWORK IMPLEMENTING THE MODEL AND CONCLUSIONS

After the creation of the model, we developed an application framework for developing Interactive Learning Modules (iLM) [7]. This framework uses a component architecture based on the four components of the proposed model. Currently, the tutoring features are being implemented. The development of iLM using it has resulted in the refactoring process of four existing systems, which facilitated this process. Future work includes adding more features to the framework according to the proposed model and using it to create other systems. This will also serve to evaluate its impact on the development tasks.

The main contribution of this paper is considering the flexibility of use and interactivity features in designing educational systems in general and ITS in particular. Also, by providing abstract reusable concepts and architectures such as the proposed model, the development effort and time of these systems are reduced. The model presented centralizes many concepts and design decisions that serve as a basis for developing educational systems such that the design effort can be focused on the instructional dimension.

ACKNOWLEDGMENTS

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Redesign of Senior Capstone Program in Electrical and Computer Engineering and its Assessment

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Abstract—Our students are required to take part in a year-long capstone program consisting of a one quarter lecture course and a follow-on two-quarter industry-sponsored capstone project. Feedback from students, alumni and capstone sponsors indicated that: a) students needed better preparation before starting their projects, b) we should introduce a realistic mini-project, and c) students should learn and apply project management, time management, teamwork, and communication skills. Our redesigned lecture course has a term-long practicum project that mimics the follow-on project, requiring completion of a project from concept to test. During this practicum project, students apply all the best practices in design and project management that they are learning in lectures. Our program is assessed using multiple methods (focus groups, surveys, evaluation of student work) and multiple sources (students, alumni, sponsors and faculty). This enables triangulation of data and increases our confidence in validity of the results. Data was collected over four years and overall we have found good agreement between different methods and sources. This rich set of data validated our course redesign and provided an insight that students' writing skills and project management need even further improvement.

Index Terms—Capstone program, design, assessment.

INTRODUCTION

Capstone courses are a critical part of engineering education and are also part of ABET requirements. Many approaches exist to implementing them [1] although their overall goals and implementation share many common features. For example, 71% have some form of industry involvement [1-2]. Despite this, there are still many open questions, such as: choice and implementation of assessment tools [3-4], how to integrate project management into capstone design courses [5] and how to use assessment to improve courses and curriculum leading up to them [6-8]. In this paper we will share our experience in redesigning and teaching our latest version of the capstone program, with emphasis on assessment techniques that led to these changes and that we continue to use to monitor the quality of the capstone program.

I. ECE Capstone Program

The Portland State University ECE Capstone Program in its present form was created in 1996. Every ECE student

participates in the program as a requirement for graduation. The overall goals of the program are to:

- Provide students with a realistic design engineering experience, including working in teams,
- Require students to apply fundamental engineering knowledge, and
- Require students to learn and apply project-related skills.

The capstone program consists of two parts: a fall quarter, four credit lecture course entitled “ECE 411 Industry Design Practices,” followed by a two-quarter industry-sponsored project called “ECE 412/413 Senior Project Development I and II.”

II. The Lecture Course: ECE 411 Industry Design Practices

This course prepares students for their upcoming capstone project and for embarking on a career in electrical and computer engineering. The course covers a broad array of topics, such as project requirements specifications, project proposals, test plans and test cases, design reviews, project scheduling, intellectual property (non-disclosure agreements, patents, assignment of rights agreements), communications, and team behavior. In the past, the course was taught in lecture format with homework assignments corresponding to each of the major topics.

III. The Capstone Project: ECE 412 and 413

Following ECE 411, students enroll in ECE 412/3 during which they work on their capstone project. Typically students work in teams of four on an engineering project proposed by an industry or community partner. Over 40 local partners have recently participated in our program. These sponsors include local and internationally recognized technology companies, governmental organizations, and non-profit organizations. More recently, we have included projects from startup companies in order to give students an opportunity to work on projects with smaller, more entrepreneurial partners.

During the fall ECE 411 course, project proposals submitted by sponsors are posted on the capstone program website for students to peruse. In order to accommodate student interests we strive to have a range of project proposals from different disciplines in electrical and computer engineering. This usually requires soliciting many more proposals than there will be teams. Students indicate their preferred choices for projects and the program coordinator assigns them to teams, matching them to

projects and faculty advisors. Students are usually assigned to one of their three preferred projects. From 2004 to 2011, we have a yearly average of 37 proposals, from 20 sponsors, for 70 students, divided in 18 teams.

Teams are created not only on the basis of student preference, but also with an attempt to create a realistic project environment where there is a mix of academic ability (using GPA as a proxy), native English language ability, and cultural background. If students are permitted to self-select their team they tend to choose students of similar background with whom they have worked before in other courses. Although ECE 412 begins in the winter quarter, most teams take advantage of the break between fall and winter quarters to do more extensive background reading, needs assessment, and preliminary requirements definition with the goal of preparing and presenting a project proposal to the sponsor by the end of January. This project proposal includes requirements definition, a preliminary project schedule and a preliminary design strategy.

While project success is obviously stressed, emphasis is placed on teamwork and demonstrating a disciplined design methodology throughout the project. This includes quality design documentation and strong communication processes. Throughout the project students submit weekly progress reports, maintain an engineering logbook, and meet regularly with their faculty advisor and with their industry sponsor as needed. During the project, teams will typically write, review, and present detailed specifications, and test plans. At the conclusion of their projects students make a final project presentation to their sponsors and turn in the project deliverables that include final documentation, prototypes, test results, etc.

The entire department makes a substantial commitment to the capstone program. All full-time faculty participate by advising at least one capstone team each quarter. They meet with the project sponsor and the student team throughout the quarter, review the students' design documentation, and attend and evaluate their project presentations and final report. Further, the capstone program coordinator and other faculty maintain close relationships with sponsors and host an annual event for returning and prospective sponsors. In addition to our surveys of project sponsors these events give us an informal venue for soliciting feedback on the program and on the preparedness of our students.

IV. Assessment and Evaluation Prior to Changes

During a faculty curriculum analysis, we identified ABET student outcomes f, h, i and j as under-represented in our curriculum. Several of these outcomes are natural fits for the ECE capstone program. In addition, review of feedback from capstone program partners, students and alumni showed that:

- ECE 411 should prepare students better for their capstone projects. For example, only 63% of students in 2008 survey strongly agreed or agreed with the statement "ECE 411 adequately prepared me for my senior capstone project."

- Alumni focus group in 2008 suggested that we might:
 - introduce a "mock" project in Capstone program,
 - "teach early and practice often: project management, time management, effective meeting management, teamwork, and communication," and "include more emphasis on applied work."

As a result of this assessment and evaluation, several changes were implemented in 2009-10 academic year.

REDESIGN OF CAPSTONE PROGRAM

The lecture course ECE 411 was the primary target of our redesign. Organization of the two-quarter capstone project, i.e. the second part of the program, was not changed except for the addition of a poster session, poster competition and the addition of several new assessment techniques.

I. ECE 411 Course Changes

Teaching soft skills to engineering students has always been a challenge. To tackle this, we decided to more systematically cover these topics, put them in a proper engineering context and have the students put their newly acquired skills to immediate use. Doubling the number of contact hours and lectures permitted us to add topics and increase time spent on existing topics including: ethics, globalization, contemporary issues, communication, and life-long learning.

In addition, in 2009 we added a "practicum project" consisting of lectures and a term-long project. This team-based practicum project was added to closely mimic the capstone project and gives students a more direct experience with applying the skills and methodology taught in ECE 411, prior to embarking on their capstone project.

The practicum project requires students to form teams and propose a small electronics project. Each project requires one or more sensors, one or more actuators, and a processing section (either analog or digital, with an emphasis on microcontrollers). Students have to develop requirements, write a project proposal, create a project schedule, and develop a test plan. The students must then create schematics, layout a printed circuit board, solder on their components, program their processing sections, and test their design. Benefits of such mini-projects were discussed in [6]. At the end of the term teams must demonstrate their projects in a presentation to their peers, the course instructor, and teaching assistants. Further, each team is required to utilize "best practices" collaboration techniques, such as using collaboration tools like a project wiki and source repository for all design documentation, design files, and code.

Evaluations of the final projects and presentation are modeled on the capstone project and even use the same evaluation forms. This reinforces the parallels between the methodology taught in ECE 411 and expectations for successful capstone projects. Finally, team building and team dynamics have often been cited by students as areas of conflict or difficulty during their capstone project. By giving students a chance to experience these dynamics beforehand

during the practicum they are better able to recognize and address team issues earlier in their projects.

II. Poster Session

To showcase their projects and to give students more experience in communication, a poster session and competition were introduced in 2008. After the conclusion of their two-term capstone projects, each project team creates a poster presentation. Students present their posters during a two-hour session in an event that is open to the campus, our capstone sponsors, and area high school students. A panel of industry and faculty judges selects the best three projects, and winners are given a cash award. The poster session and competition gives students more experience organizing and presenting information graphically and verbally, and has helped them to build confidence in their presentation skills. It also helps to engage the broader community and keep them abreast of our program.

RESULTS AND DISCUSSION

We also implemented new assessments and attempted to triangulate the results by using different techniques [3,4]:

1. surveys of students and capstone sponsors, and
2. direct, rubric-based evaluation of student work by both faculty and sponsors, mostly through evaluations of student presentations and written reports.

Survey results for 2008 are for the program prior to the redesign described here, while those conducted in 2009 and later assess results after the implementation of the redesign. Participation in the surveys is given in Table 1. Note that formal sponsor survey began in 2009, at which time only 3 replies were received. In the last two years we have increased the participation to well over 50% of our capstone project sponsors. Student participation varies, but the sample is big enough to be considered representative and in 2011 it exceeded 50%. The student survey consists of 18 questions which are answered anonymously online while the sponsor survey consists of 11 questions, also answered anonymously online. Survey utilizes Likert-type scale: strongly agree (A), agree (B), neutral (C), disagree (D) and strongly disagree (F).

Three of the statements/questions are common to both student and sponsor surveys:

1. Capstone team met sponsor's goals and expectations.
2. Capstone team was cohesive and worked well together
3. Even though students were not familiar with software and/or hardware tools required, they learned them quickly and became proficient.

This enables us to triangulate student self-assessment with observation and evaluation by their sponsors. Note that sponsors have very detailed and intimate knowledge of students' performance because they work with them directly.

TABLE 1
PARTICIPATION (SAMPLE SIZE) FOR SURVEYS, ORAL PRESENTATION EVALUATIONS AND WRITTEN REPORT EVALUATIONS.

| | Participants | 2008 | 2009 | 2010 | 2011 |
|----------------------|--------------|------|------|------|------|
| Surveys | Students | 22 | 27 | 24 | 47 |
| | Sponsors | N/A | 3 | 10 | 13 |
| Presentation eval. | Faculty | N/A | 8 | 10 | 11 |
| | Sponsors | N/A | 13 | 8 | 15 |
| Written report eval. | Faculty | N/A | 5 | 6 | 9 |
| | Sponsors | N/A | 4 | 5 | 13 |

Figure 1 shows that better than 75% of students and sponsors strongly agree or agree with the statement that the teams met their goals. This seems to be true both pre- and post-changes.

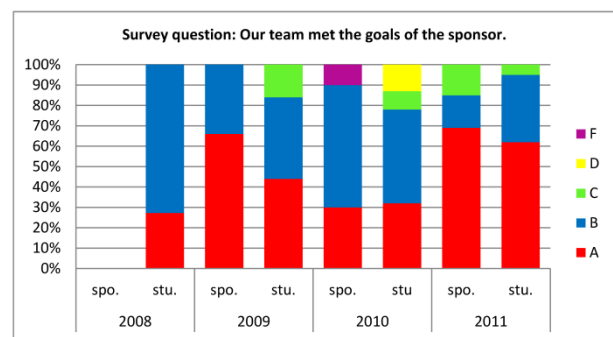


FIGURE 1

COMPARISON OF SPONSOR AND STUDENT RESPONSES TO SURVEY QUESTION: OUR TEAM MET THE GOALS OF THE SPONSOR.

Figure 2 illustrates that in the last two years (2010 and 2011) students and sponsors had very similar evaluation of effectiveness of student teamwork. In 2010 we can observe a brief decline in student performance which bounced back very strongly in 2011. Between 2009 and 2010 the percentage of students agreeing or strongly agreeing dropped by 10%, from 66% to 56%. However, the next year (2011) it bounced back up to 80% which is a 24% increase over 2010. We interpret the 2009 result as a transient and believe that we have turned the corner and now see a significant improvement. We will continue monitoring this result for possible signs of need for improvement in teamwork.

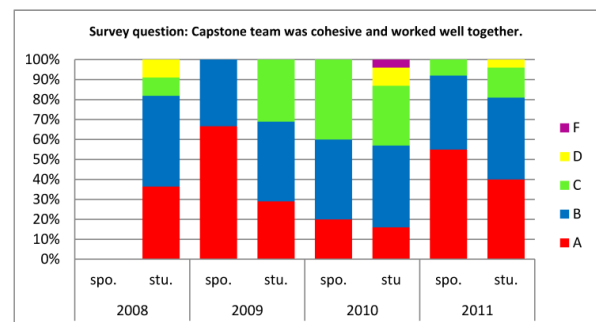


FIGURE 2

COMPARISON OF SPONSOR AND STUDENT RESPONSES TO SURVEY QUESTION: CAPSTONE TEAM WAS COHESIVE AND WORKED WELL TOGETHER.

When it comes to learning new hardware and software tools, Figure 3 shows that students are quick learners. There is a very high degree of agreement between student self-evaluations and sponsor evaluations. Note that the question was asked slightly differently in 2008, and in 2009 only 3 sponsors filled out evaluations. There is a trend of increased percentage of students strongly agreeing with the statement which we interpret as improvement in student abilities and learning over last four years.

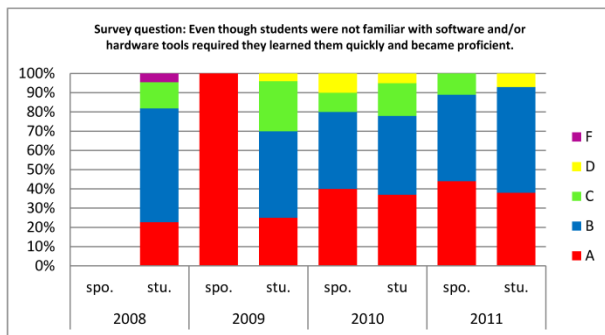


FIGURE 3

COMPARISON OF SPONSOR AND STUDENT RESPONSES TO SURVEY QUESTION: EVEN THOUGH STUDENTS WERE NOT FAMILIAR WITH SOFTWARE AND/OR HARDWARE TOOLS REQUIRED, THEY LEARNED THEM QUICKLY AND BECAME PROFICIENT.

Surveys provide a wealth of additional data that can be used in assessing student learning. One example is shown in Figure 4 which gives students' self-evaluation of their learning regarding ethics. Originally, we intended to triangulate this result with more direct observation and evaluation by capstone sponsors or faculty advisors but few capstone projects have a significant ethical component that can be evaluated directly. Note that the results have steadily improved over the last four years, as measured by those strongly agreeing or agreeing with the statement.

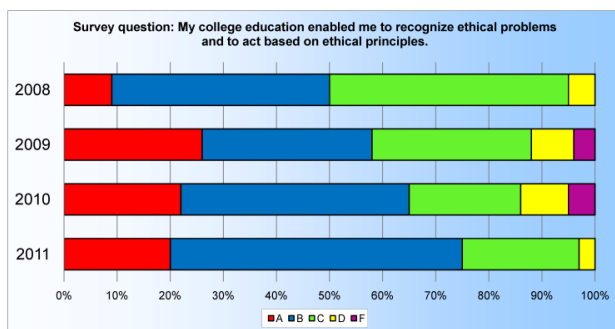


FIGURE 4

STUDENT RESPONSES TO SURVEY QUESTION: MY COLLEGE EDUCATION ENABLED ME TO RECOGNIZED ETHICAL PROBLEMS AND TO ACT BASED ON ETHICAL PRINCIPLES.

Another survey question judges the effectiveness of ECE 411 in preparing students for the capstone project, as shown in Figure 5. The percentage of students who agree or strongly agree that ECE 411 adequately prepared them for

the capstone project was nearly unchanged - around 75% - from 2009 to 2010. In 2011 it rose significantly to almost 90%. Similarly, the percentage of students strongly agreeing rose from under 35% to 45% in 2010 and 44% in 2011. Our 2008 survey had a total of only 63% who agreed or strongly agreed, with only 13% who strongly agreed.

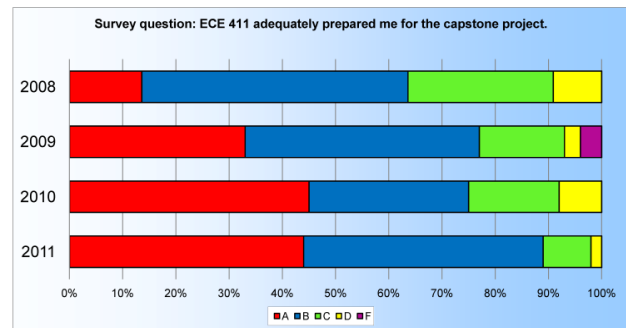


FIGURE 5

STUDENT ANSWERS TO SURVEY QUESTION: ECE 411 ADEQUATELY PREPARED ME FOR THE CAPSTONE PROJECT. NOTE: ECE 411 IS THE LECTURE PORTION OF THE CAPSTONE PROGRAM.

Finally, we also asked students about their preparation for written reports and oral presentations. Survey results are given in Figure 6.

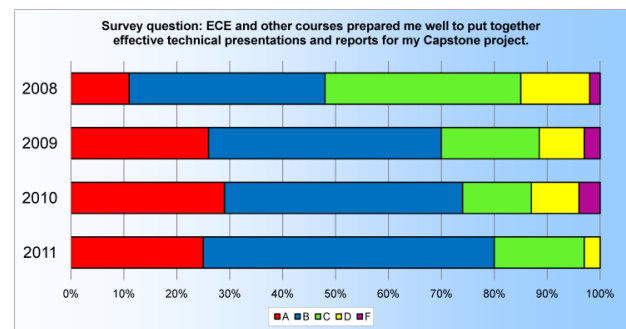


FIGURE 6

STUDENT ANSWERS TO SURVEY QUESTION: ECE AND OTHER COURSES PREPARED ME WELL TO PUT TOGETHER EFFECTIVE TECHNICAL PRESENTATIONS AND REPORTS FOR MY CAPSTONE PROJECT.

The percentage of students who agree or strongly agree that their courses prepared them to put together effective technical presentations and reports for their capstone projects rose from 70% in 2009 to 74% in 2010 to 80% in 2011. The corresponding 2008 figure was 48%. This shows a very encouraging positive trend but these results need to be further evaluated through sponsor and faculty evaluations.

I. Assessment of presentations and reports

Due to the emphasis that employers place on communications skills, we decided to better assess these student outcomes by developing a set of rubrics for oral presentations and written reports. There are seven presentation rubrics: overall organization, preparedness, visual aids quality and effect, technical content, delivery, handling of questions, and effective use of time.

There are two larger areas covered by written report rubrics: overall organization and report mechanics, and technical content. The latter consists of: executive summary, introduction and motivation, problem identification, appropriate analytical method, tools and theory, conclusions, project management, design of experiments, ethical, professional or social issues, and discussion of project weaknesses and strengths. Details on problem identification and conclusions are provided in Table 2.

The rating scale used is: exceeds expectations (4), meets expectations (3), below expectations (2), and unacceptable (1). Note that this is a four point scale whereas our other assessments (surveys) use a five point scale. Participation numbers (sample size) are given in Table 1.

Figure 7 shows the overall assessment by faculty and sponsors of written reports and oral presentations. These plots are obtained from evaluation forms by creating a histogram of how many times each score (1 to 4) was entered. We combined the scores from all of the rubrics and scaled the results to percentage.

Figure 7 shows that the quality of student presentations is exceeding expectations. This assessment is shared by both faculty and sponsors. It is also in agreement with student self-assessment results shown in Figure 6. There were no significant differences from year to year. For written report evaluations in Figure 7 we observe similar results: the number of “4” and “3” scores exceeds 80% indicating that our students are doing very well. Given this level of performance, year-to-year variations are not significant although faculty seem to be a little bit more critical of the written reports than sponsors.

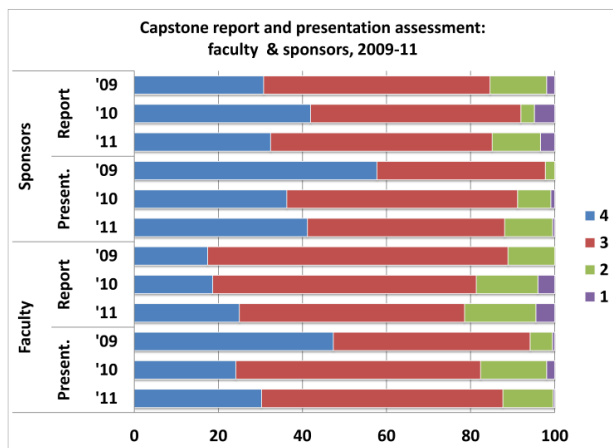


FIGURE 7

OVERALL FACULTY AND INDUSTRY SPONSOR EVALUATION OF REPORTS AND ORAL PRESENTATIONS.

Another way to look at the presentation and written report rubrics data is through average scores, as shown in Figure 8 and Figure 9. For evaluation of attainment we use the following guidelines: average scores in the 1.5 - 2.5 interval are “below expectations,” in the interval 2.5 to 3.5 they “meet the expectations” while those above “exceed

expectations.” For each rubric given in the figures below we also show the ABET student outcome to which it maps.

Rubrics for presentations show little variation between faculty and sponsors, or from year to year. Averages vary from just below 3.0 to over 3.5. Based on this assessment, students meet expectations for their project presentations.

There was a wider variety of rubric scores for the written reports, as shown in Figure 9. Project Management is getting somewhat lower scores, although they are still meeting expectations. Project management is difficult to address through in-class activities due to limited time available. We will be asking sponsors and faculty to pay special attention to this issue in upcoming years, and work more closely with students early on in the project when they are defining and managing the project.

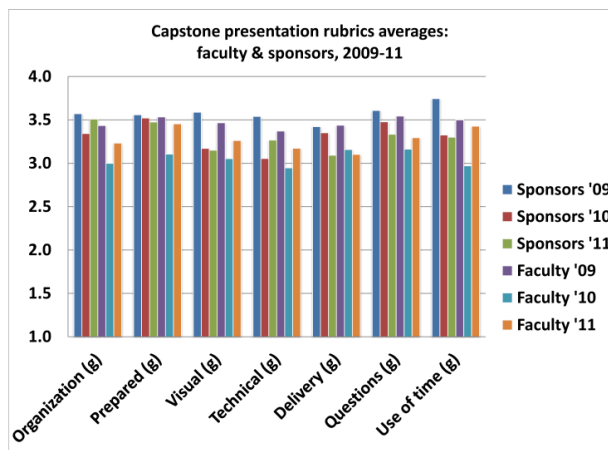


FIGURE 8

FACULTY AND INDUSTRY SPONSOR EVALUATION OF CAPSTONE STUDENT PRESENTATIONS; AVERAGE SCORES FOR A GIVEN YEAR ARE PRESENTED.

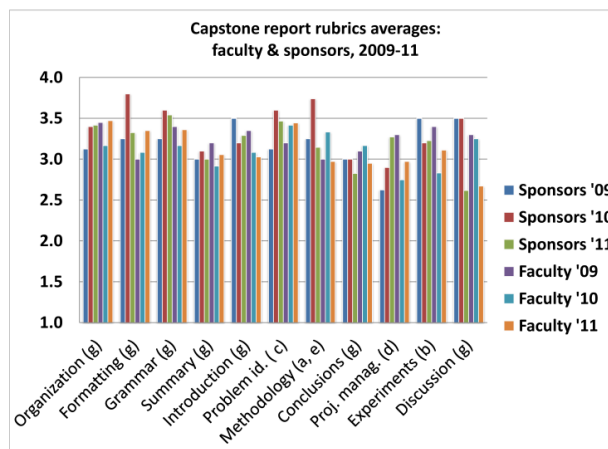


FIGURE 9

FACULTY AND INDUSTRY SPONSOR EVALUATION OF CAPSTONE STUDENT WRITTEN REPORTS; AVERAGE SCORES FOR A GIVEN YEAR ARE PRESENTED.

Overall, our students meet or exceed all of the expectations we had for presentation and written reports outcomes. This is supported by the good agreement between the faculty adviser, sponsor and student assessments.

However, since we started presentation and report evaluations after the capstone program changes, it is not possible to make a pre- and post-change comparisons.

CONCLUSIONS

We redesigned our three quarter long capstone program in two ways. First, we expanded coverage of project management, ethics, globalization, contemporary issues, communication, and life-long learning topics. Second, we provided an experiential component to the project management lecture material by introducing a practicum project that requires completion of a capstone-like project from concept to implementation to test. This approach may appear to be very time consuming but we have found that once we overcame initial hurdles, it was straightforward to implement and it was very well received by students.

Assessment of the program was done over four years and through a variety of techniques: focus groups, student and sponsor surveys and evaluation of presentations, and written reports by sponsors and faculty. We have demonstrated how a combination of all of these assessment methods can be used to effectively improve capstone program design and implementation. We believe that other programs can follow similar approaches. While the assessment process is involved, we did not find it too time consuming. In return we get a rich set of data that enables an in-depth analysis of the program and student learning.

We continue to use the same assessment techniques for quality control and further program improvements. We have documented improvements in several areas and observed consistency between student, sponsor and faculty evaluations. Through faculty and sponsor appraisals we have

observed that students perform very well on their project presentations, but their writing skills and project management need further improvement.

We believe that the new capstone program is a multifaceted, well assessed and novel approach to teaching and organization of capstone courses and projects. Most importantly, it better prepares our students to be successful practicing engineers.

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TABLE 2
DETAILS OF TWO RUBRICS FOR WRITTEN REPORTS.

| Rubric | Unacceptable | Below expectations | Meets expectations | Exceeds expectations |
|--|--|---|--|---|
| Problem identification & working criteria | <input type="checkbox"/> Completely misidentified the problem <input type="checkbox"/> no attempt at defining a "solution space" (alternative solutions) <input type="checkbox"/> no requirements identified | <input type="checkbox"/> Problem identified but very narrowly <input type="checkbox"/> Solution space small and unrealistic <input type="checkbox"/> Some requirements identified and documented | <input type="checkbox"/> Problem identified and expanded to a more general case <input type="checkbox"/> Realistic solution space considered <input type="checkbox"/> Most requirements identified and documented | <input type="checkbox"/> Recognition of underlying root problem <input type="checkbox"/> Realistic solution space considered <input type="checkbox"/> All requirements identified, validated and documented |
| Conclusions | <input type="checkbox"/> Confusing or not given <input type="checkbox"/> include more than two ideas not discussed in report <input type="checkbox"/> rambles on; no focus <input type="checkbox"/> no recommendations <input type="checkbox"/> no extensions to other applications or future work | <input type="checkbox"/> unclear <input type="checkbox"/> Includes one or two ideas not already discussed, <input type="checkbox"/> missing some important parts; <input type="checkbox"/> not concise <input type="checkbox"/> incomplete recommendations <input type="checkbox"/> too few or unrealistic extensions to other applications or future work | <input type="checkbox"/> Clear, <input type="checkbox"/> follows report discussion, <input type="checkbox"/> all important parts covered <input type="checkbox"/> have meaningful recommendations <input type="checkbox"/> several realistic extensions to other applications or future work | <input type="checkbox"/> so clear and complete as to enhance impact of report |

Work in Progress: A Machine Learning Approach for Assessment and Prediction of Teamwork Effectiveness in Software Engineering Education

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Abstract - One of the challenges in effective software engineering (SE) education is the lack of objective assessment methods of how well student teams learn the critically needed teamwork practices, defined as the ability: (i) to learn and effectively apply *SE processes* in a teamwork setting, and (ii) to work as a team to develop satisfactory software (SW) *products*. In addition, there are no effective methods for *predicting* learning effectiveness in order to enable early intervention in the classroom. Most of the current approaches to assess achievement of SE teamwork skills rely solely on qualitative and subjective data taken as surveys at the end of the class and analyzed only with very rudimentary data analysis. In this paper we present a novel approach to address the assessment and prediction of student learning of teamwork effectiveness in software engineering education based on: a) extracting only objective and quantitative student team activity data during their team class project; b) pairing these data with related independent observations and grading of student team effectiveness in SE process and SE product components in order to create “training database”; and c) applying a machine learning (ML) approach, namely random forest classification (RF), to the above training database in order to create ML models, ranked factors and rules that can both explain (e.g. assess) as well as provide prediction of the student teamwork effectiveness. These student team activity data are being collected in joint and already established (since 2006) SE classes at San Francisco State University (SFSU), Florida Atlantic University (FAU) and Fulda University, Germany (Fulda), from approximately 80 students each year, working in about 15 teams, both local and global (with students from multiple schools).

Keywords-assessment; software engineering teamwork; software engineering education; assessment; machine learning.

I. INTRODUCTION AND BACKGROUND

There is now a consensus across industry and academia that to be successful in today’s workplace, computer science students must learn practical SE teamwork skills defined as the twofold ability (i) to learn and effectively apply SE processes in teamwork setting and (ii) to work as a team to develop satisfactory software (SW) products which have requested

features, and are delivered on budget and on schedule. The need for improved teaching and training in this area is evidenced by statistics on the unacceptably high incidence of failure of industrial SW projects: about ten percent are abandoned, about one third fail, and over half experience cost and schedule overruns [1-5]. The evidence also indicates that these failures stem primarily from failures in communication, organization and teamwork aspects of SE and are not due to the SW technology [1], [4-8].

Most of the current literature on student learning and assessment of SE teamwork skills, while well conceived and developed like CATME [18] and TIDEE [19], or applied on individual instructor basis, relies mostly on qualitative and subjective data from class surveys and instructor observations at the end of the academic term. Due to the subjective and qualitative nature of the collected data, where entries are heavily dependent on the human responder’s judgment, these instruments are difficult to use consistently and repetitively. The use of simplistic data analysis methods fail to address complex interactions among team members and the tools they use (e.g. for communication, code management, issue tracking). The absence of objective, quantitative and comprehensive data on student team activities (e.g. team communication dynamics; usage of software development tools) leaves team communication patterns understudied and poorly understood. The fact that the assessments are performed only at the end of the course also precludes early classroom interventions, which are critically important for improving students’ learning effectiveness. Sophisticated automated machine learning (ML) techniques that are now regularly applied in bioinformatics, medicine, data mining, marketing, analysis of customer behavior, and even in SE for SW quality assessments (e.g. [9-11]) have not been applied to the acquisition and assessment of SE teamwork skills. The work described in this paper aims to discover new factors that can objectively and quantitatively determine, assess and predict SE student learning teamwork outcomes by applying powerful ML

data analysis techniques using only objective and quantitative measures of student team activity.

The authors have been engaged together in joint teaching of SE classes, data collection and some preliminary research since 2006 [12-16]. These SE classes were conducted at SFSU, FAU and Fulda, in a synchronous fashion, using the same team project with the same milestones, with approximately 80 students each year working in about 15 teams. Teams comprised of students only of a particular university (*local teams*) and teams comprised of students from multiple universities (*global teams*).

II. APPROACH

The approach has several distinct steps (see Figure 1).

A. Step 1: Collection of the data on student team activity

A wide range of data (measures) pertinent to student teamwork activity are collected during the joint SE classes from students while they are actively engaged in intensive team projects. All data are: i) quantitative and objective; ii) related to measurable manifestations of teamwork activity; iii) easy to collect; and iv) amenable to analysis by machine learning methods. All student teams are assigned to develop the same project and fulfill the same five synchronized milestones using the same SE tools (e.g. e-mail server, Bugzilla, SVN) during project development. Teams are formed such that the level of combined expertise and gender mix are approximately equal across teams, in order to factor out the students' skill level from this study. Instructors maintain a log of their regular observations about the teams which are later used for assessment and grading. *Student Activity Measures (SAM)* focus on the activity of *each student* and are obtained by weekly online surveys and analysis of usage of SE tools. These are quantitative measures, such as time used for certain activity, counts of e-mail, incidents, etc., which are either measured by automated tools or easily observed by instructors or students. *Team Activity Measures (TAM)* are computed for each team by combining the *SAM* for the team's members. For example, a SAM datum is the number of commits to the team's source code repository; the corresponding TAM is the average and standard deviation of commits for all the team members. We believe that by focusing only on quantitative variables and combining them at the team level we reduce the influence in reporting error and significantly eliminate subjective bias. To examine different patterns of behavior at different stages of project development, a *time variable* related to each of five project milestones is introduced.

B. Step 2: Creation of ML training database

At the end of the semester, independent evaluators (faculty who do not teach the SE classes) evaluate/grade each student team for achievement of SE teamwork outcomes using: a) the class grading rubrics; b) information from the instructor logs; c) manual evaluation of the developed student SW; and d) final team project demonstration. These grades, one for adherence to the SE *process*) and one for the quality of the team's SE *product* , are categorized as "A - above expectations", "C - at expectations", or "F - below expectations". These grades constitute "decision classes" for the ML algorithm, and are

paired with TAM data for each team to construct a *ML training database*.

C. Step3: Applying ML to discover factors that determine and predict student SE teamwork achievement.

The training database will be used as an input to ML training, which will produce a ML classifier that predicts the student team performance based on TAM data, and can assess the effectiveness of TAM measures by evaluating ranked TAM factors. We chose the random forest (RF) [17] ML algorithm for its accuracy, success in many application areas, and its ability to generate simple rules that explain its behavior. We are using open source SW for statistical computing, R [25] for which an easy-to-use RF implementation from [24] is available.

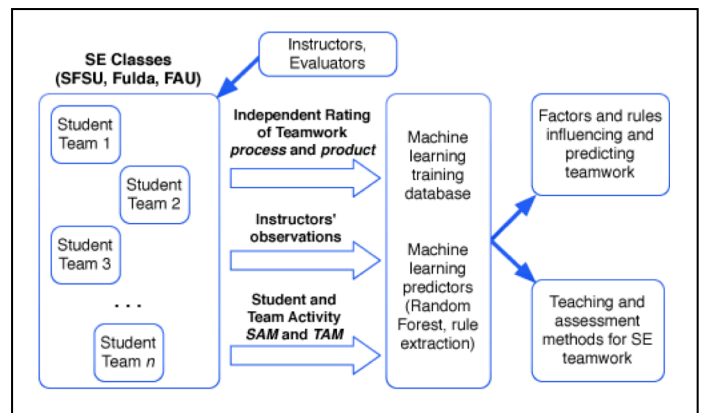


Figure 1. Using ML to assess and predict student teamwork achievement

III. STATUS AND PRELIMINARY RESULTS

We have fully established collaboration, team management and grading methods for the joint SE classes that have been ongoing since 2006 [12-15]. Modified data gathering methods have been in place since Fall 2011 to reflect the new SAM and TAM measurements, when new custom data gathering software started to be used on a new suite of SE tools. These open-source SE tools used by students include: 1) tools for collaboration and communication such as e-mail and wikis; 2) tools for SW development management such as Bugzilla [20] and Subversion [21]; 3) tools for application development such as NetBeans [22]. All team projects are deployed on a server using LAMP (Linux, Apache, MySQL, PHP) stack. Student surveys are administered with LimeSurvey [23]. Tool usage and outcome data is stored in a MySQL database, which is used as training data by the RandomForest package [24] for the SW package R [25]. Data analysis has begun, with first results expected by summer 2012. This work is supported in part by NSF TUES grant 1140172.

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Trust in Engineering Teams and Groups and Virtual Facilitation Methods

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Abstract-- This paper presents two related studies; the first explores the typical recurring dysfunction engineering student teams face, and the second evaluates the effectiveness of a virtual facilitator, called the Droid Communication System (DCS), in training such teams to address the dysfunction. Using Patrick Lencioni's Theory of Five Dysfunctions of a Team, this study first measured for the following: absence of trust, fear of conflict, lack of commitment, avoidance of accountability, and inattention to results. Then, a virtual trust-building vignette was developed and loaded onto Droid phones to guide students to potential solutions.

The studies' findings indicate that absence of trust seems to be a significant problem for engineering student teams and that 42% of participants indicate that the DCS process increased their confidence in communicating and interacting with their teams. The development of the vignettes and experimental evaluation can provide a model for future research on engineering education and on student team development.

INTRODUCTION

Engineering students, like the ones enrolled at Missouri University of Science & Technology, are increasingly called upon to work in teams as part of their undergraduate experience. To work effectively in teams, engineering students "must learn not only the technical knowledge of a particular discipline, but also gain the ability to work with and manage team dynamics" [2]. Since they are not yet experienced, they often run into difficulties, but they may be afraid to share these difficulties with their professors, partly due to fear of getting a bad grade [1]. In addition, since many interactions between students occur outside the instructor's view, or may even be purposefully hidden from the instructor, it can be difficult to provide helpful feedback and guidance in a timely fashion. This exploratory investigation attempts to answer the following research questions and hypotheses:

Study One:

Research Question One: What is the most significant problem that collaborative engineering student teams encounter in teamwork?

Study Two:

Research Question Two: How effective is the virtual facilitator (the Droid Communication System) as an intervention in addressing the most recurring problem engineering student teams encounter in teamwork? although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

CONTEXTUAL BACKGROUND

A team is a special type of group in which people work interdependently to accomplish a goal. According to Hackman [3], there are three primary factors for team success and these relate to the task, social relations, and the individual. A successful team develops social relations while completing the task, and participation in teamwork is personally rewarding because of the social support, the learning of new skills, and the rewards given for participation. Indeed, motivation, group cohesion, role assignments, and performing both task and social behaviors are the building blocks of successful team performance [6]. According to Levi, teams in any type of collaborative context can face many issues. Levi suggests, "the collaborative dynamic can perpetuate common problems involving conflict, power and social influence, decision-making, emerging leadership, problem solving, and diversity" [6]. Any one or combination of 2

these areas can cause problems within a group. In turn, Johnson and Johnson give special attention to addressing the source of group problems. They explain the interrelated nature of group dysfunctions and how to overcome these “through maturity, practice, and planning” [4]. A study of engineering teams found that more than 90 % of a team’s interactions was task-oriented [7]. When teams are under time pressure as is the case with student teams, they may not have time to devote to group process issues and “may fall back on traditional management methods rather than using teamwork to get the task accomplished” [8].

In an effort to provide aid for educators and to add to the extant literature on teamwork in educational settings, this exploratory study first applied the lens of Lencioni’s theory of Five Dysfunctions of a Team to isolate the recurring problem that engineering students encounter during their work as a team. Then, the researchers considered DCS’s effect on training students in addressing the dysfunction.

For both studies, Institutional Review Board (IRB) approval was obtained before data was collected. Participants were not deceived or misled, and their responses remained anonymous. Participants were volunteers who were recruited as individuals, and they did not receive compensation or payment. No institutional sponsorship was pursued and written consent by human participants was provided. The short informed consent form was administered at the beginning of each survey.

STUDY ONE

The first study explored the following research question and hypothesis:

Research question one:

What is the most significant problem that collaborative engineering student teams encounter in teamwork?

Hypothesis one:

Absence of Trust, the foundational layer in Lencioni’s model, is a highly significant problem that engineering student teams encounter in teamwork.

Method

Quantitative descriptive research was used to identify the recurring problem faced by engineering student teams in the undergraduate program at Missouri University of Science & Technology. This method was selected because it is a means to describe

systematically, factually, and accurately the characteristics of an existing phenomenon.

Participants

A convenience sampling method was used to identify 17 students in the engineering program at Missouri University of Science & Technology. The participants, aged 18 or older, were part of student teams enrolled in undergraduate engineering classes. In addition, the participants were members of student teams composed of 4 members per team.

Measure

Patrick Lencioni’s diagnostic model of Five Dysfunctions of a Team posits that teams fail to achieve teamwork because they unknowingly fall prey to five natural but dangerous pitfalls known as five dysfunctions of a team: absence of trust, fear of conflict, lack of commitment, avoidance of accountability, and inattention to results [5].



Figure 1. Lencioni’s 5 Dysfunction of a Team

These dysfunctions can be mistakenly interpreted as five distinct issues that can be addressed in isolation of the others, but in reality they form an interrelated model so that the susceptibility to even one of these issues is potentially lethal for the success of the team. These dysfunctions build on each other, so having one builds the foundation for the other dysfunctions. An overview of each dysfunction, and the model they comprise, is essential to understanding effective teamwork. Taken individually, each dysfunction means:

Dysfunction #1: Absence of Trust: This occurs when team members are reluctant to be vulnerable with one another and are unwilling to admit their mistakes, weaknesses or needs for help. Without a certain comfort level among team members, a foundation of trust is impossible.

Dysfunction #2: Fear of Conflict: Teams that are lacking on trust are incapable of engaging in unfiltered, passionate debate about key issues, causing situations where team conflict can easily turn into veiled discussions and back channel comments.

Dysfunction #3: Lack of Commitment: Without conflict, it is difficult for team members to commit to decisions, creating an environment where ambiguity prevails.

Dysfunction #4: Avoidance of Accountability: When teams don't commit to a clear plan of action, even the most focused and driven individuals hesitate to call their peers on actions and behaviors that may seem counterproductive to the overall good of the team.

Dysfunction #5: Inattention to Results: Team members naturally tend to put their own needs (ego, career development, recognition, etc.) ahead of the collective goals of the team when individuals aren't held accountable.

According to Lencioni, trust is the first foundation in teamwork and lies at the heart of a functioning and cohesive team. In the context of building a team, trust is "the confidence among members that their peers' intentions are good, and that there is no reason to be protective or careful around the group" [5]. Lencioni further contends that trust in teamwork requires team members to communicate and to make themselves vulnerable to one another. Vulnerabilities in this context include skill deficiencies, interpersonal shortcomings, mistakes, and requests for help. Teammates must become confident that their respective vulnerabilities will not be used against them.

The researchers of this study hypothesized that achieving vulnerability-based trust is challenging because, in the course of education, most students learn to be competitive with their peers and protective of their reputations. It becomes difficult to turn those instincts off for the good of the team. In fact, the researchers agree with Lencioni's assessment that members of teams often have absence of trust as their first and biggest hurdle in teamwork. In fact, if absence of trust is the biggest hurdle for the engineering student teams sampled in this study, then "there should be clear signs that the team members are engaging in the following detrimental behaviors: concealing weaknesses and mistakes from one another, hesitating to ask for help or to offer constructive feedback, holding grudges, dreading

meetings and avoiding spending time together, and jumping to conclusions about the intentions and aptitudes of others without attempting to clarify them" [5]. Of course, our data-gathering instrument should shed further light on our assumption that absence of trust may be the main culprit in undermining student teamwork.

Procedure

During fall 2011, surveys were administered to a sample of engineering student teams to explore typical recurring team difficulties or dysfunctions. Through the lens of Patrick Lencioni's Theory of Five Dysfunctions of a Team, a questionnaire with fifteen questions and a Likert scale measured for the following team dysfunctions: absence of trust, fear of conflict, lack of commitment, avoidance of accountability, and inattention to results (appendix A). For the descriptive question of this study, each item was rated on a scale of 1 (rarely), 2 (sometimes), and 3 (usually). Although not specifically listed in the Lencioni Team Assessment, researchers also included an optional rating in the Likert scale of 0 (no/unknown) for each of the fifteen questions. This allowed for the zero score to be represented in the overall calculation in each statement. A zero rating identified a complete dysfunction of that particular team in the eyes of the sampled student. The placement of the zero score in the Likert scale further argues for (1) allowing a participant in the survey to select a no answer rather than being forced to select a score (i.e., rarely/one point) that may not accurately represent the student team for a particular question, and (2) once a no answer is selected the impact would represent a lower overall score giving a probable indication that the dysfunction needs to be addressed. Each dysfunction comprised of 3 statements. Scores for the statements were summed for each dysfunction and a total score of 3 to 5 indicated a high probability that the dysfunction needs to be addressed.

Results

The analysis of the data collected from the fifteen questions was used to support the researcher's assumptions about the team dysfunction that prevented the student teams' success. Lencioni provided instructions how to calculate an individual sample from the Likert scores of the fifteen questions. The researchers were not necessarily interested with individual scores and the impact these scores would have on an individual member of a student team. Rather, the interest focused on the entire cohort of

engineering students at Missouri University of Science & Technology and how they collectively interact with one another in a team setting. Therefore, taking the 17 individual Likert responses, researchers listed them onto a spreadsheet to determine the frequency in each of the rated areas. Next, the collective scores in each section were calculated taking the number of respondents and multiplying it by the scale score. For example, for question number one, 10 respondents answered Usually which equates to a score of 3. Multiplying 10 and 3 gives a score of 30. Divide 30 by the number of 17 respondents, the average score in this column is 1.76. Researchers continued this calculation to attain the average score for each of the remaining columns as seen in Table 1.

TABLE 1: SCORE CALCULATION

| | Usually =3 | Sometimes = 2 | Rarely = 1 | Unknown/No = 0 |
|-----|---------------|------------------|---------------|-------------------|
| Q1 | 1.76 | 0.59 | 0.12 | |
| Q2 | 0.71 | 0.94 | 0.24 | 1x0=0 |
| Q3 | 1.94 | 0.59 | 0.06 | |
| Q4 | 0.71 | 0.12 | 0.41 | 5x0=0 |
| Q5 | 1.41 | 0.94 | 0.06 | |
| Q6 | 1.06 | 0.82 | 0.18 | 1x0=0 |
| Q7 | 1.41 | 1.06 | 0 | |
| Q8 | 1.59 | 0.59 | 0.06 | 2x0=0 |
| Q9 | 1.59 | 0.59 | 0.12 | 1x0=0 |
| Q10 | 2.29 | 0.35 | 0.06 | |
| Q11 | 1.41 | 0.71 | 0.12 | 1x0=0 |
| Q12 | 0.53 | 0.71 | 0.29 | 3x0=0 |
| Q13 | 2.12 | 0.47 | 0.06 | |
| Q14 | 1.59 | 0.71 | 0.06 | 1x0=0 |
| Q15 | 0.53 | 0.94 | 0.24 | 2x0=0 |

Using the overall respondent average for each statement, the scores were then listed on the scoring sheet as offered in Lencioni (Table 2).

TABLE 2: TOTAL SCORES FOR EACH DYSFUNCTION

| Absence of Trust | Fear of Conflict | Lack of Commitment | Avoidance of Accountability | Inattention to Results |
|-----------------------|----------------------|-----------------------|-----------------------------|------------------------|
| Statement #4 1.24 | Statement #1 2.47 | Statement #3 2.59 | Statement #2 1.89 | Statement #5 2.41 |
| Statement #6 2.06 | Statement #7 2.47 | Statement #8 2.24 | Statement #11 2.24 | Statement #9 2.3 |
| Statement #12 1.53 | Statement #10 2.7 | Statement #13 2.65 | Statement #14 2.36 | Statement #15 1.71 |
| Total: 4.83 | Total: 7.64 | Total 7.48 | Total 6.49 | Total: 6.42 |

A score of 8 or 9 is a probable indication that the dysfunction is not a problem for your team. A score of 6 or 7 indicates that the dysfunction could be a problem. A score of 3 to 5 is probably an indication that the dysfunction needs to be addressed.

The scores on the sheet were added together for an overall average score of 17 responses. The five total scores for each of the five dysfunction statements were compared to the scoring table. The data supported Hypothesis 1 and the literature since Absence of Trust appeared to be the most pressing challenge facing engineering student teams.

STUDY TWO

The second study attempted to answer the following research question and hypothesis:

Research question two:

How effective is the virtual facilitator (the Droid Communication System) as an intervention in addressing the most recurring problem engineering student teams encounter in teamwork?

Hypothesis two:

Student teams who participate in the Droid Communication System intervention will show an improvement in team communication, a meaningful step to building trust.

Method

A descriptive method was used to evaluate the effectiveness of the virtual training intervention or trust-building vignette in helping engineering students address absence of trust in their teams.

Participants

A convenience sampling method was used to identify 55 students in the engineering program at Missouri University of Science & Technology. The participants, aged 18 or older, were part of student teams, enrolled in spring semester undergraduate engineering classes. In addition, the participants were members of student teams composed of 4 members per team. 26 students consented to the post-experiment questionnaire.

Measures

In spring 2012, through a post-survey, the researchers assessed the perceived effect of the vignette on student team communication. The survey was designed to include questions pertaining to the communication aspects of teamwork as guided by the DCS. The premise for the post-survey stems from Lencioni's observation that communication and member interaction, if done within a mode of inquiry and

observation, increases the likelihood of open dialogue and sharing of vulnerabilities [5]. Vulnerabilities at this level include skill deficiencies, interpersonal shortcomings, mistakes, and requests for help. Lencioni contends that teammates must get “comfortable being vulnerable with one another for trust to develop” [5]. Of course, this requires the confidence that members’ vulnerabilities will not be used against them. In effect, an essential component to the sharing of vulnerabilities is non-violent communication and interactions, which, in turn, foster trust-building tendencies.

Procedure

The outcomes of Lencioni’s questionnaire were used to develop a virtual scripted vignette that illustrated absence of trust. The Droid Communication System (DCS) guided students through a trust-building exercise modeled by a team of students from the theater arts department. The scripted vignette was loaded onto wireless Droid phones via an application-based software program designed to mimic approaches similar to expert facilitators. The same students were guided through a trust-building exercise via in-ear Bluetooth devices. The scripted vignette through the DCS modeled specific communication behaviors and guided students through inquiries and observations. Scenarios included instances where group members were troubled with one member of the team. They were prompted in-ear to say a pre-scripted statement as it related to the dysfunction. Fellow team members responded according to the script. The experiment took approximately one and one-half hours to complete. The objective of the vignette was to increase communication and interaction among the team members and to invite inquiry, so some “vulnerability is shown; an essential component for building trust” [5].

Results

After the intervention training concluded, participants were surveyed regarding their impressions of the trust-building vignette and the DCS process. Forty-two percent of participants indicated that the DCS process increased their confidence in communicating with their teams. Similarly, 46% felt that the DCS process helped them become more comfortable in actually communicating with their teams. And just over a third believed that the DCS training would improve their personal interactions with their teams. Furthermore, 44% rated their experience using the DCS process while working with team members as either positive

or somewhat positive. These data suggest that the DCS training was perceived as useful by a substantial proportion of participants. It is unknown exactly why some participants found the DCS process to be useful while others did not. However, these findings are consistent with our hypothesis that participating in a digitally-aided trust-building exercise would improve team communication. However, given the expediency and relatively low expense of this type of team-building intervention, further investigation of the Droid Communication System process is warranted.

RECOMMENDATIONS

This study indicates that absence of trust seems to be a significant problem for engineering student teams; hence, faculty should consider creating opportunities for student teams to engage in trust-building exercises in order to increase communication and interaction among team members. The frequency of communicating and interacting engenders an open environment in which vulnerability is encouraged and trust is built. Furthermore, faculty should consider digitally-aided trust-building exercises in helping address student team dysfunction.

Future research should expand this investigation in three ways: First, it should compare the Droid Communication System process to alternate, more established team-building approaches in order to assess its relative efficacy. Second, future research should utilize standardized, comprehensive assessments of team dynamics in order to capture the nuances of the team structure as it changes over time. Third, it should employ the use of control groups and a pre-test post-test research design in order to allow causal inferences

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Work in Progress: Integrating Writing Instruction in Engineering Courses

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Abstract— Communication modules were incorporated within engineering projects in an integrated second-year mechanical engineering curriculum. Students learned to identify appropriate communicative strategies and obtained problem-solving experience through design, prototype development, testing, and reporting, with additional activities related to team building and community service learning. The integration process required collaboration among instructors teaching various disciplines and presented challenges that are discussed in the paper. The authors argue that incorporating writing modules with engineering projects adds a substantial emphasis on communication and teamwork and allows students to explore human and social dimensions of engineering. From describing their projects, students move towards the exploration of rhetorical and ethical implications of engineering practice and an understanding of their professional identity. Instructor feedback indicates that students' motivation has improved, their engagement and enthusiasm have increased, and learning outcomes have consistently been achieved. Student feedback has been positive and encouraging; they self-report that they are better prepared for taking upper-level courses. The authors conclude that students are likely enabled to reach higher levels of knowledge in senior courses.

Keywords—communication; teamwork; mechanical engineering; integration; program development; outcomes-based assessment

I. INTRODUCTION

An innovative pedagogical approach was implemented in an integrated second-year mechanical engineering curriculum (Mech 2) at the Faculty of Applied Science at a leading Canadian university. This approach was developed in response to the evolving academic needs of students, the institutional move towards outcomes-based assessment, and the new accreditation criteria. Its purpose is to incorporate communication modules into mechanical engineering courses and to promote rhetorical awareness, teamwork and community service learning. The interdisciplinary context of the project encompasses writing-in-the-disciplines (WID) and engineering education, thus providing an opportunity to bridge the gap between the understanding of writing pedagogy in these two fields. Engineering educators, with their over-arching focus on design skills, view writing skills as fully transferable to the workplace. In contrast, recent writing research and knowledge transfer literature [1, 2] question the notion of transferability and provide a compelling argument that transformation of knowledge, rather than transfer, takes place. Our longitudinal study aims to address this issue.

II. PEDAGOGICAL INNOVATION

A. Integrated Approach

Mech 2, a new fully integrated second-year curriculum, was designed in 2003 and implemented in 2004 to replace the conventional curriculum for 130 second-year mechanical engineering students [3]. The purpose was “to apply a systematic approach for developing analytical, practical and design skills of second-year mechanical engineering students” [3]. Its development required collaboration among seventeen instructors teaching various disciplines [3]. The program has evolved over the years and is now in its 8th year. The engineering component involves design, prototype building and testing, competition, and assessment. Learning activities include elements related to the attending ethical issues, team dynamics and community knowledge-building. The writing component is divided into two parts: 1) integrated assignments linked to Mech 2 projects in content, delivery, and assessment; 2) generic writing assignments (e.g., summary, definition, process description, research report, business correspondence).

Our approach borrows on an established tradition of integrating writing instruction in engineering education [4, 5, 6]. However, this tradition, though long-standing, is not widespread. Only nine US programs use integrated communication instruction, mainly through team-teaching by communication and engineering instructors [7]. Just 15 US and Canadian programs use a combination of required stand-alone communication courses and integrated instruction [7]. Inspired by recent research in engineering education [8], we aimed to develop an approach that would further be applicable in the global context. Topics related to ethics, intellectual property, copyright and global engineering practice were explored through the use of case-studies and research reports. Subsequent to our field observations, we refined our own teaching practices to foreground the global engineering aspect even more, and to help students learn how to use their rhetorical awareness to make sense of new rhetorical environments (see the list of assignments in Table 1 below).

Table 1: Course Assignments

| Integrated assignments | Generic assignments |
|-------------------------------------|---------------------------------|
| Informal memo-report (Project 1) | Research report on ethics |
| Formal report (Project 2) | Process description |
| Oral presentations (Projects 1 & 2) | Summary |
| Mechanism description (Project 2) | Definition |
| Set of instructions (Project 1) | Business letters (case-studies) |

B. New Genres for Mech 2 Design Activity System

The new integrated course could not be a simple adaptation of APSC 201: Technical Communication, our stand-alone course with generic assignments. (It was developed in 1995 for a multidisciplinary context and continues to be a mandatory course for engineering students in other departments at the Faculty.) We modified APSC 201 to suit the needs of Mech 2 and to promote a more inclusive use of writing that would enable engineering students to draw upon their interest in design projects and their own rhetorical resources. Clearly, this integration created an exciting opportunity to compare the standards, disciplinary values and pedagogical practices of writing instruction and mechanical engineering. We used genre theory and activity theory [9] to decide what genres to assign and teach in Mech 2 in order to meet 1) the course requirements of APSC 201; 2) the design requirements of Mech 2; 4) CEAB graduate attributes [10] (i.e., attributes relevant to technical communication, namely criteria 3.1.6-3.1.12 -- communication skills, individual and teamwork skills, professionalism, ethics and equity, life-long learning). We created rhetorical situations that promoted the use of genres related to the activity system of engineering design. Our writing assignments (both individual and collaborative) were linked to projects that students were undertaking concurrently and assessed in terms of both classroom genres and "real-world" genres of engineering communication. Intensive teamwork was introduced to replicate collaboration that is paramount in the engineering workplace. Collaborative writing requires a lot of shared interaction, decision-making and responsibility [11], so it fits the program well. While we accept the view that it is futile to try to import workplace genres wholesale into the academic world [1] and vice versa, we share the belief that transformation of writing skills (if not transfer) will take place in the workplace [2]. Through this transformation students will be equipped with attitudes, competencies and values that will serve them well in the interconnected world of global engineering.

III. CHALLENGES

Whereas our engineering colleagues claim that all Mech 2 components are fully integrated in content and delivery [3], recent evidence suggests that it is not always the case with the writing component. Firstly, design projects received most of the classroom time; therefore, students saw engineering design as the real focus of the course. Integrated writing assignments (see Table 1) are seen as linked to the design activity system; however, generic APSC 201 assignments are seen as irrelevant because they are not specifically linked to Mech 2 projects. Students see them as extra work necessary only for passing the course. We have received feedback from students that demonstrates lack of appreciation for the value of writing instruction, especially towards generic assignments. We agree with [7] that integration of the writing component with the design activity system might have had the effect of diluting or diminishing the value of writing instruction.

Secondly, discipline-specific communication within the Mech 2 cohort becomes somewhat insular. It is permeated with jargon and technical terms that only insiders understand. We have repeatedly expressed a concern that mechanical engineering graduates might then continue this kind of insular communication in the workplace. To increase audience and genre awareness, we have created a lot of meta-documents where we set standards and require performance: guidelines, course notes, assignment specifications and evaluation rubrics. However, requiring performance is not the same thing as providing instruction. Similar to findings reported by [12], we are concerned that Mech 2 students received less writing instruction than they would in a stand-alone course (APSC 201). Whereas all aspects of technical writing are given full attention in APSC 201, Mech 2 students clearly see generic assignments in the integrated course as an additional activity. Therefore, the intensity of the design activity system in Mech 2 tends to de-emphasize the writing component of the course.

IV. OUTCOMES

Overall, the integration of communication modules into a second-year mechanical engineering curriculum helped to increase students' awareness of certain aspects of writing. Appropriate communicative strategies and common knowledge-building activities led to better teamwork and a larger-scale attitudinal change. Such important outcomes as improved motivation, more ambitious projects, inspiration, increased level of enthusiasm and greater student engagement with learning have been reported [3]. Students' in-class engagement and digital discourse on Vista demonstrate the critical role of community in the creation of knowledge; indeed, the creation of a robust learning community is the major outcome of Mech 2. The program won several awards and was recognized by ASME as one of the best curriculum innovations that foster collaboration in university teaching [3]. Mech 2 has recently been recommended to other engineering departments in the Faculty as a model for integrating writing instruction into an engineering program.

Importantly, over the years we have observed a dramatic five-fold reduction in the percentage of students failing the writing component. Another positive outcome is zero plagiarism which is linked to the fact that Mech 2 projects are always new and not recycled from year to year. Moreover, our students do not just need to produce assignments for their instructors' approval; student teams have an investment in the relationships being mediated by their discourse. Students know that the whole Mech 2 learning community is interested in their work. Therefore, plagiarism stops being an issue. Upon completion of the program students self-report better preparedness for taking upper-level courses. As instructors, we believe that they are likely enabled to reach greater levels of knowledge in senior courses; whether this is indeed the case is a question for further research.

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Work in Progress: Enhancement of Student Learning via Recorded Worked-out Examples and In-Class Team Based Problem Solving

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Abstract—This paper describes our continued work in creating a set of narrated dynamically worked-out problems and the team based in-class problem solving for the Electric Circuits students to improve their problem-solving skills by understanding the key concepts and the way that they should be utilized in solving circuits' problems. The dynamically worked out problems, consists of problem solution annotated with auditory explanations, which students can watch and listen to. The in-class team based problem solving includes students working together, in teams of two, to solve problems that are presented during the lecture and are related to the recorded worked-out problems. The preliminary evaluations of the proposed approach by a group of students and faculty have been very encouraging.

Index Terms—Assessment, Electric Circuits, Multimedia, Problem Solving.

I. INTRODUCTION

In our previous works [1]-[2] we reported that due to the importance of the Electric Circuits course (EE 210) at Penn State's Electrical and Computer Engineering programs, and to address some of the challenges that were reported by students and faculty, we started developing a set of dynamically worked-out problems. We first start with brief background information. Like most other institutions, EE 210 is the first course in electrical engineering and gateway for subsequent EE core courses. Our statistics indicates a direct correlation between strong performance in electric circuits (i.e. B and above) and subsequent success in the follow-up courses in the curriculum. In this regard, our experience with this course, and similar type courses, indicates that the major instructional problem faced by instructors is that students have difficulty knowing where and how to start a given problem as opposed to the mechanics of problem solving. As was reported in [1], in order to address these challenges, we started developing a bank of dynamically worked-out problems, so that students could obtain a greater understanding of the subject matters and increased competency in their ability to analyze basic circuits using the appropriate tools and concepts. The general approach was developed based on step-by-step, expert, think-aloud process to model the details of the problem solving process, and thereby scaffold student problem solving. The worked-out examples focused on:

- Recognizing/identifying the 'type' of problem that is being considered.

- Identifying the tools/laws/concepts that can be used to solve the problem.
- Identifying the most appropriate and efficient approach/tools to solve the problem.
- Setting up the problem given the problem constraints.

While students would obtain the same information through in-class problem solving activities, the intention of this project is to provide the students a supplementary resource that can be used outside of class, while supporting good problem solving skills. Our intention is that students use the supplementary resource either before or following instruction as a way to enhance understanding of the course concepts. In order to reiterate the problem solving approach that was used in worked-out problems, we introduced in-class team based problem solving exercises related to these problems. The presented approach, on one hand, can be considered an enhancement of recorded worked-out problems that can be found on YouTube or publishers' complementary resource sites such as [8]-[9], and on the other hand, a different scaffolding problem solving to achieve deeper learning such as [7].

II. PROPOSED APPROACH

This section briefly describes the approaches that were introduced in [1]-[2] and the modifications that were made or we are planning to make.

In [2], we first tackled the question of number of problems per topic and their relationship. We indicated that depending on the complexity of a subject that is being covered, we designed 1-4 worked-out problems for the topic. A worked-out problem is defined as a detailed solution of a problem, made up of captured annotation with auditory explanation. Next, two other circuits problems along with several multiple-choice questions, related to the worked-out problems were designed. The first circuit problem would be similar to the worked-out problem but with different numerical values. The second circuit problem in the set would again be similar, but more challenging. The multiple-choice questions would correlate to the steps that might be involved in solving the worked-out problem. For example, if a worked-out problem is about maximum power transfer, multiple-choice questions would be related to the relevant power equations/calculations

and Thevenin/Norton equivalent circuits. A more detailed explanation of this structure is provided in the next section.

III. PRODUCTION DETAILS

Production has been done by using Tablet-PC, Microsoft OneNote, and Camtasia [10] for recording the auditory explanation and capturing the annotations. The hypothesized outcome of the narrated engineering problems is the following: Students who listen to and watch the narrated problems will better understand the steps necessary for successful completion. As was reported in our previous work [1], using Tablet-PC in the classroom has provided significant benefits to instructors in the classroom [3]-[6]. While some of the advantages of the Tablet-PC in the lecture format can be duplicated on the chalkboard, students have expressed greater interest and attention in the material when the Tablet-PC is used in the lecture. Production of a worked-out problem takes about 2-4 hours. The process starts with problem selection for a topic, 1-4 problems as stated before. The next step is to solve each problem and identify the key points. The key points will be used for creating multiple-choice questions and identified as points of entry to the video, showing up as links below each video, enabling students to start a video from different scenes. This further emphasizes the key concepts related to a problem, see Table I. At the end of each problem, students are asked to evaluate its usefulness with respect to the intended concepts and problem solving skills. Student feedback will be used to revise the problem solutions as needed to best enhance students' understanding of the material. Each worked-out problem, along with its associated problems, is placed on a separate web page. The aforementioned structure enables students with a wide range of problem solving skills to benefit from our production. Many of the current editions of textbooks come with an accompanying website for students, e.g. [8]-[9]. These websites include recorded worked-out problems for students, which are nicely done, but they lack the flexibility and the emphasis on improving students' problem solving skills. This is the main difference between our approach and the recorded worked-out problems that are available.

IV. A TYPICAL WORKED-OUT PROBLEM

A typical worked-out problem would start by going over the five basic steps of solving a problem, namely, (1) define the problem, (2) present the information related to the problem, (3) discuss the solution steps or alternative solutions, if they exist, and determine the one solution that promises the greatest likelihood of success, (4) work out the problem, and (5) evaluate the solution. The second step would start by identifying the characteristic of the problem that would help students to identify the right tool or approach for solving the problem. The third step will include discussion of alternative approaches, if they exist, and possible pit falls. Students are then encouraged to stop the video and attempt to solve the problem and compare their answer(s) with a provided answer key. Next segment of the video provides a step-by-step solution of the problem. Each video production includes links

to these steps and the main points that are used in solving the problem. As mentioned, Table I illustrates this concept; each description is a link to a specific part of the video that students can go to and start watching the part that they need help with.

V. IN-CLASS TEAM BASED PROBLEM SOLVING

In order to reiterate the key concepts in solving electric circuits problems and encourage students to take advantage of the dynamically worked-out problems, we introduced in-class team based problem solving exercises. These exercises were identical or very similar to the produced recorded solved problems. To motivate students to review the problems before the lecture, bonus points were awarded to the first group that would come up with the right answer during the class. This part is the major addition to our previous works [1]-[2].

VI. MEASURING PROJECT SUCCESS

A set of ten video worked-out problems, along with their associated problems, have been evaluated by a limited number of students, faculty, and teaching assistance. General comments from all three groups have been very positive and encouraging. Summary of these comments will be presented at the conference.

VII. DISSEMINATION PLAN

The dynamically worked-out problems, follow up surveys, and evaluations were made accessible and conducted via ANGEL (A New Global Environment for Learning) [11].

CONCLUSION

Based on our collected data, which will be published in details in near future, we believe that recorded worked-out problems can improve student learning and could be enhanced to promote and achieve deeper learning, by incorporating the approach outlined in this work

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TABLE I
DETAILED TIMELINE OF AN EXAMPLE (MAX-POWER TRANSFER)

| Time (min) | Description |
|---------------|--|
| 0:00 – 1:14 | Explaining the problem and what is asked |
| 1:15 – 2:29 | Explaining how to find Max Power Transfer |
| 2:30 – 3:20 | General Explanation of solving Thevenin |
| 3:20 – 6:00 | How to solve Different Thevenin Problems |
| 6:01 – 6:50 | The Thevenin approach that will be used here |
| 6:51 – 8:30 | Details of the Thevenin Circuit used here |
| 8:30 – 13:56 | Mesh Equations needed for solving V_{TH} |
| 13:57 – 15:04 | Solution for Mesh Currents needed for V_{TH} |
| 15:05 – 16:14 | Solving for V_{TH} |
| 16:15 – 20:35 | Thevenin Calculation |
| 20:00–20:17 | I_{SC} |
| 20:17–20:20 | R_{TH} |
| 20:36 – 20:58 | Thevenin Circuit |
| 20:59 – 22:02 | Max Power Transfer Calculation |

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Team Learning

Developing interdisciplinary project teams

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Abstract—Teachers of STEM students and employers of graduates recognize that success in many professions requires effective multi-disciplinary team performance. While there is abundant evidence that having "diversity" on a team can contribute to greater creativity and innovation, it is not clear how a group of individuals come to function as a team or how they learn from one other [1,2]. To better understand how university students learn in multi-disciplinary teams, 256 undergraduate students participating in teams in the spring of 2010 at a Midwest university were studied. Data collection included self-reported efficacy for cross-disciplinary team learning (CDTL), as well as self-reported attitudes toward team processes and outcomes, and individual characteristics. During the course of the semester, overall self-efficacy for CDTL increased across all respondents. However, a large number of individual students also displayed decreases in self-efficacy from the beginning to the end of the semester. A previously developed framework for CDTL [2] was further tested and modified as part of this study. Individuals with a high "identity" score at the start of the semester tended to report a smaller increase in this score at the end semester, probably for two reasons: they had less room for improvement, and greater likelihood of overestimating their abilities at the start. Several other findings related to team processes and characteristics were identified and will be discussed.

Keywords: *multi-disciplinary teams; cross-disciplinary; self-efficacy*

I. INTRODUCTION

Hundreds of research studies have collectively identified the major dimensions of team functioning and effectiveness and it has been concluded that structural and compositional aspects of teams account for most of the variance in performance. In contrast, research related to team and organizational learning has emphasized how interpersonal and cognitive factors including beliefs about interactions influence effectiveness. These research streams have guided the current cross-disciplinary learning study. The current emphasis on developing a *cross-disciplinary* perspective as one of the desired outcomes of working on a multidisciplinary team presents significant challenges in university project design settings [1]. There is a substantial difference between working on a team where each person "takes on" the expertise related to their discipline, but has minimal interaction with others, and a team where members actually listen and learn from each other, and can appreciate the assumptions and pressures involved within the practice of other disciplines. This shift from multidisciplinary to interdisciplinarity implies that team members really understand enough of the technical terms, models of reality, and constraints to use that knowledge in their

own thinking about complex problems. Furthermore, the communication between team members is thought to be transformative as opposed to transactional, and new ways of learning and knowing are created as part of the process of interacting with others (Pea, 1994). While there is abundant evidence that having “diversity” on a team usually contributes to greater creativity and performance it is not clear how a group of individuals come to function as a team or how they learn from one other. Schaffer, Lei & Reyes (2008) developed a measure of cross-disciplinary team learning, based on the work of Fruchter & Emery (1999), assessing the extent to which team members related to each other as colleagues on a multi-disciplinary team, or felt comfortable with using the vocabulary, conceptual frameworks, and “constraints” embedded in each of the disciplines represented in their team. It was concluded that most of the undergraduate student teams assessed had not evolved from a multidisciplinary to interdisciplinary state during projects.

One effective way to measure students’ psychological perspectives in a team environment is to measure their self-efficacy for performing design tasks (Carberry & Lee, 2010). The theoretical framework for self-efficacy developed by Bandura (1977, 1982, 1986) highlights the role of self-referent thought in guiding human action and change. Students’ self-reported confidence level in working and learning with team members from different disciplines theoretically reflects belief in their ability to engage in such teams. According to Bandura’s model, behavior changes achieved through methods such as guided exposure, modeling, persuasion, and anxiety reduction, are in part the result of creating or strengthening one’s efficacy expectations. Self-efficacy has been hypothesized to influence choice of behavioral activities, effort expenditure, persistence in the face of obstacles, and task performance (Brown & Lent, 1991). It has been measured in many contexts and is typically related to specific skills and abilities related to performance (Eccles & Wigfield, 2002; Schunk, 1994; Stone & Bailey, 2007). Prior research on students’ self-efficacy in project-based learning environment suggests that the quality of project-based learning experiences impacts students’ self-efficacy (Dunlap, 2005). Positive experiences will lead to an increase of self-efficacy, while stress or fearful experiences will lead to a reduction of self-efficacy. However, it is not clear from the literature how project based learning environments impact learner efficacy for cross-disciplinary learning in the undergraduate education context. The current study is intended to address two research questions: 1) Does self-efficacy for CDTL change over the course of a semester? 2) What factors influence this change?

Self-efficacy has been defined in many contexts, and it is often linked to specific skills and abilities (Eccles & Wigfield, 2002; Schunk, 1994; Stone & Bailey, 2007). Existing research suggests that both individual level factors and team context may potentially influence the extent to which individual acquire technical knowledge as well general understanding and skills related to working with people from different disciplinary background. We consider four individual characteristics (gender, GPA, year in college, and prior

experience with teams), four team context variables (team size, task characteristics, team composition including demographic diversity and disciplinary diversity) that may potentially influence learning and self-efficacy, and one team process variable, namely, CDTL behavior.

II. METHODS

Participants were undergraduate students in a service learning program at a Midwestern university. Service-learning is an experiential instructional approach that provides the opportunity to apply knowledge and skills in authentic, real-world environments (Lindsey & Berger, 2009). Purposive sampling (Patton, 1980) was used in this study. Participants were selected on the basis of their commonness (they were typical cases), and convenience (they were students registered in a project-based learning program). Students participated in this program for one or two academic credits, and were assigned to a team based on stated interests or selected by an existing team based on needs. Teams consisted of a mix of freshmen, sophomores, juniors, and seniors, with many majoring in non-engineering fields such as education, technology, liberal arts, science, and consumer and family sciences. In general, students were expected to participate on the team and contribute to one or more projects for at least two consecutive semesters on campus. Three hundred and three students enrolled in the program in the 2010 spring semester on a total of 27 teams.

Questionnaires were administered at two points in time via paper and pencil, and it took about 10 to 15 minutes to complete each. Nearly all 303 students received the surveys and their participation was voluntary. The first efficacy for CDTL questionnaire was administered during week 4 when the project teams were newly formed (T1). This survey included questions regarding students’ educational and demographic background (e.g. gender, age, year in school, major and GPA), prior experience with teams, and efficacy for CDTL. The post-efficacy for CDTL questionnaire was administered at the end of the semester at week 15 (T2). In addition, the post-survey examined characteristics of the task and intra-team learning behaviors. 178 students filled out the pre-survey, while 191 responded to the post-survey. In total, 256 students from 60 teams responded to at least one survey, out of which, 112 from 34 teams responded to both. We also collected information on the college and major of the participants from archival records provided by the service learning program.

III. RESULTS

There are two major findings of this study: first, the change from pre to post survey self-efficacy change is significant; secondly, researchers of this study identified several key team variables that might influence students’ self-efficacy change.

We tested 8 models on the team variables, and we find out that 1) individuals with a high identification score at T1 tend to report a smaller increase (or larger decrease) in their identification score at the end of the project, probably for two

reasons: They have less room for improvement, and greater likelihood of over estimating their ability at the beginning of the project; 2) compared to females, males tend to report a smaller increase in their identification score over the semester. Individuals with higher GPA tend to report a slightly greater increase in their identification score from the beginning to the end of the project; 3) we found that team size have a significant negative impact on change from the beginning to the end of the project. Teams with more members tend to report a smaller increase in the team's average identification score. Tasks that involve more design stages are also associated with a smaller positive change in team average identification score. Both proportion of males and the number of disciplines in the team is significant at 0.1, and both are negatively associated with increases in team's average identification score from the beginning to the end of the project; 4) when we include all team level variables, only the number of design stages involved in team tasks is significant at 0.1, while all other team level variables become insignificant. Students that are more senior tend to report a larger increase in their identification score from T1 to T2. We also found out that gender becomes insignificant when team level variables are controlled.

IV. IMPLICATIONS OF RESEARCH TO PRACTICE

Based on the findings of the study, we were able to better understand how the team environment influences team member levels of self-efficacy for learning in multidisciplinary teams. Some implications that form the basis for recommendations to guide practice include:

- 1) *Organize the teams with male and female students balance*
- 2) *Organize the teams with no more than three disciplines*
- 3) *Organize the teams with mixture of students from different years in college*

4) *Examine methods to formatively assess levels of identification, formation, and integration as defined in the validated CDTL model.*

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Work in Progress: Leadership Emergence among Groups in an Online Environment

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Abstract - Virtual learning is a growing means of expansion for both courses and programs for numerous colleges. As the popularity of online courses and programs increases, the question of ensuring “excellence” often follows particularly when discussing curriculum concerns. Certifying online instruction presents challenges especially with regard to traditional methods such as that of group work. One factor that assists groups or teams with their work is that of leadership. Often, in more traditional classroom settings, group leaders are selected by the team after several meetings. How then is the selection and the determination of a leader established in online groups? Is the process similar or different? Does an online group share the same experiences in regard to leadership as a face-to-face group? These questions assisted in directing a two year study at the School of Engineering and Technology at Indiana University-Purdue University Indianapolis (IUPUI) that sought to determine how leader emergence is realized in one online course, International Management, in which a group project has been assigned in place of the final exam. The goal of our project is to not only better understand the process of leader selection in group work, but to help guide faculty in developing an online learning that will enhance and promote student engagement. There are several steps to be performed in our project and this work-in-progress paper will outline those steps and our progress to date.

Learning Management System, Online Groups, Leader Emergence

I. INTRODUCTION

With the growth in popularity of both online courses and programs, curriculum issues persist, especially in regard to the integrity comparable to those same courses that are taught face-to-face (F2F). Part of the issue remains about the perceived limitations that online courses may have in a learning management system. A great deal of courses are taught in an asynchronous environment for the convenience of students due to family obligations and work schedules, while still others mix in elements of weekly or bi-weekly real-time chats to help provide the one-on-one interaction students crave.

As instructors try to find the perfect balance to interaction within the courses they teach online, they also deliberate the appropriate assessments for their courses as well. One particular method more often preferred in face-to-face instruction than that of online instruction is that of group work. Group projects present challenges to both students and

instructors in any environment based on one particular factor: leadership. In the more traditional face-to-face setting, students would elect or choose their group leader amongst themselves once they have met together for at least a couple of class sessions. But in an online setting, and in especially an asynchronous environment, this can be difficult. This quandary led researchers to explore this topic with the launch of a two year study at the School of Engineering and Technology at Indiana University-Purdue University Indianapolis (IUPUI) that sought to determine how leader emergence is realized in one online course, International Management, in which a group project has been assigned in place of the final exam. Three main questions guided the research including: (1) How is the selection and the determination of a leader established in online groups? (2) Is the process similar or different than face-to-face courses? (3) And finally does an online group share the same experiences in regard to leadership as a face-to-face group?

II. FRAMEWORK

Researchers focused on several key terms and concepts examining what previous research had already defined to provide a better understanding of the context the study encompassed.

Within a learning management system (LMS), collaboration is an important element that can be very beneficial to students in regards to engagement within the group work. Harasim, Hiltz, Teles, and Turoff define collaboration as "... any activity that in which two or more people work together to create meaning, explore a topic, or improve skills" [1]. Collaboration used in a LMS environment should be viewed as "an essential ingredient in the recipe to create an 'effective learning environment' as it provides learners with the opportunity to discuss, argue, negotiate and reflect upon existing beliefs and knowledge. The learner is "involved in constructing knowledge through a process of discussion and interaction with learning peers and experts" [2]. This is an essential element then in engagement, and more specifically, within a group project used as an assessment in an online course.

Leadership has long been determined to be found in the situation with certain leader behaviors emerging dependent upon the situation [3]. One of the earliest researchers to study

emergent leadership within a group setting was Robert F. Bales. Working with various colleagues on several studies Bales concluded that emergent leaders within a group environment primarily demonstrated two types of behavior: task-focused and socio-emotional [4], [5], [6]. So then we anticipate that an emergent leader within a group will keep their group focused on the goal at hand, while at the same time consciously tending to the social or emotional concerns and needs of the group. Several researchers since Bales have not only confirmed this early discovery [7], but also provided further advancement of the work in the areas of member development, idea cultivation, and support [8], [9], [10].

With this structure in mind, we examine leader emergence as one inclusive to teamwork that is goal driven with the creation of trust amongst members.

III. THE PROJECT

Since our larger goals for this project are to better understand leader emergence in regard to group work within online courses in a learning management system, we must complete several stages in order to reach a final recommendation on elements crucial to the project goals.

Our project is divided into the following four stages:

1. The development of the group project within the selected course, International Management.
2. The launch of the first group project within the International Management online course, fall 2011, with follow-up student survey.
3. The continued assigning of the group project each semester the online course, International Management, is taught between fall 2011 and fall 2013, with follow-up student survey.
4. The final comparison of survey results and student remarks with final recommendations

Stage One was completed last summer 2011 as the class was reassigned to one of the researchers at the School of Engineering and Technology at IUPUI, and the project subsequently planned. For students, the group project consists of the creation of an International Management Business Proposal, consisting of both a written paper and PowerPoint presentation that are turned in at the end of the course. Each student group is assigned their own chat room within the LMS so that they can freely interact whenever most convenient for them. Milestone assignments are set by the instructor to aid the groups in the completion of the task. A "communication" leader is established early in the process as liaison between the group and the instructor; but researchers intend to discover if this same person truly leads the group throughout the entire project or another leader emerges as groups are given the option to change leaders at one point. Finally, a survey is administered at the end of the course with results provided and summarized from all the courses studied in Stage Four of the project.

Fall 2011 observed the completion of Stage Two as the first initial group project within the course was launched. A

total of six groups, each with four student members, occurred. A 10% total response rate to the survey was received from the students as no incentive was given and the approach of the holidays limited response time. Those early results though indicated that a different leader had emerged and that groups experienced similar issues to their F2F counterparts in regards to finding time to meet for the project. Students also expressed that in their opinion, an online group project was more challenging to complete than that of a group project in a traditional F2F course, and as a result they preferred not to have them assigned in online courses.

Stage Three will continue with the scheduled course, International Management, through the end of 2013. The next scheduled sessions will be held in summer and fall 2012.

A final comparison of all results and remarks will conclude during Stage Four, providing researchers with a small-scale example of emergent leadership within online groups to reach a final recommendation.

IV. FINAL REMARKS

As Stages One and Two are now complete, researchers are anxious to continue with the project through the final stages to see if the early results are consistent throughout the project. Researchers are also hopeful that the additional sets of results will continue to reveal details to assist them in answering the research questions posed by the study.

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Present@: A Virtual Environment for Dissertation Defense

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Abstract— At the end of their technical studies, students have to present a final project in order to finish their degree. With this project, students prove that they have got all of the competences they should have acquired. Some competencies, such as the ability to communicate orally or the ability to argue may be evaluated during a face-to-face dissertation defense, but how to translate this evaluation scenario to a virtual environment is a challenge. This paper faces the problem of presenting dissertations in a virtual environment, to evaluate the aforementioned competences. The solution proposed, called Present@, is focused in teaching and technical dimensions, and is complemented with some materials and tutorials that help students to acquire those competences. Therefore, the paper shows Present@ as a solution to the problems that virtual universities have to face when dealing with the evaluation of final degree projects and particularly in their defense. Present@ has been tested over 131 students during six semesters and the results show that it actually helps students to acquire the desired competences in virtual environments. In addition, the analysis about the use of the tool has denoted that videos are an efficient mechanism to evaluate the ability to communicate of students and to work on transversal competencies. Some students also commented that the use of videos make the dissertation defense more natural and closer to face-to-face environments.

Final degree project, virtual dissertation, presentation

I. INTRODUCTION

At the end of their technical studies, students have to present a final project in order to finish their degree. With this project, students prove that they have got all of the competences they should have acquired. Many students are able to develop very good engineering projects, where they show their technical abilities and a dominion of the technical competences acquired during their studies. However, a degree project is not only focused on technical competences, but also

on transversal ones, such as the ability to write and present effectively. These transversal competencies are usually evaluated during the face-to-face dissertation defense of students, but how to translate this evaluation scenario to a virtual environment?

In e-Learning environments multimedia resources are being extensively used to support the student learning, however, the resources students produce during their learning activity are mostly textual. This makes it difficult to assess some transversal competencies that students have to learn; mostly the ones related to oral expression [1] and argumentation [2]. This problem has been addressed by different works to support oral presentations. Some examples are [3][4], which are focused to support oral expression in English for non-English speakers students; [5], on the other hand, shows an environment that is used to teach PhD students to make presentations. It is important to note that actual approaches to that problem are more focused to the methodology than to the technology since, nowadays, the sophistication of learning management systems efficiently supports the use of multimedia resources.

This paper faces the problem of presenting dissertations in a virtual environment, in a way that allows evaluating transversal competences. The solution proposed consists in that students make a video presentation, upload it to a web within the context of the classroom, and answer questions from both the evaluators and their partners, also within this web space. To be successful, the problem is faced from three dimensions: teaching, understood as giving instructions on how to acquire those competences; learning, understood as how students manage to acquire those competences; and technical, understood as offering students the software they need. Thus, some learning resources are given to students explaining how to make effective presentations (teaching dimension); and a tool has been developed, named Present@, that allows students to upload their videos and develop, in the same place, the virtual debate (technical dimension). The proposal has been evaluated by using questionnaires. The paper presents some results about the application of this solution over 100 dissertation defenses in the Computer Engineering grades offered by Universitat Oberta de Catalunya (UOC), a virtual university, during the last three years.

From the analysis of the results it can be concluded that: 1) Students actually face the objective competences, since in the open questions they highlight aspects like making oral and visual presentations, sharing them, and the stress of answering

to partners and members of the tribunal; 2) time dimension should be taken into account, since students complain about the time they have to invest to make the presentations; but also complain about the little time they have to enjoy the virtual debate; and 3) students evaluate positively the changes introduced in the project dissertation. From all these items we conclude that the changes introduced in the final degree project (FDP) actually help students to acquire the competences related with final project dissertation in virtual environments. Nevertheless, some improvements should be made, mainly in the technical and teaching dimension.

The paper is structured as follows. Section two defines the context of the problem to solve (the virtual university where Present@ has been integrated), what a dissertation defense is, the difference between dissertation defenses in virtual and face to face (F2F) universities, and the lack of dissertation defenses in virtual universities. Later, third section deals with Present@, which is the proposed approach to support all the necessary functionalities of the virtual defense. Thereafter, some analysis about the use of Present@ during the last two years and over 100 students is presented in order to evaluate its usefulness. Finally, a brief discussion and conclusions are presented.

II. DISSERTATION DEFENSE: WHAT IS IT AND HOW IT IS CONDUCTED IN VIRTUAL AND FACE TO FACE UNIVERSITIES

A. *The Context: The Virtual Univesrity*

The UOC is the main virtual university in Spain, with over 45,000 students. The UOC corresponds to a 100% online learning university that focuses in the asynchrony in time and space, meaning that teachers and students neither meet in time nor in space. The UOC's Virtual Campus has been the medium through which students and lecturers have communicated ever since the university was founded in 1994. The Virtual Campus has virtual classrooms, where the subjects are taught. Each classroom has a communication facility that enables lecturers to guide learning activities and students to ask questions. The communication facility uses forums and bulletin boards to record the messages that classroom users (lecturers and students) exchange with each other.

The profile of UOC students differs from the profile of F2F university students. UOC students choose this university, among other reasons, because of the virtual environment and the asynchrony, which allow them to combine work, family and studies.

B. *The Problem: Disertation Defense in Virtual Environments*

We are therefore in a context that deviates from traditional patterns [6] and, of course, also affects the completion of FDP. In particular, at UOC various students deal with the same FDP and it has to be delivered at the end of the semester. There are many universities where the project is unique for each student and the student decides when to deliver it. The UOC model leads to a situation where students have passed all other subjects but the FDP, because they are working part or full time and never find time to finish FDP. The fact that different students work on the same project, facilitates the comparison of

results from several students and it even makes possible to suggest bigger collaborative projects where every single student deals with a given part.

It is important also to take into account that the communication between students and teachers is through e-mail within the Virtual Campus context and there is no compulsory personal contact between teachers and students, since they can both live abroad (for example, a teacher can live in Hong Kong and the student in Buenos Aires).

As stated before, in some cases FDP are developed in groups. In these projects a group of students works on different parts of a project under the guidance of the teacher who directs and coordinates the project. Eventually each student submits his/her own deliverables, for the part that he or she is responsible. With this type of project two objectives are accomplished: firstly, to tackle more ambitious goals, and secondly, to learn and practice virtual teamwork techniques within major projects.

At the end, every student has to deliver a report of the personal part of the project as well as a visual presentation. In this scenario virtual students acquire or improve their competences in writing and communicating in virtual environments, in project management, and in some projects, also team work techniques. So, these are some advantages of the FDP at UOC, but there are also some disadvantages, mainly regarding the virtual presentation of the FDP, as we will show in next sections.

C. *Dissertation Defense in Face to Face Universities*

Presentation defense is a usual procedure in most of the universities. Even though there are some differences, there are some common features::

- There is a committee, usually consisting of at least three people. It is advisable that they should be experts on the topic. At some universities, the advisor is also a member of the committee.
- The student writes a report of his/her work, and submits it to the members of the committee.
- The student presents his/her work in an oral presentation during about 30 minutes. Thereafter, the members of the committee make questions in order to clarify some aspects of the work as well as to evaluate the students' knowledge about the topic.
- After the presentation, the committee qualifies the final degree project.

Regarding the oral presentation, the students who pass the final degree project have worked the following competences:

1. Synthesizing their work in a presentation which has time limits.
2. Speaking in public.
3. Making oral and visual presentations.
4. Facing questions about their own work in a stressful situation (argumentation).

All these competencies are really important in a professional environment since a large amount of the work of most of the technical professionals consists in preparing and presenting projects.

D. Dissertation Defense in Virtual Universities: the Case of the UOC

UOC is an on-line asynchronous university and, when dealing with the FDP the question that arises is: how can students at UOC get all the competences regarding the FDP that students in F2F universities develop?

Until the presented work was deployed, the students made a presentation document, with 20 slides maximum, "to be read and not to be presented". Students used to prepare the document using Power Point®, libreOffice[7] or Prezzi [8]. The document should be delivered at the end of the project together with the project report. A few days later, there is a virtual debate in which the members of the committee send their questions to the student by email and the student has to answer in less than 24 hours.

With this method students could address competences 1 (synthesizing) and 4 (argumentation), but not competences 2 (speaking in public) and 3 (presenting). In addition, competencies about synthesizing and argumentation are not fully addressed because it is not the same to synthesize the work in a number of written slides than in an oral presentation, which includes slides as well as a speech. The same happens with fourth competency because answering questions in a face to face presentation with audience increases the stress and is more difficult than doing so from home. Furthermore, students have to deal with a contradiction because "a presentation to be read and not to be presented" is unnatural.

Thus, we faced a situation that started from a contradiction and was not able to deal with all the competences that have to be faced in a final degree project. In the next section it will be shown how to overcome these limitations.

III. A VIRTUAL ENVIRONMENT FOR DISSERTATION DEFENSE

At this point we have already stated the problems faced by FDP presentations in online environments, regarding the main competences the students should address in this exercise. To overcome these problems, a solution has been proposed and tested during several semesters at UOC so that virtual students could acquire the competences related with presentations.

The solution consists on applying several actions, which are grouped in 3 dimensions:

- Teaching dimension: students receive a document explaining how to prepare effective presentations and how to write technical documents correctly [9].
- Learning dimension: students elaborate a video presentation shorter than 20 minutes.
- Technical dimension: a web application integrated in the Virtual Campus has been developed so that students can: 1) upload their presentation file; 2) see and comment about their partners' presentations; and

3) answer the questions from the committee. This web makes the presentation, questions and answers available to other students and teachers.

Regarding the learning dimension, students can use any available software in order to make their presentation, although teachers make some suggestions (see Section IV.B for more information about the tools used by students).

This method could allow virtual students to face all the competences that should have to be acquired in a final degree project. In particular, learning dimension allows addressing competences 1 (ability of synthesizing their work in a presentation which is limited in time) and 3 (ability of making oral and visual presentations), teaching dimensions give the basic knowledge to students to address successfully competencies 1 and 3, and technical dimension allows facing competence 2 (ability of speaking in public), although in a restricted way; and competence 4 (ability of facing questions in an stressful situation). The new proposed system also avoids the contradiction of a "presentation to be read".

Present@ is a tool that has been created to support the participants in the dissertation defense during the dissertation defense. Therefore, it can be seen as an integrated tool that allows:

1. Upload the deliverables of the FDP: including the documentation of the project and the presentation in a video format,
2. Download and visualize the deliverables of the FDP: the access to the documents will be restricted to the students who have made the same (or similar) project and the members of the committee, and
3. Conduct the debate: the system has a communication space where the members of the committee can make questions and students can answer such questions within the time limit.

Sharing the same space with students that have made similar (or the same) projects allow making more interesting and fruitful virtual debates. In some cases teachers may allow that students with similar projects participate in the virtual debate to make questions to their colleagues. We have found that, when allowed, students tend to make questions to other students with similar projects in order to discover alternatives of implementation or how to make something that they have not been able to do.

Present@ has been created by reusing a Wordpress blog with some new developments and pluggins that allow connecting it with a video streaming server and integrate it within the UOC virtual campus using a single sign-on. There are some software systems that could be used instead of Present@, but the necessity to integrate the environment in the Virtual campus of the UOC and the fact that the dissertation defense is asynchronous advised the creation of a new tool.

In Figure 1 the main page of Present@ is shown. It offers the list of videos uploaded, which can be ordered according to author name and surname, title, labels, status, license and comments. It is important to note that the number of comments in red indicates the unread comments. So it is very useful to

committee members in order to see whether there is any new answer of a student, or to students to find out if there are new questions for them. Another useful functionality is to download all the videos in a single zip file, which will facilitate to store and visualize them anywhere and using any kind of device.



Figure 1. Main page of Present@.

When clicking on a video file, the video page is accessed. There, information about the video is presented, the video can be visualized and comments can be added. Since the purpose of this system is to help in the dissertation defense, the comments allowed in this page are only questions of the committee's members (or from other students when allowed) and answers of students to such questions.

It is important to note that this tool is useful for students of any discipline, making it a relevant tool for virtual environments. Also comment that the created tool is fully integrated to the virtual campus, taking profit of the security control of the virtual campus, and has been designed to be used in any platform and web broser.

IV. THE USE OF PRESENT@ IN THE LAST 6 SEMESTERS

The proposed approach has been tested during 6 semesters and 131 students have been questioned about the several items introduced: teaching documentation, preparing a video-presentation and the software tool. In this section results from the questionnaires are presented. Due to space constraints we summarize the results of teaching and learning dimension and give more details about the experiences of the tool created to deal with the technical dimension.

A. Teaching Dimension: The Teaching Material

The students were asked about the usefulness and the completeness of the materials that explain how to write technical deliverables and how to make effective oral presentations. From the answers of students we conclude that the teaching material fits the main aspects expected by students, but actually lack a bit more of information about how to make visual presentations both technically and conceptually.

B. Learning Dimension: Making Visual Presentations

The second item evaluated is the elaboration of visual presentations. The students were asked about the software used

to create presentations and why such software was selected, the experience of creating visual presentations, and what would they improve.

Regarding the software used to create the visual presentations, the most used software was Camtasia Studio [10], which was employed by 80% of the students. Other software used were CamStudio (9%)[11], and, with no more than 1%-2% of users: FireScreen, Quicktime [12], FlexBuilder [13], Windows Movie Maker [14], iMovie [15], PresenterSoftPower VideoMaker [16] and RecordMyDesktop [17]. The main reasons the students give to choose Camtasia Studio were that they find it easy to learn; and find the post-edition capabilities that the software offers both important and time-saving. Students also commented that, even though it is commercial, there is a 30 days trial license, which is time enough for students to elaborate their presentation.

The next set of questions refers to preparing the presentation. It is important to note that 25% of students already created visual presentations before. Most students found easy to make a visual presentation (74%); only 6% of students said that it was difficult.

The 93% of students find the experience of making a visual presentation enriching and 92% of them said that they will create this kind of presentations in the future to transmit their ideas. However, the students were not completely convinced about the necessity of using this kind of presentation in the FDP, in fact only the 51% preferred a visual presentation.

The students were also asked, using open questions, about the best and the worst aspects of making visual presentations. Regarding the best aspects, 57% of the students gave answers regarding their personal enrichment, preparation and experience (even professional experience). 29% emphasize the technical aspect, since they say that the best is learning to use the software, including, edition and post-edition tools. There are a 9% of the students that compare with F2F situations and say that thanks to the video presentations, F2F and virtual experiences are very close. We find also about 4% of the students that highlight the possibilities of webcasting. Finally, we found about 3% of the students that see nothing positive in this kind of presentations.

About the worst aspect of doing visual presentations 30% of the students complained about time: they have to invest extra time to learn new software, as it requires more time to prepare a video-presentation than a "presentation to be read"; also, they would like to have more time in order to get a better result, for instance they would prefer longer presentations (over 20 minutes) and save time in reducing the duration of the presentation. 22% of the students complain about hearing themselves in the video and a 5% complain about scripting capabilities. This item also affects the technical dimension since 17% complains about the software itself, mainly because of the problems with audio level, and the time consumed by testing several software; and 12% complain about the problems to reduce the size of the video file in order to upload it. Only 3% of the students found that nothing has to be improved.

At the end the 90% of students considered that they learnt how to make better presentations.

C. Technical Dimension: Present@

The last two semesters the new tool Present@, version 2 was introduced and 33 students were asked explicitly about this tool. The questions and answers given are:

- *What is the students' opinion about Present@?*
Answers go between 1 (bad) until 5 (very good). 88% of the students answered between 3 and 5 and 55% between 4 and 5. No student marked 1.
 - *What do students liked more?*
 - 48% answered simplicity.
 - 48% answered the possibility of commenting the work from their colleagues and seeing everything at the same place: videos from partners, comments, virtual debate, etc.
- The rest of students highlighted the possibilities offered by the tool.
- *What do students liked less, and what should have to be improved.* In fact, these were two questions but answers were so related that results can be presented together. The answers from students were:
 - 47% complain about technical problems, mainly when uploading the video.
 - 21% criticize about the poor format of the comments, the few flexibility of its editor and the lack of an automatic notification of new comments (similar to a RSS syndication).
 - 16% of the students say that everything is O.K. and would introduce no improvement.
 - 12% complain about usability
 - The rest of students suggest that the tool should have to be more used within UOC.
 - *Do students recommend the tool in future semesters?*
The answer to this question is "yes" from all students but one.

From these results we conclude that students have a good opinion about the tool, although some technical improvements should have to be developed, mainly in the uploading and commenting elements.

V. CONTRIBUTION

From the experience of the Present@ environment during the last 6 semesters, which has been summarized and analyzed in the previous section, we have seen that the new approximation really supports final degree project dissertations, satisfy the students in the process and helps them to address transversal competencies that were not addressed with the former environment.

In the following points we enumerate the competencies that can be evaluated and addressed using Present@. For each competence, we add some complains from students that denote

that they have to excel themselves in such competence in order to achieve the expected results:

- Ability to synthesize the work done in a presentation limited in time: some complains from students about time constraints show that they have to work hard to acquire this competence.
- Ability to speak in public: once again, comments of students about virtual debate, where they emphasize that can comment and receive comments from the rest of the partners, show that they actually work this competence.
- Ability of making oral and visual presentations: complains from students about how to make oral and visual presentations show, once again, that this competence is actually worked.
- Ability of facing questions about their own work in an stress situation: once again, comments from students about the importance of questions from the members of the committee as well as their partners, combined with complains about time, and some comments about stress, show that this competence is also worked.

We believe that the defense process used in Present@ is more natural and closer to the defense process performed in F2F universities. This fact, together with the fact that it allows addressing more transversal competencies, demonstrates that Present@ environment is a useful environment for virtual universities to deal with dissertation defenses. In addition, in the case of the UOC, Present@ clearly improves the former environment.

It is also important to note the good acceptance Present@ had in students, as can be seen in previous section. Unfortunately, no questionnaires have been sent to teachers. But from some private interviews with teachers who have used the environment, it seems that they also find the tool useful. However, as a negative aspect they said that in the new environment they need to spend more time to evaluate each student. This is because with Present@ they have to visualize a video presentation for each student, which takes around 20 minutes, while before they had to read a presentation, which could take less than 5 minutes.

The innovation of the presented approach is not only in the developed environment, but also in the integration of the three dimensions. Therefore, a similar environment may be created and used in other environments using other software able to manage video files, such as Blackboard or eCollege. In fact, regarding the management of video files, the functionalities provided for some other learning management systems may exceed the ones implemented in Present@.

Another contribution of this work is the information that has been extracted from the questionnaires done to students, which has been summarized in the previous section. Such information is being used in order to improve the environment and the related resources. On the one hand, new functionalities are being developed in order to facilitate the upload of videos. Some improvements are also being done to the functionalities related to the debate by both improving the discussion

visualization and allowing to create multimedia comments (audio, video and text). On the other hand, more support have been provided by creating new tutorials that explain how to use the most popular tools and a new book is being created explaining how to make an effective video presentation taking into account the comments of the users.

VI. CONCLUSIONS AND FURTHER WORK

In this paper it is shown a solution to the problems that virtual universities have to face when dealing with final project dissertations. It is especially difficult to face competences regarding speaking in public or making oral and visual presentations.

The solution proposed consists in that students have to make a video presentation, upload it to a public web within the context of the classroom, and answer questions from the committee as well as from fellow students. In order to be successful, the problem is addressed from three dimensions: teaching, understood as giving students instructions on how to acquire those competences; learning, understood as how students manage to acquire those competences; and technical, understood as offering students the software they need.

Thus, some documents are given to students explaining how to make effective and efficient presentations (teaching dimension); and a tool has been developed, named Present@, that allow students to upload their videos and develop, in the same place, the virtual debate (technical dimension).

The proposed approach has been tested during 6 semesters and 131 students have been questioned about the several items introduced by this software: teaching documentation and preparing a video-presentation. From the analysis of the results it can be concluded that:

- Students actually work the desired competences, since in the open questions they highlight aspects like making oral and visual presentations, sharing them, and complain about the stress of answering to partners and members of the tribunal.
- The time dimension should have to be taken into account, since students complain about the amount of time they have to invest to make the presentations; but also complain about the short time they have to enjoy the virtual debate.
- Students evaluate positively the changes introduced in the final degree project dissertation.
- Some technical improvements should have to be introduced in Present@ in the uploading and commenting elements.

From all these items we conclude that the changes introduced in the final degree project actually help students to acquire the competences related with final project dissertation in virtual environments. Nevertheless, some improvements should have to be made, mainly in the technical and teaching dimension.

In addition, Present@ has revealed itself as a very useful tool to communicate and we are starting to use it as a video repository in a similar way to [18]. The repository is located within the classrooms, where teacher makes short explanations and students can ask questions and comment about them.

ACKNOWLEDGMENT

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Infusion of ABET–specified Professional and Academic Content into Off-campus Work Experiences via Distance Learning Modules

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Abstract— Educating engineering students on ABET-required professional and nontechnical skills is usually a challenging task. The related challenges include finding a balance between the content, the delivery format, the time of delivery, and location in the curriculum for this material. This paper presents details on a pilot project to deliver professional and academic content to engineering students via distance learning during required co-op semesters. Assessment of this experience to solve multiple challenges simultaneously is also presented. Students were educated on engineering ethics, engineering economics, and project management, which are readily applied in workplace settings.

This pilot study was conducted during the winter 2011 semester and included six modules, targeting the level of the first co-op course. Twelve co-op students were carefully chosen as a controlled sample to participate in the study. This sample included a horizontal cross section representing all engineering programs, and a vertical cross section including students from each of the three co-op courses. Direct and indirect assessment methods were conducted to assess the project.

Students' perceptions of their knowledge in the targeted topics were greater than their demonstrated knowledge. Direct assessment showed an increase in students' knowledge for all three topic areas.

Keywords – cooperative education; online distance education; professional skills

I. INTRODUCTION

Continuous improvement is a living process that is built into the engineering curricula and emphasized through periodic assessment and evaluation. This project was initiated and conducted as part of this process to assess, evaluate, and improve the academic content and requirements of the co-op sequence of courses at the School of Engineering (SOE) at [the institution]. The sequence includes three co-op courses with a total of nine credit hours that students register for during their co-op experience with an engineering employer.

The goal of this was to identify, deliver, and assess, new content to students via distance learning during co-op

semesters. The new content would focus on educating students on professional and nontechnical skills, such as engineering ethics, engineering economics, and project management, which are not easy to incorporate in classic technical courses, or in an engineering curriculum at content capacity. These skills are emphasized in several ABET program outcomes [1] which are common to all engineering students, and have been difficult to define and assess in traditional education settings [2].

Online education programs in engineering have been around since the early 1990's [3], and internet-based interventions in workplace-based learning date to at least the late 1990's (e.g. [4]). Learning communities for co-op students have been recently studied at the University of Cincinnati [5], with a focus on organizational culture, ethics, social responsibility, and connecting theory to practice. Other studies have looked at the use of online communities during co-op to help with reflective thinking about learning related to the workplace experience [6, 7] and augmenting skills in professionalism [8, 9]. However, none of these studies go to the level of presenting specific academic content, such as engineering economics and project management, and assessing students learning of the presented material from the educational institution.

II. BACKGROUND OF CO-OP PROGRAM

A. Co-op Program Format

The SOE at [Institution] offers a bachelor of science in engineering degree with majors in computer, electrical, interdisciplinary, product design and manufacturing, and mechanical engineering. All programs are accredited as co-op programs through ABET. All admitted undergraduate students participate in a mandatory co-op program, for a total of twelve months of work experience, during the junior and senior year of the academic program. The cooperative education program is an alternating semester program that the student participates in during the last two years of the academic curriculum. Students work with the same company/organization for each of three four-month-long semesters. A typical sequence for a student is shown in Table 1.

TABLE 1. ACADEMIC/CO-OP SEQUENCE

| | <i>Fall</i> | <i>Winter</i> | <i>Spring/Summer</i> |
|---------------|---|---------------|----------------------|
| | (Sept.-Dec.) | (Jan.-April) | (May-Aug.) |
| <i>Year 1</i> | | | |
| <i>Year 2</i> | | | Co-op I |
| <i>Year 3</i> | | Co-op II | |
| <i>Year 4</i> | Co-op III | | |
| | | | |
| | = Engineering Fundamentals Coursework | | |
| | = Engineering Upper Division Coursework | | |

B. Existing Processes and Academic Content

Students receive three credits for each semester of co-op, for a total of nine co-op credits applied towards graduation. The student receives a letter grade for each co-op semester which is determined by taking into account the evaluations provided by the work supervisor, and the accuracy and quality of written work. A faculty member monitors and assesses the work of the student in collaboration with the co-op supervisor, including review of weekly student journals and visiting the work site each semester.

Prior to the current study, the requirements for a student when participating in a co-op semester included reading and writing assignments, participation in cultural and/or civic activities, and analyses/discussion of an ethical issue. The content of the readings addressed the relationship between technology and society and, usually, its relationship to ethical decision-making. Students were required to write a summary of the reading material each semester. In addition, students kept a written journal of weekly activities that was submitted and reviewed by the supervising faculty member. The student was encouraged to not only document day-to-day activities but also to reflect on learning and observations of the work environment, including the roles and actions of professionals in their workgroup. Each co-op semester, the entire group of co-op students came together for a meeting to discuss their co-op experiences and reflect on an ethics case study.

III. STUDY RATIONALE

There were two converging events that led to conducting the work described in this paper: 1) continuous improvement instigated by recent self-study reports for ABET reaccreditation, and 2) assessment of the existing academic content of co-op. The following ABET program outcomes are assessed and evaluated through a dual process during the co-op courses:

- 'd': an ability to function on multidisciplinary teams
- 'f': an understanding of professional and ethical responsibility
- 'g': an ability to communicate effectively
- 'h': an understanding of the impact of engineering solutions in a global, economic, environmental, and societal context
- 'j': a knowledge of contemporary issues
- 'k': an ability to use modern engineering tools

At the end of every co-op semester, each student is assessed by the company supervisor using an online data collection tool.

The assessment tool includes questions that are directly mapped to each of the program outcomes. In addition, a faculty member is assigned as an advisor to each student during the co-op semesters. The faculty member corresponds on a regular basis throughout the semester with the student, and visits the worksite to meet with the student and supervisor to review the student's work. This process provides two points for assessing the program outcomes for each student.

Through this on-going process, and in the course of summarizing evaluation of program outcomes for the writing of the Self-Study report for ABET re-accreditation, several themes emerged. It was determined that program outcomes that could use increased and continued attention included: applying economics considerations in engineering design; engineering ethics; professionalism, and professional responsibility.

The co-op courses sequence was reviewed to determine the suitability of current academic content and if there was an opportunity to add value to the co-op course sequence by potentially adding academic content. Two key reasons emerged supporting this approach:

- co-op is a common experience in the upper division for all engineering students, and;
- the workplace environment relates well with the delivery and application of the content and spirit of several program outcomes.

Furthermore, it was determined that potentially adding content to the co-op course sequence could free up time in other courses to either expand or add content. Finally, if academic content was added, review of student's work related to this content would become more robust by adding a level of assessment. In addition to the current assessment practices of obtaining feedback from the workplace supervisor and the faculty advisor, academic content in the co-op course would provide assessment of work product from students as well, essentially resulting in a triangulation of assessment data.

As part of the assessment of the academic content of the co-op semesters, both faculty and students were consulted and provided input on the existing co-op academic content and proposed content through a survey instrument. The results of this survey are provided in Figure 1 through Figure 3. Figure 1 presents faculty and student ratings of the activities required during a co-op semester prior to the pilot work conducted for this project. These activities are referred to as 'existing' to represent academic components that have existed for several years for the co-op course sequence. As seen in Figure 1, both faculty and students rated journaling periodically, analyzing ethics case studies, and reading and reporting on a book related to engineering professionalism the highest of the existing content. Note that there is no student rating for books on professionalism for students as there were no students in the pilot group that had read this book as part of their requirements at this stage of the co-op course, and therefore could not provide an opinion.

Prior to the current study, the requirements for a student when participating in a co-op semester included reading and writing assignments, participation in cultural and/or civic activities, and analyses/discussion of an ethical issue. The

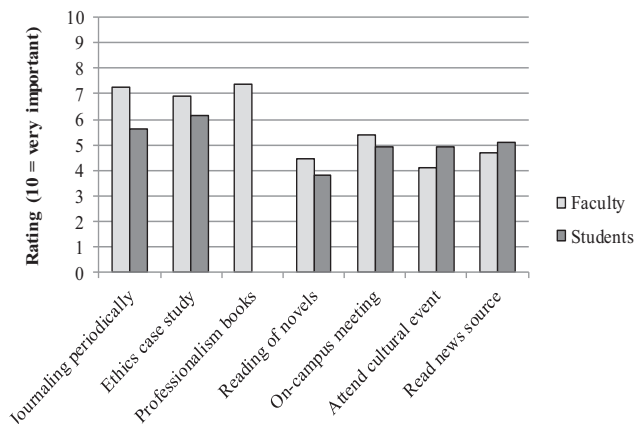


Figure 1. Faculty and student ratings of 'existing' co-op activities.

content of the readings addressed the relationship between technology and society and, usually, its relationship to ethical decision-making. Each co-op semester, the entire group of co-op students came together for a meeting to discuss their co-op experiences and reflect on an ethics case study.

Faculty members were asked whether the 'existing' pedagogical approach was appropriate, and whether there should be any adjustments. Figure 2 shows their responses regarding the pedagogical approach to the co-op course sequence. A small percentage of faculty (8.5%) recommended full replacement of the 'existing' academic content in co-op, while the majority (68%) of faculty recommended partial replacement of the co-op content. Another 20% of faculty believed that the 'existing' academic content of co-op should

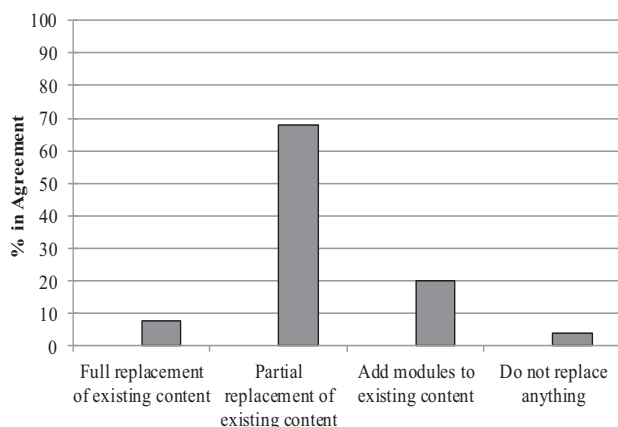


Figure 2. Faculty opinions of pedagogical approach to the co-op course curriculum (25 responses).

be kept and to add academic content to the 'existing' requirements. Finally, 3.5% of faculty recommended not changing the co-op content at all.

Review of assessment results across the greater curriculum, coupled with discussion among the faculty, resulted in strong support (70% of overall faculty respondents or greater in agreement) for added content in the co-op curriculum in the

following areas: professionalism, engineering economics, engineering ethics, communication, and project management. There were also 50% of overall faculty respondents or greater supporting the topics of leadership and team building (see Figure 3).

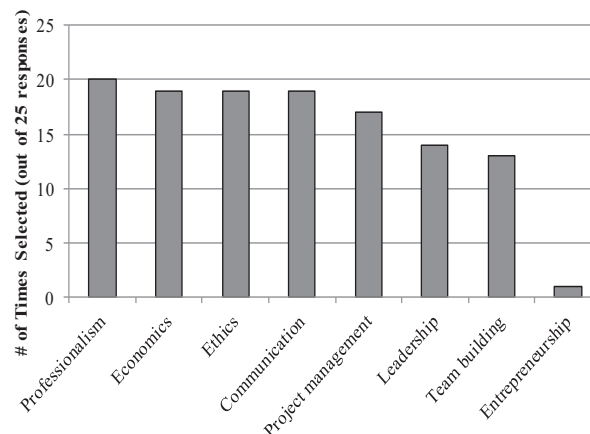


Figure 3. Support for topics to add to the co-op curriculum.

In summary, it was determined that there was support from faculty and students to update and modify the 'existing' curriculum during the co-op course sequence, and that this change in curriculum should replace some of the 'existing' co-op content – namely the reading of novels with technical-ethical themes, on-campus meetings, attending a cultural event, and reading of a news-source. The focus of the additional content should be in the areas of engineering ethics and professionalism, engineering economics, professional communication, and project management.

IV. NEW CO-OP ACADEMIC CONTENT

A. Format

The development of additional academic content for the co-op course sequence received funding through an internal grant for the development of curriculum, in response to a proposal by the authors. The grant supported the proposed production of modules to be used as distance-learning educational material during the co-op education courses by engineering students. These modules targeted the coverage of professional skills that engineering students need but do not easily get from on-campus, traditional technical courses. The content of the modules for the pilot study were geared toward the first co-op semester and included introductory material on engineering ethics and professionalism, engineering economy, and project management. Additional content on professional communication is proposed for the second and third co-op semesters, but was not incorporated into the pilot study.

The complete set of on-line modules would constitute a thread of three full courses that would be divided over the three required co-op courses. Having exposure to these practice-related issues while being in the workplace presents a unique opportunity for the students to apply what is learned. The curriculum was designed with the following characteristics:

- Use of a scaffolded approach to accommodate the logistics of the co-op courses and the maturity level of the students. In every co-op course the students will be exposed to a related set of skills at a gradually advanced level.

- The pedagogical basis provides maximum flexibility for unlimited time and location access. However, the rigor and order of the educational process are maintained by assigning timely periods for the students to provide feedback and responses to the exercises and tests associated with the modules.

Modules were designed to be relatively brief, focused packets of information that could be reviewed within a 30-60 minute timeframe. The modules were delivered via Blackboard, the university-wide, web-based course management software, and consisted of various media including written materials, papers, videos, websites, podcasts, etc. Each module had an associated, short test or quiz that was automatically graded in Blackboard. The objective was to have six to eight modules to complete in a given co-op semester, which is almost equivalent of one lecture-course credit. Modules were 'open' at scheduled times throughout the semester and students were required to complete them during that timeframe. A primary instructor was available for discussion and to answer questions at both regularly scheduled times for phone or video chat, as well as via email, chat or discussion board.

The target was for modules (review and assessment via test or quiz) to take no more than a total of eight (8) hours in a co-op semester. This would not unduly interfere with the primary objective of co-op, which is for students to focus on applying and developing engineering knowledge, skills and abilities through work experience. It also would not preclude the continuation of important pedagogical and developmental activities such as weekly journaling. In addition, there was no anticipated additional work required of the student's co-op faculty advisor each semester, other than incorporating the grading of the tests/quizzes from the modules into the student's final grade.

B. Pilot Study Overview

The pilot study was conducted during the winter 2011 semester, as described above. The content of the modules for the pilot study are presented in Table 2. Twelve co-op students were carefully chosen during the EGR 390 course, as a sample to participate in the study. The student demographics can be seen in Table 3. The sample was selected to include a horizontal cross section representing all engineering programs, and a vertical cross section including one student from the first co-op level and one student from the third co-op level for comparison purposes. A pre-study survey and a post-survey were conducted. The pre-survey included questions about the student's interest in, and the appropriateness of, the past approach and the pilot study approach to delivering academic content during co-op. In between, modules were released, within Blackboard, in a timely fashion and students were given between 7 to 10 days to read each module and answer a companion quiz, which were graded electronically. Finally, the pre- and post-surveys included quiz questions that were used in

TABLE 2. CO-OP COURSE CURRICULUM FOR COURSE I (PILOT STUDY)

Engineering Ethics I & II

- personal vs. professional ethics
- engineering as a profession
- understanding codes of ethics
- connection of ethical problem solving to engineering design
- professional responsibility and legal liability
- legal responsibility of engineering

Engineering Economics I & II

- cost vs. price
- time value of money – cash flow diagrams
- simple and compound interest
- time value of money – uniform series factors, gradient series factors

Project Management I & II

- project life cycle
- types of projects
- project stakeholders
- project planning process – project charter, work breakdown structure

the module quizzes to determine what students knew prior to reviewing the modules, and to assess retention of information after the modules and quizzes were completed.

TABLE 3. DEMOGRAPHICS OF PARTICIPATING STUDENTS

| Category | Number of Students |
|--------------------------------|--------------------|
| <i>Major:</i> | |
| Computer | 2 |
| Electrical | 4 |
| Computer and Electrical | 1 |
| Mechanical | 4 |
| Product Design & Manufacturing | 1 |
| <i>Co-op Semester:</i> | |
| EGR 290 | 1 |
| EGR 390 | 10 |
| EGR 490 | 1 |
| <i>Gender:</i> | |
| Female | 1 |
| Male | 11 |

V. RESULTS

The areas targeted by the project were not as familiar as traditional technical areas to students in both content and measurement instruments. Students are usually exposed to some pieces and ideas related to these professional and nontechnical topics in a random fashion that provides them with some impression of being knowledgeable enough in them. That impression results in students' resistance to investing time in these areas and makes their perception of any required effort related to them very negative or indifferent. To investigate this point, students were surveyed on their own perception of how much they know about the different areas targeted by the project, before and after exposure to the proposed modules. Results were collected and compared to an actual test of their knowledge in these areas using both pre- and post-tests. Results are shown in Figure 4.

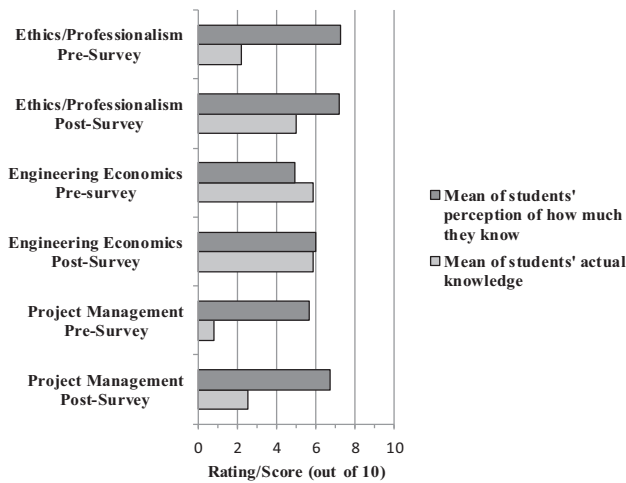


Figure 4. Pre- and post-test results for online co-op modules.

The results displayed in Figure 4 indicate that students' perceptions of their knowledge in the targeted topics by the project were greater than their actual demonstrated knowledge in both the pre-survey and post-survey. For all three topic areas (ethics/professionalism, engineering economics, and project management), scores in the post-survey did increase (if only slightly for engineering economics) from the scores in the pre-survey. In all three topic areas, the actual demonstrated knowledge post-survey was below expected levels, particularly in project management, and will be addressed in future offerings. The content of the modules will be assessed for completeness and appropriateness for the course level, the quiz questions will be reviewed to ensure they are consistent with module content, and additional support will be provided for students including increased instructor contact and access.

Direct assessment was also conducted during this project for performance evaluation and further improvement of the proposed modules. The mean scores on the quizzes associated with each module are shown in Figure 5. The results indicated that students performed at an acceptable level. Mean scores on the quizzes ranged from 61% (ethics/professionalism module 2) to 94% (project management module 1). It is evident that students performed well in general on the quizzes for each module. This was expected since students were encouraged to review their materials as needed when taking the quiz. The one exception was the ethics/professionalism module 2 which was

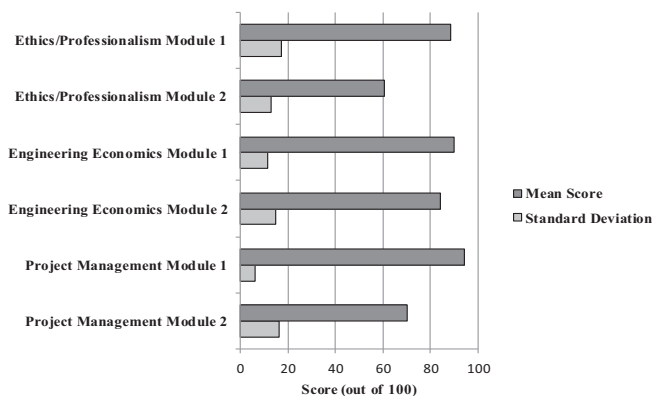


Figure 5. Mean scores on the quizzes for each online co-op module.

written at an advanced level intentionally to act as a check for content appropriateness. As expected, students did not have the knowledge level or professional maturity yet to score at an appropriate level on the quiz for this module. This module will be used in the future during the third co-op semester which is in the students' senior year.

Students were also asked to provide feedback on the experience of participating in this study as part of the post-test. One point of emphasis was how beneficial the students felt the modules were in relation to their educational and professional growth. Figure 6 provides the responses of the students. In total, the students felt that the modules were beneficial, with the project management modules being most beneficial.

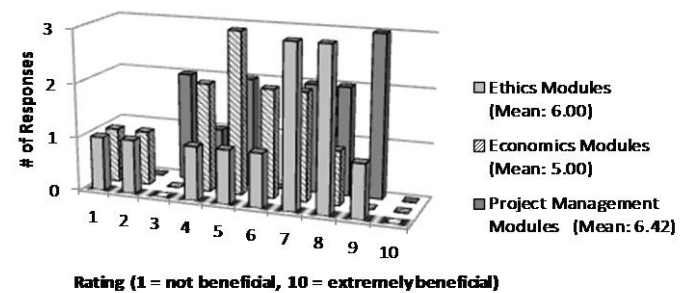


Figure 6. Student ratings of the online co-op modules.

Figure 7 presents the responses of students relative to the overall worthwhileness of having the online modules during the co-op semester. Approximately 60% of students agreed that the modules were worthwhile, while only 8% strongly disagreed with this sentiment.

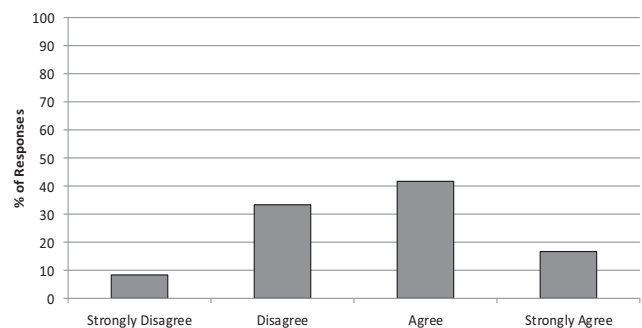


Figure 7. Student agreement of worthwhileness of online co-op modules.

Finally, students were asked to comment on whether the module content was appropriate for a first semester co-op. The majority (approximately 91%) of students indicated that the modules were appropriate for the targeted level of first-semester co-op students (see Figure 8).

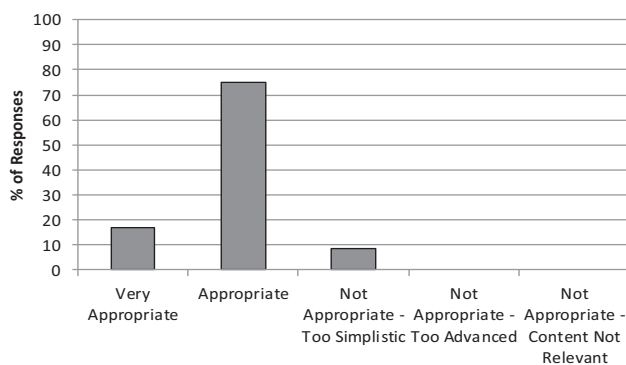


Figure 8. Student perception of appropriateness of online modules for the first co-op semester.

VI. CONCLUSIONS AND RECOMMENDATIONS

This pilot project was conducted to assess the academic side of the co-op course sequence and to develop and test new academic content targeting ABET outcomes which are not easily incorporated in traditional engineering classes. The project aimed at providing this content in an electronic format, as well as its grading process, and with supervision by a specialized instructor to guarantee both flexibility in delivery and reduction of burden for the other co-op instructors, as well as specialized depth in content. The targeted topics for academic content included the following categories:

- Engineering ethics and professionalism
- Effective communication
- Project management
- Engineering economics

Results of the study included:

1. Students falsely perceived their knowledge in the targeted topics. Furthermore, students had a false impression that they already knew enough, based on irregular and unstructured exposure to information and ideas related to these areas. Well-structured academic information with clear purpose would help students realize their knowledge levels in these areas and would motivate them to perform with enthusiasm as the benefits become obvious to them.
2. Students were often incapable of seeing long term benefits or the big picture view, and their maturity level dictated their vision and perception of the importance and relevance of information. The timing of these modules while students are in co-op satisfied that perspective. However, students may not have an appreciation for the content in the modules which does not directly relate to their current context. Therefore the instructor has to convince students of the value and benefits of the content.
3. Students often did not appreciate activities if they were not provided the rationale behind it, and informed about its benefits to their career and education. This was most likely a result of immaturity and compartmentalization of knowledge amongst students as well as a perceived lack of time. Breaking these habits is a significant challenge to engineering instructors. Structured and focused academic

curricula (e.g. scaffolded curriculum) would help alleviate these issues.

For a pilot effort, the academic modules introduced into a co-op course had enough promise to be tried again with modifications and improvements. Because the content of the modules is important to meeting program outcomes requirements in all engineering majors, and the co-op courses provide an efficient means for delivering the content to all students in all programs, the co-op courses are appropriate for this effort. The modules were added to the first co-op class (EGR 290) in the summer semester of 2012 for a larger pilot to collect more data.

It is recommended that the modules and associated quizzes that were pilot tested in winter 2011 be reviewed and modified, then implemented with all EGR 290 students in the summer 2012 co-op course. It is also recommended that changes, elimination, or improvements be introduced to the activities and content of least value, and that some older requirements be removed in favor of new content that is academically focused and covered by the modules.

ACKNOWLEDGMENTS

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Work in Progress: Extending a LMS with social capabilities: Integrating Moodle into Facebook

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Abstract—Merging a Learning Management System (LMS) and a social network has social advantages for students. Among others, students can show off their achievements among their acquaintances, which in turn improves their social leadership and self-esteem. This is specially true in the case of distance learning, where there are no physical interactions between students, so their student life is totally isolated from their everyday life (e.g. students do not go out together, since they may live in different cities or even countries although they study the same subjects). All these points suggest that the use of social networks for distance teaching has clear advantages that can be harnessed.

In order to achieve the aforementioned benefits, we are working on integrating a commonly used LMS, Moodle, into one of the most widely-used social network, Facebook. This integration allows students and faculty to use Facebook as a communication tool that improves the learning process and social life of students in the ways presented before.

I. INTRODUCTION AND MOTIVATIONS

With the recent development and wide-spread use of Web 2.0 [1] concepts, such as social networks [2] and cloud computing [3], an interesting guideline for research is how these new technologies can be applied to education. These technologies have a number of interesting features, and some of them can be of real interest for educational purposes. Among others, the easy ways of sharing information and interacting between users in social networks (users can write in walls, define their status, like and dislike learning resources, send messages, chat, share applications, etc). We are working on the implementation of a full-featured system that uses the aforementioned Web 2.0 concepts for e-learning purposes. Authors have worked on harnessing another main technology among the Web 2.0 realm, which is cloud computing [4], and in this work we propose how to harness social networks for e-learning purposes.

Social networks can be of real interest because they allow the creation of virtual classroom spaces outside the Learning Management Systems (LMS) of the University. Thus, these tools can increase the interoperability of students and faculty and improve the quality of the learning process of students. For example, students can be hanging around in their favorite

social network and get instant updates on the status of the courses or evaluation feedback from their activities (e.g., the practical exercise 5 has come out, it must be presented by 1st of February).

Social networks are a very important communication media in Spain. According to [5], 50,9% of Spaniards use a social network (which rises to 80.3% for young people between 16 and 24 years old), and 35,3% of Spanish people use social networks as the main tool to communicate with each other, which increases to 54.1% of Spanish youth (a 19% increase compared with the previous year). Also, more than 79,2% of young users connect to a social network at least once a day (60,4% considering all the ages).

Among all the Web 2.0 tools available at the moment, Facebook (www.facebook.com) stands up in the crowd of the social networks. According to [5], Facebook is the leader in Spain in terms of the generated web traffic (e.g. users visit web sites recommended via Facebook), since 63.9% of this traffic is generated by Facebook, distantly followed by YouTube (13.8%). Moreover, more than 40% users choose Facebook as their favourite social network, followed by Tuenti with 14.4%.

All these figures highlight the wide-spread use of Facebook in Spain and identify it as a very interesting tool to improve the learning mechanisms of a University. This is specially true for totally distant universities, such as the National University for Distance Education of Spain (Universidad Nacional de Educación a Distancia, UNED, www.uned.es) which depend on technological infrastructures (such as LMS, videoconferencing, etc) to make the learning processes feasible in the absence of face-to-face classes.

Furthermore, integrating a LMS into a social network has social advantages for students. Among others, students can show off their achievements among their acquaintances, which in turn improves their social leadership and self-esteem. This is specially true in the case of distance learning, where there is no physical interactions between students, so their student life is totally isolated from their everyday life (e.g. students do not go out together, since they may live in different cities or even



Fig. 1. Searching the application using Facebook search engine.

countries although they study the same subjects). All these points suggest that the use of social networks for teaching has clear advantages that can be harnessed.

In order to achieve the aforementioned benefits of social networks, we are working on integrating a commonly used LMS, Moodle, into Facebook. This integration allows students and faculty to use Facebook as a communication tool that improves the learning process and social life of students in the ways presented before. For this integration, several tasks have been performed. First, an in-depth study of the Application Programming Interface (API) of Facebook has been conducted. After that, the integration of the log-in facilities of Facebook and Moodle has been performed, which allows participants in the learning process log-in into Moodle using Facebook credentials.

The next step is the development of web services in Moodle to be accessed by Facebook. Moodle supports several types of web services, and for this work, services using Representational State Transfer (REST) will be used for their ease of implementation. A web service showing the course information has been developed in this work, which allows participants see the contents of the course.

Finally, Facebook applications have been developed to access the aforementioned web services. The application that performs the integration between Moodle and Facebook is called PFC UNED Mdl-Fbk and can be found using Facebook search engine as can be seen in Figure 1. Once it is installed, it allows us to connect to our Moodle LMS and offers the possibility of logging in to it and see our courses.

II. FUTURE WORK

Regarding future work, a more detailed integration is being implemented. Among the points being treated, the publication of messages from the LMS forums or assessments results in the wall of Facebook are two of the first ideas. For this, the Spanish Organic Law for Data Protection (*Ley Orgánica de Protección de Datos*, LOPD [6]) must be taken into account since no private data can be published. Facebook privacy settings can be of real interest to decide what students/faculty want to publish/hide from public view.

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Work in Progress: Software for remote laboratories designed with the focus on learners

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Abstract— The work presented here has a focus on the software controlling the remote laboratory in the context of pedagogy. This in contrast to the traditional focus when developing remote laboratories, which has been on functional performance as seen from an engineers' perspective: number of functions to perform, similarity to the physical laboratory it should imitate, scheduling of experiment, etc. As the supervisor is removed from the scene in the transition from physical to remote laboratories, the remote laboratory environment must facilitate the student-teacher interaction in a more or less automated manner. A list of requirement for the software controlling the remote laboratory environment has been developed where focus is set on ease of setup, access and readability, integrity of the hardware, protection from misuse, and support for learning. We here present a preliminary report on the implementation of such a system.

Remote laboratory; Automated pedagogical support

I. INTRODUCTION

Laboratory exercises are an important part of engineering education, and should aid the theoretical understanding, as well as give hands-on experience for the students. Running laboratories requires significant resources from the institution and is time consuming for the students. Therefore, it is a current trend in engineering education to transfer these laboratories into remote controlled laboratories that can coexist with the vast developments of online learning offerings. A number of examples of remote labs using premade software environments exists, many of which use LabView[1,2] other use different development tools and platforms, like[3] with Matlab.

The authors have over a number of years worked on implementation and use of remote laboratories for learning and support for learning at university level. Most work in the area of developing remote laboratories has focused on functional performance as seen from an engineers' perspective: number of functions to perform, similarity to the physical laboratory it should imitate, scheduling of experiment, development of portals or creating of metadata for learning objects for these remote labs, iLab[4], Lab2Go[5]. A significant difference between the systems presented in the above referenced publications and the system presented in this article is the software controlling the hardware and the web server, or the environment that the students should benefit from. The focus

for the development is the constructs needed to support pedagogical aspects like adaptive individual feedback.

A student doing a laboratory exercise in a traditional setting, i.e. physical laboratory, will typically have immediate access to a supervisor in the laboratory, giving feedback according to the progress of that particular student or group of students. A remote laboratory is an installation that in most cases will be available for the students 24/7, anywhere in the world, and a user of the remote laboratory will probably not have access to a supervisor should they run into problems. This means that the software must facilitate transfer of information on each user's usage of the remote laboratory and the results obtained from the laboratory experiment for later supervisions, alternatively a system with automatically generated adaptive feedback can be envisioned.

A survey was carried out on a group of students that had utilized remote labs for a set of experiments in two different modules in an electrical engineering course. The feedback from this survey identified that the main challenge with the current remote labs that is based on a LabView setup, is mostly connected to access and setup of the software. Once the setup was sorted out, the use of the lab itself was straight forward, enjoyable and was reported to give a good learning effect. Another main point for the students is that the lab is available 24/7.

II. NEW DIRECTION IN REMOTE LAB

The work in the community on remote labs is shifting toward a focus on how to integrate remote labs into learning. Our work is focused on the next step in this evolution: How to support learning and utilize pedagogical and games based techniques in remote labs. The key to achieve this is to look at the software controlling the remote laboratory in the context of pedagogy. As the supervisor is removed from the scene in the transition from physical to remote laboratories, the remote laboratory environment must facilitate the student-teacher interaction in a more or less automated manner.

A list of requirement for the software controlling the remote laboratory environment is created and serves as the basis for the implementation. The focus for these requirements are set on ease of setup, access and readability of the environment, points for integrity of the hardware and protection from misuse are also included. A significant effort is

also committed to describe the system requirements for learning support.

The authors has identified that the main shortcoming of most of today's remote labs are a lack for support for learning. Software like LabView and Matlab are tools built for a specific purpose. The configuration options for these tools are limited, particularly when it comes to adding in pedagogical support, a necessity in a learning situation where the tool is used without any other support.

III. FOCUS FOR WORK

The process of creating a remote lab environment with learning support is complex and requires several steps. First the system is designed to allow capture of information on who performed the experiment, what functions were utilized, how the setup looked like and what the results are. Information about what strategy individuals are using, and how different users are progressing with the experiment can then be generated from these captured data by comparing different experimental runs by a single user over time. A user attempting multiple different setups in quick succession may indicate that a trial and error approach is being used, or multiple attempts at longer time intervals may indicate a struggling user, attempting to calculate or use other sources to arrive at a more correct setup.

The project described here does include the setup of a framework for implementing remote labs. An outline for the requirement for such a framework for remote laboratories have previously been published [6]. A test implementation of a remote laboratory is set up. This test implementation embodies the basic requirements set out for the framework: Simple setup and support for multiple browsers i.e. use of a web page that does not require external installed components, graphical display, and setup of experiment on client without the control of the experiment whenever possible. The implementation utilizes a structure shown in figure 1.

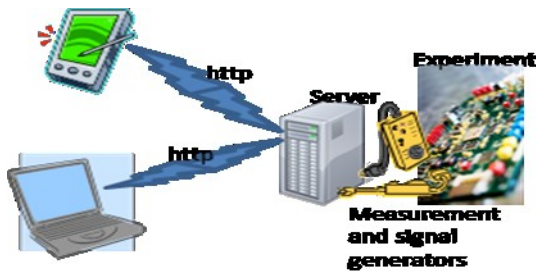


Figure 1: Structure of a remote laboratory setup.

The remote laboratory setup utilizes a standard web server with a webpage based on java script to setup the experiment. The experiment is then submitted to the server by the user via the web client. The server maintains a queue of experiments that needs to run. In the current set of implemented experiments the runtime for a single experiment is 0.5 to 1 second so this queue is mostly short or even empty and the wait time for running is equally short. Once the experiment is admitted to the queue the web client is updated with an estimated waiting time. Once the experiment is complete the data obtained is temporary stored in a database and then

transmitted to the web client, on a web page utilizing java script and if necessary an AJAX setup where data is loaded as it is required.

Multiple implementations of remote laboratories are planned that will serve as test cases for the developed framework. The reasoning behind these implementations is that in addition to serve as a test case for the framework, an implementation of a remote laboratory is used to capture information and serve as a basis for the desired user support described above.

IV. FURTHER WORK

A substantial further effort is required to indentify behavior, scenarios and a set of rules that can be included in the remote lab environment, giving the environment the ability to detect these predetermined behaviors, notifying the instructor or take automated action. The information captured about the users will also be used for further identification of behavior, for development of a more complete and complex rule-set. These rules will give the system the ability to detect predetermined behaviors and take automated actions. These automated actions will be determined by the rules and can be to offer assistance, hints or to simply notify the instructor. The development of a more complete and complex rule-set will be of primary importance to a remote learning environment.

It is also necessary to ensure that captured information about the users is not made available to the wrong persons. The information captured will not be of a highly sensitive nature, but any information relating to individual students must be kept secure and only be made available to the identified persons, like a lecturer/instructor in a module.

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The Role of Social Networking Sites in E-learning

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Abstract—This paper explores the role of Social Networking Sites (SNS) in e-learning by investigating the attitudes, behaviors, knowledge and views of computing students towards the use of SNS in e-learning. Data was collected from an online survey and interviews, and analyzed to discover the practices, tendencies and the current status of the use of SNS in e-learning as well as how these can be improved.

Major factors that facilitate the usage of SNS in e-learning were identified as collaboration, communication, resource sharing, social influence, usefulness and ease of use. Facebook was identified as the most popular SNS.

The role of SNS in e-learning is supportive and important. Although the participants were computing students with a high level of IT literacy, and were interested in using SNS for e-learning, only a few were frequently using SNS for e-learning.

Reasons for this minimal utilization of SNS for e-learning were identified as security and privacy concerns, reliability and currency of content and network issues such as speed of access, real time synchronization and efficiency.

We believe that SNS can play a major supporting role in e-learning and that the potential for using SNS in e-learning is not fully reached. The situation may be improved by providing increased guidance and training to students. Learning activities using SNS should be planned and organized.

Brief guidelines on using SNS in e-learning are also included in this paper. These guidelines may be further refined and adapted for use in other institutions.

Keywords—component; teaching and learning; social networking sites, facebook, collaboration, interaction, personalised environment.

I. INTRODUCTION

Modern educational theorists argue that knowledge transmission depends on the individual's participation and reconstruction and that learning can be considered as a kind of social process and that it happens by sharing information and interactions in each individual [1]. Social interactions, communications or collaboration with more capable peers during problem solving will enhance the learner's understanding [2, 3].

Conventional learning management systems (LMS) such as Moodle and Blackboard, are commonly adopted as formal teaching and learning environments by tertiary institutions. While these systems provide valuable services to the teaching and learning process, some issues were identified. These LMS lack social connectivity tools and personal profile spaces that can be used by the students involved [4].

On the other hand, Social Networking Sites (SNS) can help people find connections that may be hidden in the real world. Creating an account on a social networking site such as FaceBook means that individuals can share and communicate with others in their personalized environment, which facilitates spiral building of personal understanding and interest toward learning. Therefore, SNS have the potential to be online platforms for e-learning. This has drawn the attention of certain researchers in higher education. Research studies on how to successfully include SNS in the process of teaching and learning are being conducted in recent years.

The faculty's views regarding the use of SNS in education were compared with students' views in [5]. Using SNS for learning from the Vygotskian perspective was reviewed in [3]. An Education Usage Model of FaceBook was proposed in [4]. Integrating SNS with other systems was reported in [6, 7]. Valuable experiences of medical students using FaceBook to support their learning were described in [8]. An algorithm which automatically groups distributed e-learners with similar interests and make proper recommendations was proposed in [9]. Research in this area is still continuing.

This paper is based on a study conducted to explore the role of SNS in e-learning by investigating the attitudes, behaviors, knowledge and views of computing students towards the use of SNS in e-learning.

Data was collected from an online survey and interviews [10] and analyzed to discover the current status, practices and tendencies of using SNS in e-learning as well as how these practices can be improved. Out of a total population of around 300 computing students from a tertiary institution in New Zealand, 60 took part in the survey. From these 60 participants, 9 were interviewed to gather additional data.

In the following sections, the research method is described first, followed by the presentation of the results, discussion of the findings and conclusion.

II. METHOD

A. Data Collection

Both quantitative data (via an online survey) and qualitative data (via interviews) were collected [10]. The sample population chosen was the students in the Computing Department of a New Zealand tertiary institution. Out of a total population of around 300 computing students (approximately 250 undergraduates and 50 postgraduates), 60 responded to the invitation and took part in the survey. Among these, 9 interviews were also conducted. The survey and interview questions were designed based on the researchers' experiences and relevant literature review.

The online survey questions were designed to find out the attitudes, behaviors, knowledge and views of the respondents towards the use of SNS in e-learning. There were 25 questions, most of which were multiple choice questions with three exceptions: two asked the participants to rank all the possible answers; another asked if the participants were willing to be interviewed [10, Appendix C].

Face-to-face interviews were used whenever possible and e-mail communication was used to bridge the geographical distance when appropriate. Eight open-ended interview questions were designed to explore in detail the participants' attitudes, perception and behaviors towards the use of SNS in e-learning [10, Appendix D]. There were nine interviewees (four undergraduates and five postgraduates) who agreed to be interviewed. Four participants were interviewed face-to-face, and five participants, via email communication.

B. Data Analysis

All the survey data was cleaned to eliminate invalid information and then summarized to generate categories or themes. This data was then analyzed and studied to generate possible answers to the research questions. Simple statistical information such as percentages was calculated for comparison purposes. Related and similar results gathered from the online survey and published literature were compared and analyzed. While convenience samples could provide useful information, they would differ from an ideal sample that was randomly selected. The small sample size added further limitation to the data. These limitations were taken into consideration in the data analysis and interpretation.

The researchers carefully examined all the data gathered from the interviews, and made sense as a whole, and then the data was categorized into two categories: answers from undergraduates and answers from postgraduates. In the meantime, the researchers used the method of coding to generate categories or themes according to the key points from the answers. Each individual was anonymously identified by a code. Due to the page limitation, only a summary of the interview results is reported in this paper.

III. THE RESULTS AND ANALYSIS

The survey and interview results are presented and interpreted respectively. Each set of data is analyzed and interpreted.

A. Survey Data

The demographic information of the respondents was gathered first. The majority of the survey respondents were male (83.3%) and most of them are undergraduates (68.33%). As they were all from the Computing Department, it's reasonable to assume that they all have adequate computing skills to make use of SNS.

More than half of the respondents (54%) had more than three years experience using SNS. In total, 92% of the respondents had at least one year experience using SNS. This may not be necessarily true for non-computing students.

Although the respondents have a reasonable level of experience with SNS, they do not have the same level of experience using SNS for e-learning as shown by the data in Table I, with only 56% of the respondents using SNS as a tool to discuss course related topics.

TABLE I. FREQUENCY OF THE USE SOCIAL NETWORKING SITES TO DISCUSS COURSE RELATED TOPICS WITH CLASSMATES

| Frequency | Number | Percentage |
|-----------|--------|------------|
| Always | 4 | 8% |
| Often | 7 | 14% |
| Sometimes | 17 | 34% |
| Seldom | 10 | 20% |
| Never | 12 | 24% |

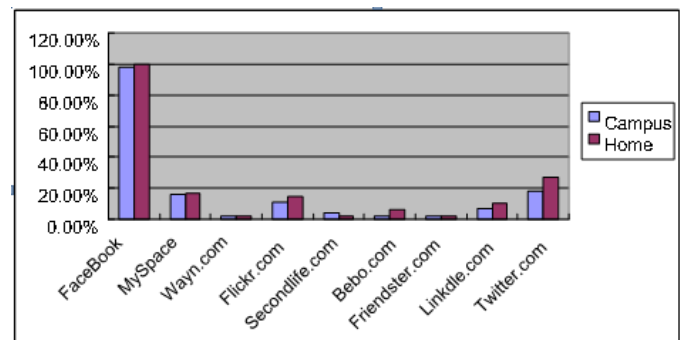


Figure 1. Social networking sites computing students like to use

Figure 1 shows the preferred SNS among the students. Nine SNS were presented. Regardless of whether they used the SNS on campus or at home, FaceBook was the overwhelmingly favored site, followed by Twitter, MySpace and Flickr. This result is consistent with the findings of similar research studies [3, 4, 5 and 11]. This is likely true in New Zealand and other similar countries. However, it may not be necessarily true for all the countries, for example, China.

Table II compares the different ways used by the students to discuss course related topics, where SNS is much less preferred than email and obviously in a less supportive role.

Table III shows that more than half (51%) of the respondents had never used SNS to find other students to collaboratively study with. Only about 15% (7) respondents

frequently used SNS to find their peers to build their knowledge in a collaborative manner.

TABLE II. WAYS OF DISCUSSING COURSE RELATED TOPICS WITH OTHERS

| <i>Ways</i> | <i>Number</i> | <i>Percentage</i> |
|-------------------------|---------------|-------------------|
| Face to Face | 43 | 87.8% |
| Social Networking Sites | 22 | 44.9% |
| Phone | 24 | 49.0% |
| Email | 42 | 85.7% |
| Other | 7 | 14.3% |

TABLE III. FREQUENCY OF THE USE OF SOCIAL NETWORKING SITES TO FIND STUDENTS TO STUDY WITH

| <i>Frequency</i> | <i>Number</i> | <i>Percentage</i> |
|------------------|---------------|-------------------|
| Always | 3 | 6.1% |
| Often | 4 | 8.2% |
| Sometimes | 14 | 28.6% |
| Seldom | 3 | 6.1% |
| Never | 25 | 51.0% |

About 61.9% respondents believed that the most important factor affecting the students' use of SNS in e-learning on campus is network speed. Approximately 35.7% respondents believed that network access is the second most important factor. 31% respondents believed that network security and privacy is also an important factor. Network was identified as a key factor in the use of SNS.

In Table IV, the majority of the respondents (66.7%) thought uploading and watching videos and photos is a feature that facilitated their learning, followed by electronic mail (64.6%).

TABLE IV. FEATURES OF WEBSITES (INCLUDING SOCIAL NETWORKING WEBSITES) THAT FACILITATE E-LEARNING

| <i>Features</i> | <i>Number</i> | <i>Percentage</i> |
|----------------------------|---------------|-------------------|
| Upload/Watch Video & Photo | 32 | 66.7% |
| Chat Room | 25 | 52.1% |
| Games | 7 | 14.6% |
| Forum | 26 | 54.2% |
| Mail | 31 | 64.6% |
| Blog | 28 | 58.3% |
| Event | 10 | 20.8% |
| Other | 5 | 10.4% |

The attitudes of the respondents in relation to the use of SNS in e-learning are optimistic and encouraging. More than half of the respondents (61%) said that SNS were helpful in e-

learning in one or more courses. On the other hand, there were 39% computing students who did not find SNS helpful in e-learning.

About half of the respondents (50.9%) were willing to use SNS for e-learning and further 40.4% respondents were sure that they would use it in the near future. In total, over 90% of the respondents accepted the use of SNS in e-learning.

What features of social networking websites facilitate your e-learning? (You can choose more than one option)

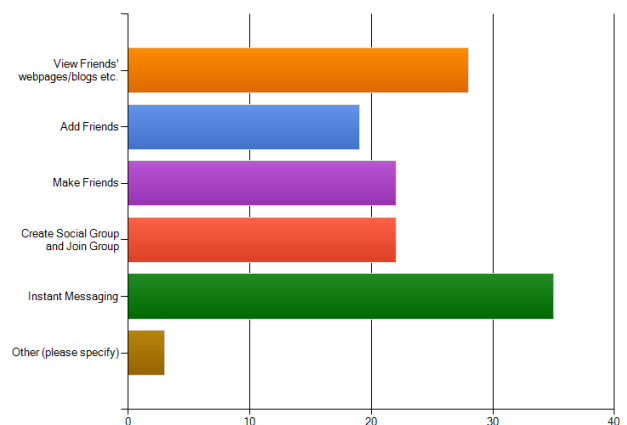


Figure 2. Features of social networking websites that facilitate learning

Figure 2 demonstrates that most computing students (35 participants = 74.5%) believed that Instant Messaging of SNS can facilitate their e-learning.

When you need to find the answer to a question related to your course, where do you go to find the answer? (You can choose more than one option)

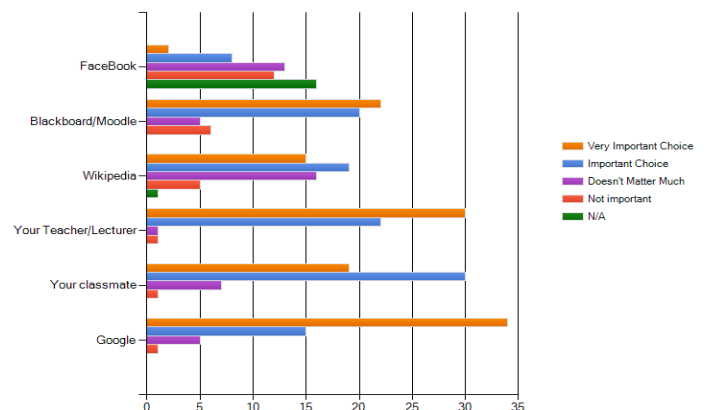


Figure 3. Ways of finding the answers when students need to answer a question related to their course

Figure 3 clearly shows a comparison of the methods the respondents used to find answers when they needed assistance with a course they are doing. Options included FaceBook, Blackboard/Moodle, Wikipedia, lecturers, classmates and Google search. These results reveal that the three most popular ways used by these students to find answers were, Google search, classmates and teacher/lecturer. About 61.8% respondents considered Google search to be very important

and another 27.3% believed Google to be important, followed by teacher with 55.6% responses as very important and 40.7% responses as important, and 'ask classmate for help' was at 33.3% very important and 52.6% important. Facebook was the least favored in this case. There was no indication that SNS could replace a teacher. In terms of e-learning, SNS could be considered as a supplement to conventional LMS like Moodle and online search engines. This reinforces the interpretation of Table II that the role of SNS is supportive.

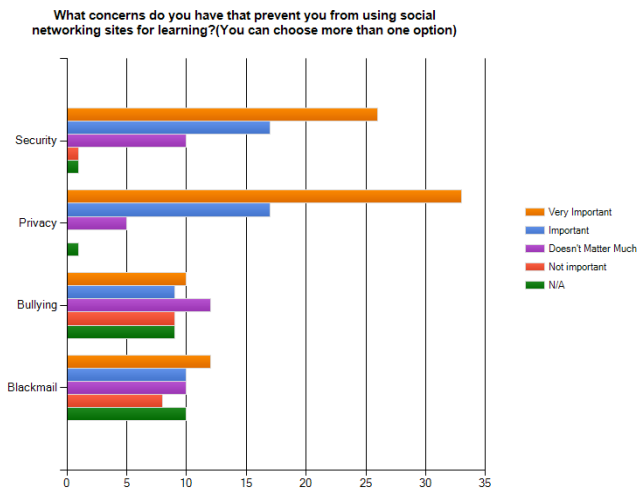


Figure 4. Factors preventing students from using SNS for e-learning

Figure 4 shows the distribution of the factors preventing students from using SNS for e-learning. Most of these computing students thought privacy was a major concern, with 58.9% considering it very important and another 30.4% considering it important. This was followed by security with 47.3% considering it a very important concern and another 30.9%, an important concern. In contrast, bullying and blackmail were two factors with only 20.4% and 24.4% concern.

Figure 5 shows that one third (38.8%) of respondents agreed that the use of SNS in e-learning will play an important role in the tertiary education sector in the future, with 14.3% in strong agreement.

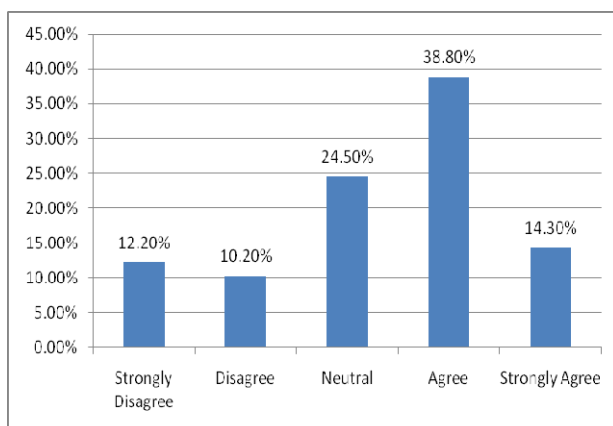


Figure 5. Opinions of the use of social network tools in e-learning playing an important part in studying at tertiary level in the future

The participants considered SNS as a supplementary tool to normal learning methods such as face-to-face discussion as well as to e-learning tools such as LMS and search engines. In terms of e-learning, search engines and email were considered more useful than SNS. This may be due to the amount of learning related information held in SNS being limited. This highlights that SNS are currently not a main stream tool in learning for these students but obviously play a supportive role.

Of the factors that had negative impact on using SNS for e-learning, security and privacy were found to be the most significant. Amongst the SNS features that facilitate learning, instant messaging and video/photo were the two most useful. Blog is a personalized environment and forum is a shared environment, however, there was no significant difference in the participants' preferences in the use of these in e-learning.

Attitudes towards using SNS for e-learning now and in the future were clearly positive. Although they did not use SNS much for their learning, the participants were very confident about the future of SNS in e-learning.

B. Interview Results

Nine interviews were conducted. Eight questions were asked, the results from undergraduates and postgraduates were studied respectively, and the key points regarding each question in the discussion were identified [10]. Due to the page limitation, only a summary of the results is reported below.

Questions:

1. What are the advantages of using social networking sites for e-learning?
2. What are the disadvantages of using social networking sites for e-learning? Why?
3. What experiences do you have using social networking sites and/or Web2.0 technologies in e-learning?
4. In your opinion, do social networking sites help in your e-learning now and future? If yes, how? If no, why?
5. How many people you know are using social networking sites? How many of them use these sites for e-learning? What are their attitudes towards this?
6. Are there any features of social networking sites that affect your decision to use social networking sites in your e-learning?
7. In your opinion, do the factors (such as network access, speed, security and privacy) impact your using social networking sites in e-learning on campus? Why?
8. Do you have any suggestions about the use of social networking sites for e-learning at present or future?

In summary, the views held by the undergraduates and the postgraduates were very similar. The following points are worth noting.

Responses to Question 1, indicate that *Communication* (Sharing opinion and other Communication), *Collaboration* (Collaborative studying), *Resource Sharing* (Useful e-learning resource), *Usefulness* (Studying efficiently, Meeting new

people) and *Ease of Use* (Convenient and comfortable) were clearly identified as SNS features that could facilitate e-learning. These findings are consistent with the research results published in [4], that *Communication*, *Collaboration* and *Resource Sharing* will have a significant influence on the educational usage of FaceBook; *Usefulness* and *Ease of Use* will have a significant influence on FaceBook adoption and will in turn have a contribution to the educational usage of FaceBook.

Issues that form barriers to using SNS in e-learning were identified by the responses to Question 2. These include *Synchronization* (Hard to get answers immediately), *Security and Privacy*, *Currency* (Online resource not up to date), *Efficiency* (Wasted time), *Authority* and *Network* (Access, Speed and Policy). Some of these issues, such as *Security and Privacy* and *Network* also featured heavily in the survey results. The *Synchronization* issue may explain why instant messaging was identified as the most important feature of SNS to facilitate e-learning in the survey results.

Responses to Question 3 reveal the participants' experiences with SNS. Most of the students have used FaceBook for *Resource Sharing* and *Communication*. Postgraduates used SNS more than undergraduate students, however, they used SNS less for e-learning than the undergraduates. During the interviews this was explored further and led to the finding that the postgraduates had higher standards regarding the quality and reliability of the resources.

The participants' attitudes towards using SNS for e-learning, explored using Question 4, were certainly positive. The factors that contribute to these positive attitudes included *Collaboration* (Collaborative studying) and *Communication* (Discussing with other students, Keep in touch anywhere, Sharing different opinions). These findings are in agreement with the Education Usage Model of FaceBook [4].

Question 5 was used to explore the experiences and attitudes of the participants' social community in relation to SNS and the use of SNS in e-learning. Some interviewees said they joined a SNS on the invitation of a friend. This conformed to the argument that *Social Influence* will have a significant influence on FaceBook adoption [4]. Obviously SNS were very popular in their social community. This should have a positive impact on the participants' SNS adoption and educational usage. It is worth noting that the undergraduates and the postgraduates had differing views on using SNS for e-learning. The undergraduates thought many of their fellow students made use of SNS to aid their learning while the postgraduates thought not many of their peers used SNS to aid their learning. This may be due to issues relating to currency and reliability and how these are viewed, as discussed under Question 3.

Features that might impact the participants' adoption and educational usage of SNS were explored using Question 6. These features included *Communication* (Online forum, Blogging, Chatting room, Bulletins), *Collaboration* (Group) and *Resource Sharing* (E-book collections, Sharing resources). It is worth noting that there was no special preference of blogging over online forum. This led to the question: Are personalized learning environments important to these computing students?

Question 7 investigated the factors that may have a negative impact on the participants using SNS in e-learning. These factors included *Security and Privacy* as well as *Efficiency*. Some of the undergraduates believed that these issues won't prevent them from using SNS for learning.

Responding to Question 8, the participants made suggestions for the improvement for the future usage of SNS in e-learning. It was observed that the postgraduates had better understanding of SNS than the undergraduates. The suggestions included the following.

- The concerns such as security, privacy and reliability of information and issues such as network bandwidth should be addressed.
- Provide training and guidance (training and education for web2.0).
- Provide more powerful features (virtual tutor, 3G mobile technologies support, LMS integration with SNS).
- Organized learning activities on SNS such as study groups on SNS.

IV. DISCUSSION

All the participants, being students in a computing department had at least a reasonable understanding of computing and communication technologies. Most of them had been using SNS for more than one year. Although they were using SNS for e-learning now or willing to use in the future, only a few were frequently using SNS for e-learning. These few students not only had a high level of comfort and satisfaction, but also their perceptions of advantages of the use of SNS in e-learning considerably exceeded the perceived disadvantages.

Most of the students thought SNS have good potential for e-learning. They identified the factors that could facilitate the usage of SNS in e-learning as *Collaboration*, *Communication*, *Resource Sharing*, *Social Influence*, *Usefulness* and *Ease of Use*. It's interesting to see that all these were included in the Education Usage Model of FaceBook proposed by [4]. As FaceBook was identified as the most popular SNS in this study as well, it can be said that the participants' view of this research partially verified the Model of [4] from New Zealand.

The main issues that might create hurdles for the students using SNS in e-learning were identified as *Security and Privacy*, *Content Authority*, *Content Currency*, *Network Issues*, *Real Time Synchronization* and *Efficiency*. Some of the participants mentioned problems such as the inability to type a mathematical equation or a chemical symbol as barriers to using SNS for learning.

Judging from the overall results it can be said that the use of SNS for e-learning is another way to help achieve study goals complementing other e-learning tools such as LMS and search engines and traditional learning methods such as face-to-face lectures and discussion. SNS, as a supportive environment, allows communication and collaboration during learning, which positively influences learner development [3].

However, the full potential of using SNS in e-learning has not yet been realized and there are a number of reasons for this. Some current features of SNS were not fully utilized. For example, there was no obvious evidence showing that the students were using SNS to build study relationships with more capable peers from different locations remotely.

How SNS can be effectively used in e-learning deserves further study [12]. For improvement, the students need to be guided and trained in using SNS for e-learning. The perception (and, perhaps the intention of SNS developers) that the main purpose of SNS is for social activities and not for learning activities [5] may hinder the use of SNS in learning.

Resolving some of the issues raised by the participants of this study may make SNS more valuable and effective in e-learning. We could either integrate SNS with appropriate LMS and other systems [6, 7] or find out what types of learning are suitable to use SNS.

The case studies in [8] provide valuable experiences. In the four cases presented, the first case (to facilitate exam revision) and the last case (to keep in touch while studying in different locations) were more successful, which suggested that SNS are more suitable for broader topic and remote learning. In addition, the learning activities on SNS should be planned and organized. For example, [9] proposed an idea of grouping distributed e-learners with similar interests.

The following is a proposed set of guidelines for using SNS in e-learning:

- Select a suitable SNS.
- Select suitable learning contents.
- Train the students to become both technique competent and pedagogy competent.
- Group the students in an appropriate manner.
- Design learning tasks carefully, which should include task description, learning objectives, milestones, member roles and implement steps.
- Provide authoritative and current learning materials.
- Check progress regularly.

V. CONCLUSION

The findings of this study, although limited to computing students in one institution in a small country, are significant. Further studies are needed to explore how students of engineering, other sciences and disciplines use or plan to use SNS in their e-learning, by investigating their attitudes, behaviors, knowledge and views of the use of SNS in e-learning.

Noting that the role of SNS in e-learning is supportive and important, SNS are underutilized in e-learning, even computing students need guidance and training to make better use of the many features of SNS, learning activities on SNS need careful planning and organization, there is much work to be done.

Collaboration, communication, resource sharing, social influence, usefulness and ease of use, the desired features identified in this study, and supported by other related studies, can all be built into a new SNS/LMS combining the best features of, YouTube, Twitter, FaceBook and Moodle, taking care to eliminate or minimize the barriers to the use of SNS in e-learning, such as security, privacy, content authority and currency, real time synchronization and inefficiency.

We believe that the use of SNS to support e-learning can and will increase as network bandwidths increase, reliability and currency of content improve and security and privacy issues are sorted out with better legislation. We also believe that some major integration of SNS and LMS will soon happen as identified by some of the participants of this study. ATutor is an example of a LMS that has a social networking module which can be used to create a social learning environment.

The proposed guidelines for using SNS in e-learning may be further refined in practice and adapted for use in schools, tertiary institutions and adult education in the future. We are working on refining and putting these guidelines into practice as well as planning further studies with larger numbers of students and from other disciplines.

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What are the Implications for Teaching?

An Analysis of How Educational Implications are Represented in Engineering Education

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Abstract – The objective of this work is to explore how implications for educational practice are represented in the scholarly literature of engineering education. This work is motivated by the increasing urgency to understand how research can be used to transform educational practice. Because scholarly writing (such as conference papers and journal articles) represents one place where researchers articulate ideas about how their research can be used (i.e., educational implications), an analysis of how such implications are represented can provide insight into ideas about the uses we imagine for our research. Once we have characterized the vision of use, we can step back and think about whether the collective vision we present may provide clues to the more general issue of transforming education.

Index Terms – Educational implications, Rhetoric of science

I. INTRODUCTION

In recent years, the engineering education community has invested significant energy and resources on the creation of a rigorous empirical knowledge base to support the transformation of engineering education practice. The idea is that this research will contribute to the transformation of engineering education; however, there is evidence of impatience with the speed by which such transformation is happening.

In this exploratory project, we are seeking to add to the conversation by applying the Rhetoric of Science [1] to the analysis of journal articles that present research. Because scholarly writing (such as conference papers and journal articles) represents one place where researchers articulate ideas about how their research can be used (i.e., educational implications), an analysis of how such implications are represented can provide insight into ideas about the uses we imagine for our research. The specific questions addressed in this paper are (1) To what extent are implications for educational practice emphasized in the most recent year of the *Journal of Engineering Education*? and (2) When implications for educational practice are present, who is implicated?

Answers to these questions can create a base for pragmatic suggestions for writing journal articles. The answers to these questions can also provide opportunities for reflection, even critical reflection, on the concept,

politics, and other forces that frame research-to-practice efforts in engineering education.

II. BACKGROUND

In this section, we explore two questions related to the issue of research informing practice: (1) what can research offer practice and (2) what does practice need from research. In addition, we motivate the idea of journal articles as a place to explore the connection of research and practice. In this section, we draw on ideas from engineering education but also from the field of human-computer interaction (HCI).

What can research offer practice?

In 2005 Dourish, an ethnographer who works in the field of HCI, stirred up that community with a paper entitled "Implications for Design" [2]. This paper explored the types of implications for design that ethnography can offer HCI, such as inspiration for new products. The work was motivated by a sense that members (reviewers) of the HCI community had narrow and strong expectations for what ethnography should offer design—specifically expectations that ethnographers should be able to provide design requirements.

The idea that different research methodologies have potentially different implications for practice raises at least two questions for the field of engineering education: What types of research are being done in the engineering education community and what types of implications for practice stem from these different types of research? While these are clearly large questions, one thing we do know is that the field of engineering education has become increasingly pluralistic in terms of research methods. A ramification of these observations is that we need a way to study the research-to-practice issue that is capable of connecting to the breadth of research being done in the community.

What does practice need from research?

In 2008, a designer involved in the HCI community again drew attention to the research-to-practice issue but this time by looking at it from the perspective of design [3]. In his paper entitled "The Nature of Design Practice and Implications for Interaction Design Research," Stolterman [3] explored the challenges of design as the creation of a "particular," and posited that designers are best helped by

research that offers concepts and new ways to think about things rather than prescriptions about exactly how to go about doing design. Connected to the realm of engineering education, such an analysis raises questions about the nature of teaching. What kind of thing is teaching?

Debates about the nature of teaching are actually at the heart of critiques of the evidence-based practice movement as it has been brought into education. The general idea of the evidence-based practice movement, which originated in medicine [4], is that research provides evidence that practitioners can use in order to make their decisions. In some instances of this ideal, evidence is loosely constructed and the decisions of practitioners are represented broadly. In other instances of this idea, however, evidence is understood to be experimental studies (ideally randomized controlled trials) and the evidence from such studies will indicate to practitioners what they should do. In critiquing this ideal, Biesta [5] focuses on a mismatch between assumptions about teaching and the reality of teaching. Interestingly, though, many publications on evidence-based practice in education focus on the use of evidence-based practice by leaders (i.e. principals) rather than classroom teachers.

Collectively, these ideas suggest that we need a way to study the research-to-practice issue that permits us to think about what we mean by practice such as what aspects of practice are supported and which practitioners we are talking about.

The role of journal articles

In this work, we have chosen to analyze articles in the Journal of Engineering Education [6]. This choice reflects the themes introduced in the previous two sections. First, by focusing on the research published in the journal we will ensure our analysis reflects the type of research being published in field. Second, because of the nature of the mission of the journal, a requirement of the journal is that authors make connections to practice. By analyzing these connections to practice, we can then look to see what aspects of practice are implicated, such as who is implicated.

Studying research papers is admittedly only a small window into the research to practice issue, and also a problematic window for a variety of reasons. For example, journal articles are not necessarily widely read and they are only one place where research is connected to practice. At the same time, journals are a foundational part of the scientific enterprise. The recognition that journals are foundational has led to their study in the realm of Rhetoric of Science [1], a field that we draw on in this work. Drawing on the Rhetoric of Science, our analysis below contains a quantitative component as well as a qualitative component.

III. METHODS

In this exploratory work, we examined the ways in which implications for education are represented in one year

of the Journal of Engineering Education (JEE). Our methodological choices aimed for a certain degree of rigor balanced by the goal of creating information to guide the next iteration of the method.

The sample

In this analysis, we focus on the April 2011, July 2011, October 2011, and January 2012 issues of JEE —the four most recent issues as of the writing of this paper. As shown in Table 1, the resulting set of thirty-one papers covers a diversity of topics and methods.

In order to focus our analysis, we decided to code the sections of the articles most likely to contain implications for educational practice: the abstract, the discussion, and any sections in the paper following the discussion. This approach reflected an idea that if implications for education were to be present, they would likely be in these sections, and further, if implications for education were present in other sections, they would likely be overlooked by most readers. With this approach, we coded a total of 2464 sentences. The number of sentences coded per article was variable, not only because the articles differed in length but also because some papers had combined their discussion with their results (via sections entitled "Results and Discussion"). As will be discussed further below, a small number of papers had sections specifically devoted to educational implications.

The coding approach

The coding process involved two major steps: determining if a sentence could be read as an implication for educational practice and, if so, determining who was implicated. Generally speaking, a sentence was considered to represent an implication for educational practice if it could be read as encouraging or even pushing an actor to engage in an action related to education. From an analytic standpoint, such an implication for educational practice could be represented in a sentence of the following form: *Because of finding x, actor with some degree of certainty should engage in action.* From preliminary explorations of the data, we knew that such sentences were present in the dataset. We also knew, however, that sentences were often experienced by the coders as implications for educational practice even when they did not follow this formula. For example, sentences might indicate that an action needs to be taken but not identify the actor who needs to take such an action. Because of the exploratory nature of this work, we took a liberal approach to coding. Below are examples of sentences representing implications for educational practice. These examples and others later are cross-referenced with the notation x(y)-z where x represent the volume, y represents the issue, and z represents the position of the specific paper within its issue. We selected this cross -referencing approach in order to focus attention on patterns in the results rather than the identity of the authors

- "At the university level, in assessing students' readiness, educators must go beyond standardized placement tests and subsequent placement in "remedial" courses and provide opportunities to develop

other academic success skills, and help students to be aware of and take advantage of the institutional resources in place designed to help them succeed." (101(1)-1)

- "We recognize that these types of academic support systems exist in many engineering colleges, however, our data point to the importance of continuing to allocate resources and promoting such programs in order to improve retention." (101(1)-1)
- "A recommendation from the study here, which showed that there are critical processes, is to couple a structured teaching approach, like Gray et al., with an assessment rubric, in order to document and dynamically respond to the changes in thinking and reasoning that result from pedagogical interventions." (100(3)-4)
- "Software could be created to guide the student, but also to record and analyze the path the student follows in reaching a solution."
- "DAA activities may offer a potential solution to the challenge of poor instruction, a cited cause of discontentment among undergraduates in STEM." (100(3)-4)
- "Including humanities courses across the freshman through senior years, particularly courses that include materials besides textbooks, may help students retain and develop a transactional and constructivist orientation to information and knowledge to a larger extent than is currently occurring." (100(2)-8)
- "Depending on the results of these studies, changes to the typical engineering curriculum may be required to nurture and strengthen students' innovation abilities throughout their undergraduate education." (101(1)-3)
- "In other words, the time has come to thoroughly examine and deconstruct how cultures of engineering education both reinforce masculine biases and (re)produce gendered identities." (100(2)-3)

In the second part of the coding, we analyzed each "implication for educational practice" sentence to determine who was implicated. If the sentence involved explicit identification of an actor, then we recorded the identity of the actor. If the sentence did not involve explicit identification of an actor (e.g., because the sentence was written in passive voice), then we noted the actor as implicit. For example, "faculty interested in implementing problem based learning" (100(2)-2) is an example of an explicitly identified actor while "students should be given feedback and opportunities to reflect on and evaluate their own team processes" (100(4)-2) represents an implication for educational practice in which the actor is implicit.

The coding procedure

Four coders (the four authors of this paper) were involved in the coding of the data. Each coder was responsible for coding all of the articles in one of the journal issues being studied. Several procedures were used in order to contribute to the rigor of the study at a level appropriate to this exploratory analysis. First, the coding approach was developed using an iterative process and refined based on issues raised by the group. Second, we maintained a detailed audit trail of our process. Third, our analysis of the coded data provided many opportunities for the coders to inspect and question aspects of the data coded by other coders—a form of a skeptical peer review. While no formal double coding was used in this process, three of the researchers read and reviewed articles beyond the ones to which they had been assigned. This helped in the review of the coding. In future stages of this research, we plan to use a double-coding procedure to contribute to rigor [7].

Analysis and interpretation

All of the coding was aggregated into a single Excel spreadsheet containing a row for each sentence in the coding sample. In addition, for each sentence that had been identified as an "implication for educational practice" sentence, our spreadsheet also contained notes about the identity of the agent who was implicated. We addressed the emphasis question quantitatively, by counting the number of sentences coded in each article, and qualitatively, by looking at the patterns created by the number of sentences coded and also the location of the sentences that were coded. We addressed the "who is implicated" question qualitatively, by looking across the recorded results to identify themes.

IV. RESULTS

In our analysis of how implications for educational practice are represented in the most recent issue of JEE, we noted variation in (a) the extent to which educational implications were emphasized by the authors, and (b) the identification of who is implicated.

Emphasis on Educational Implications?

The papers varied in the extent to which they emphasized educational implications. Table 1 presents the results of this analysis. The table consists of a row for each paper that was analyzed (each paper is identified by the issue and the paper number within the issue). For each paper, the table indicates the number of sentences that were analyzed, the number of sentences that were coded as an educational implication ("absolute emphasis"), and the percent of coded sentences that were educational implications ("relative emphasis"). The table is sorted in terms of the results for absolute emphasis.

As the table shows, absolute emphasis ranged from zero sentences to sixteen sentences, and relative emphasis ranged from zero percent to eighteen percent. In other words, some papers had a high level of emphasis on implications for educational practice while at least one paper did not address educational implications.

On the high end of emphasis, four papers were identified as having ten or more sentences devoted to educational implications, representing 10% or more of the sentences that were coded. The titles of these four papers suggest that these four papers were varied in terms of topic and methodology: (1) Using paper-and-pencil solutions to assess problem solving skill, (2) Leaving engineering: A multi-year single institution study, (3) The relationship between team discourse, self-efficacy, and individual achievement: A sequential mixed-methods study, and (4) Problem-based learning: Influence on students' learning in an electrical engineering course.

At the other end of the spectrum, seven papers had one or zero sentences devoted to educational implications, representing one to three percent of the sentences that were coded. This is not to say that these papers did not have any implications for future activity (e.g., these papers did have

implications for future research). Rather, the finding is that these papers placed low emphasis on implications for educational practice. The titles of these seven papers suggest that they were varied in terms of topic and methodology: (1) The motivational and transfer potential of disassemble/analyze/assemble activities, (2) Information fluency growth through engineering curricula: Analysis of students' text-processing skills and beliefs, (3) An experimental investigation of the innovation capabilities of undergraduate engineering students, (4) Feminist theory in three engineering education journals: 1995–2008, (5) A psychometric re-evaluation of the design, engineering and technology (DET) survey, (6) The socially responsible engineer: Assessing student attitudes of roles and responsibilities, and (7) Nonparametric survival analysis of the loss rate of undergraduate engineering students.

Table 1. Emphasis on Educational Implications

| Issue | Article | Coded | Absolute Emphasis | Relative Emphasis |
|-------------|---------|-------|-------------------|-------------------|
| 2011-3July | 4 | 93 | 16 | 0.17 |
| 2012-1Jan | 1 | 122 | 16 | 0.13 |
| 2011-4Oct | 2 | 82 | 10 | 0.12 |
| 2011-2April | 2 | 92 | 10 | 0.11 |
| 2011-4Oct | 4 | 123 | 9 | 0.07 |
| 2011-2April | 4 | 45 | 8 | 0.18 |
| 2011-3July | 8 | 59 | 7 | 0.12 |
| 2011-3July | 1 | 44 | 6 | 0.14 |
| 2012-1Jan | 7 | 83 | 6 | 0.07 |
| 2011-4Oct | 7 | 77 | 5 | 0.06 |
| 2011-2April | 5 | 80 | 5 | 0.06 |
| 2011-3July | 5 | 82 | 5 | 0.06 |
| 2012-1Jan | 5 | 120 | 5 | 0.04 |
| 2011-3July | 3 | 75 | 4 | 0.05 |
| 2011-2April | 1 | 92 | 4 | 0.04 |
| 2012-1Jan | 2 | 110 | 4 | 0.04 |
| 2012-1Jan | 6 | 123 | 4 | 0.03 |
| 2011-3July | 7 | 50 | 3 | 0.06 |
| 2011-2April | 7 | 63 | 3 | 0.05 |
| 2011-3July | 6 | 186 | 3 | 0.02 |
| 2012-1Jan | 4 | 40 | 2 | 0.05 |
| 2011-4Oct | 1 | 46 | 2 | 0.04 |
| 2011-4Oct | 3 | 67 | 2 | 0.03 |
| 2011-4Oct | 6 | 73 | 2 | 0.03 |
| 2012-1Jan | 3 | 36 | 1 | 0.03 |
| 2011-4Oct | 5 | 49 | 1 | 0.02 |
| 2011-2April | 3 | 61 | 1 | 0.02 |
| 2011-4Oct | 8 | 73 | 1 | 0.01 |
| 2011-3July | 2 | 84 | 1 | 0.01 |
| 2011-2April | 8 | 105 | 1 | 0.01 |
| 2011-2April | 6 | 26 | 0 | 0.00 |
| Min | | 26 | 0 | 0.00 |
| Max | | 186 | 16 | 0.18 |
| Median | | 77 | 4 | 0.05 |
| Average | | 79 | 5 | 0.06 |

Looking a bit beyond the quantitative emphasis measurements, it is interesting to note that five of the papers emphasized implications for educational practice by creating a section dedicated to this issue. For example, one

paper has a section entitled, “The ‘How’ – Implications for Curriculum Design and Teaching Practice” (100(4)-4), while another had a section entitled “Recommendations for Practice” (100(3)-8). The use of explicit sections or subsections makes it easy for a reader to readily see how the work presented in the paper may be applied to educational practice. In the other papers, the implications for educational practice were often interwoven with other discussion or conclusion points.

Who is Implicated?

The implications for educational practice sentences were almost evenly divided between those in which the actor was explicit (~47%) and those in which the actor was implicit (~53%). To better understand the nature of the explicitly identified actors, we tabulated the number of times different explicitly identified actors were referenced.

The following actors were implicated more than once. It is not surprising that the more frequently mentioned actors represent relatively generic terms. It is also interesting to see the relatively equal use of the generic terms educators, faculty, instructors, and practitioners. It is also interesting to note the appearance of the first persona plural (e.g., “We need to provide students with opportunities to engage the internal frame of reference with which our participants were particularly concerned”).

- educators (6)
- faculty (6)
- instructors (4)
- we (4)
- practitioners (3)
- researchers and practitioners (3)
- students (3)
- engineering education (2)
- engineering programs (2)
- institutions (2)

In our analysis, we also looked into the actors which were used more than once in the sample. Below is an alphabetical list of actors that were mentioned only once. It is interesting to note that some of the actors on this list are distinct from the actors listed above (e.g., ABET, educational practice, advisors), some are elaborations of the generic actors above (e.g., faculty implementing inductive teaching approaches), and some are compound actors (e.g., engineering professors and educational practitioners). It is also interesting to note that the categories vary in terms of how many people are being implicated (e.g., “educators at the university level” is a broader category than “high school summer camp”). The breadth of this list reminds us of the breadth of the engineering education system.

- an educator
- ABET
- advisors of teams in project-based learning programs
- college professors
- educational practice
- educational programs
- educators at the university level

- engineering colleges interested in increasing the level of preparation of students
- engineering colleges with the goal of increasing the self-efficacy of engineering students
- engineering educators
- engineering faculty
- engineering professors and educational practitioners
- engineering professors, educational practitioners and students
- engineering programs seeking to encourage program completion
- entire college or school
- faculty adopting instructional approaches, such as PBL, with expectations of seeing results similar to this study...
- faculty implementing inductive teaching approaches
- faculty implementing the PBL approach
- faculty who work with advisory boards and employers on the development of curriculum
- faculty interested in implementing problem based learning
- high school summer camp
- instructors and the students, and especially those just starting out or disappointed with their groups
- Instructors interested in scrutinizing homework quality
- K-12 and university educators
- K-12 practitioners who incorporate engineering education ideas in their classrooms
- outreach programs
- outreach programs focused on preparing students to study engineering in college
- outreach programs intended to prepare students to study engineering
- pre-engineering programs
- schools who graduate a large percentage of students who are underrepresented in engineering
- teachers
- the instructor
- the teacher
- those first starting out with the cooperative learning methodology, or disappointed with its initial results
- university researchers and K-12 practitioners alike

As noted above, in over half of the implications for educational practice sentences, the actor was implicit. In other words, the author is identifying an implication for educational practice but not specifically identifying who is expected to enact the practice. In some of these cases, the implications for educational practice were written in passive voice (e.g., "Vicarious experiences can be used to scaffold students' development of self-efficacy and effective teaming skills", 100(4)-2). Other sentence structures were also used. Analyzing the range of the sentence structures associated with implicit actors was beyond the scope of this paper.

V. DISCUSSION

Our goal in this paper has been to explore two questions related to implications for educational practice in the *Journal of Engineering Education*: the emphasis on this issue and the nature of who is implicated. In our analysis, we found variation to be a key feature of the answer to each question: variation in the level of emphasis on implications for education practice across the articles and variation in who is implicated. This suggests, in turn, that the discourse around educational implications is not a unified discourse.

It is interesting to think about how to interpret the varied *emphasis* on educational implications. In fact, the variation

raises more questions than it answers. For example, is one approach (e.g., low emphasis or high emphasis) more appropriate? Also, what might explain the variation that was observed? Is the variation the result of author preference, editor preference, or genre conventions? Or perhaps it is less about choice and more about the type of research. Perhaps different types of research and/or different research methods have different connections to practice? Another possibility is that different researchers have different capacities to imagine, identify, and articulate potential implications for practice. It is useful to note that the type of thinking associated with rigorous research is not the same as the type of thinking required to connect research to practice.

It is also interesting to think about the ramifications of different patterns of emphasis. For example, a consequence of having few or no clearly stated implications for educational practice is that this might cause readers to question the usability or relevance of the study. Further, when implications for educational practice are present but not in a dedicated section, they become harder to find and may simply be overlooked. As a result, if a reader does not have the imagination to make connections to practice, such connections might not be made regardless of whether such connections are possible. On the other hand, there are clearly challenges associated with including implications for educational practice, such as determining the best way to frame such implications (i.e., how assertive and specific should such implications be) and determining how much emphasis to place on such implications. While having explicitly articulated educational implications can be valuable, there could be negative ramifications to having too much focus on implications for educational practice. For example, a journal article (as an archival reference for the research) needs to fully address the relevant research issues and high emphasis on implications for educational practice could compete with emphasis being placed on the research.

The "who is implicated" analysis highlighted a split between explicitly and implicitly identified actors, and also a range of explicitly identified actors. Similar to above, it is possible that the split between explicitly and implicitly identified actors is related to author preferences, editor preferences, or genre conventions. It is also possible that deciding who is implicated by the research is simply challenging, since the system itself is composed of many people with multiple roles. Indeed, the range of explicitly identified actors in the "who is implicated" results remind us that engineering education is a large system. This breadth raises a question—how does an author know whom to focus on when there are potentially many agents who could do many things with the results of the research? Because such a question might be difficult to resolve, authors might respond by articulating implications for educational practice that do not implicate specific actors. However, such choices might decrease accountability felt by the reader.

This work is limited by its emphasis on only one year of articles in the *Journal of Engineering Education* and a coding approach that did not yet feature double coding and inter-rater reliability. Future research can address these issues and determine if the patterns identified by this analysis remain. Such future research can also explore additional issues in the data such as (a) what actions are highlighted in implications for educational practice, and (b) the extent to which implications for educational practice are connected to research findings.

V. THE IMPLICATIONS OF IMPLICATIONS

This work provides a basis for practical, scholarly, and even pedagogical implications. At a practical level, the findings suggest that there may be room to improve the writing of implications for educational practice so that, when they are present, they can be found and effectively understood by readers. For example, authors could consider adding explicit implications for practice sections to their articles, and editors of journals could consider providing guidelines about this issue. It is also possible that there could be a community solution that involves creating a space where additional "implications for educational practice" could be located. Of course such implications assume that it is appropriate or even desirable that implications for educational practice be explicitly articulated in journal articles and/or in another location.

This issue gives rise to the scholarly implication—that there may be value in exploring the cultural context that gives rise to different levels of emphasis and different levels of explicitness in the articulation of implications for educational practice. Our conversations among ourselves and with others around these findings suggest that the variability that we noticed in the data is related to important backstories concerning preferences, politics and power. In addition, as we have thought about this issue, we wonder about an assumption that researchers can always be expected to be able to identify the kinds of educational implications that their findings may have for educational practice and whether educational practitioners are prepared to read original research and identify educational implications of research findings. Complicating this issue further is the inherent complexity of education. Perhaps the variation in educational implications reflects variations in underlying ideas about the nature of educational practice.

Finally, our experience of doing this research has led us to believe that this research process has pedagogical value. In other words, when people analyze existing literature to understand the way implications for educational practice are handled in that literature, they learn a great deal. This idea deserves future investigation.

VI. CONCLUSION

This paper addressed the ways in which implications for educational practice are represented in scholarly work in engineering education. Contributions of this work include the findings concerning variation in emphasis and who is implicated, the coding approach that will make it possible to extend this work, and the ideas represented in our own implications section. In addition, a key contribution of this work is to draw attention to the issue of "implications for educational practice" as a topic that warrants further study if we are to succeed in using research to inform the transformation of engineering education.

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Development of the Science Technology Engineering and Mathematics – Active Listening Skills Assessment (STEM-ALSA)

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Abstract —The purpose of this investigation was to develop the STEM Active Listening Skills Assessment (STEM-ALSA), a conceptually grounded instrument designed to measure four components of active listening, a key element of communication in an academic setting. The STEM-ALSA is comprised of three unique scales that measure a person's knowledge (12 items), ability to apply (25 items), and self-efficacy (5 items) with respect to active listening. Two pilot studies were conducted with N = 99 upper level undergraduate students enrolled in STEM disciplines to develop and evaluate the instrument. Results of an exploratory factor analysis identified both a unidimensional factor structure for each of the three scales and total scores with adequate internal consistency reliability estimates. The STEM-ALSA provides a mechanism for measuring active listening skills among students in STEM.

Keywords—Assessment; communication; graduate students in STEM

I. INTRODUCTION

Effective communication skills are an essential commodity in today's workplace. In engineering, technology, and the sciences, communicating disciplinary knowledge to the public is considered critical. Interpersonal communication skills (ICS) are also recognized as key transdisciplinary capabilities necessary for career success [1]. For example, an estimated 50-75% of scientists' work involves communicating with others individually, in small groups, and in teams [2]. The *Engineer of 2020* report [3] and other researchers [4], [5], [6] have also highlighted the fact that communication skills will become increasingly important as engineers are required to communicate in globally diverse and interdisciplinary teams. However, despite the expressed importance of these communication skills, numerous research studies, reports from industrial recruiters, and anecdotal evidence by educators have indicated that graduates of science, technology, engineering, and mathematics (STEM) disciplines are inadequately equipped to communicate effectively in the workplace [7]. This leads organizations such as The Society for Manufacturing Engineers to list "lack of communication skills" among the top "competency gaps" in engineers' education [8].

In addition to plaguing recent graduates of STEM disciplines who work in industry, inadequate training in ICS at

the undergraduate level has implications for graduate studies in STEM. It has been stated that "science these days...increasingly draws on skills in written and oral communication with scientists and non-scientists alike" [9]. For the most part, however, the oral communications that are central in students' daily practices are conversational and informal. Additionally, students who are able to communicate their needs to their graduate program are more likely to complete their degrees [10]. In fact, recent research suggests that graduate students who take a more active role in developing ICS are more successful in graduate school [11], [12].

An ICS identified as a particularly important element for communicating across disciplines is "active listening" [13]. Active, or empathic, listening can be traced to Carl Rogers [14] and is a cornerstone of his humanistic psychology [15]. Since its introduction, active listening skills have been found to play an important role in effective communication and have now become a mainstay of communication training programs across a variety of fields [16].

In addition to being widely recognized as an important interpersonal communication skill, active listening has also been shown to be a teachable skill. For example, research has shown that the listening skills of counseling students [17] and helpline volunteers [18] improved with active listening training. Moreover, the effects of such training continued for at least nine months in the case of the helpline volunteers [19]. Yet, despite the importance of the skill and the fact that it has been shown to be something that can be learned, there are few empirically validated instruments available to measure active listening skills.

This paper discusses the development of the STEM Communication Skills Assessment (STEM-ALSA), which is comprised of three unique measures: knowledge of, self efficacy in the domain of, and skill in the application of active listening. The context of all the items in the instrument is the advisor-advisee relationship. Advising is at the heart of the institutional and interpersonal structures that make up graduate education [20]. Consequently, it is imperative that the advisor-advisee relationship takes on a supportive stance. This is especially the case for female doctoral students, for whom the graduate program milieu is often described as a "chilly

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climate” [21], [22]. The STEM-ALSA was developed for a specific study within the *CareerWISE* research program. In the following sections, we provide a brief description of *CareerWISE* to help situate the motivation for the instrument development, outline the process of instrument development, and describe the scales within the instrument in more detail.

II. CareerWISE RESEARCH PROGRAM

The *CareerWISE* research program is a large, NSF-funded, multidisciplinary research program housed at Arizona State University. The program strives to both understand the reasons that women in STEM doctoral programs drop out and to develop and disseminate a resource to strengthen key personal and interpersonal skills so that women will be better equipped to persist in their doctoral degree programs. Built on an extensive foundation of theory and research, the *CareerWISE* resource (<http://careerwise.asu.edu>) is an online resilience training program designed to address the personal and interpersonal challenges of women in science and engineering fields by strengthening their personal assets and supports [23]. Key objectives of the resilience training program are to enhance the communication skills of doctoral women and to improve interpersonal problem solving skills. The *CareerWISE* resource is unique in that it is an individualized program that pairs empirically based pedagogical materials with an interactive simulation environment designed to hone users’ ICS skills. It is the first program of its kind to provide systematic training in ICS customized for female students in STEM. Consequently, instruction in active listening skills is an essential building block in the ICS within the *CareerWISE* program.

III. OVERVIEW OF THE THE INSTRUMENT

The development of the STEM-ALSA was underscored by the following definition of active listening: “active listening requires that the listener try to understand the speaker’s own understanding of an experience without the listener’s own interpretive structures intruding on his or her understanding of the other person” [13, p. 35]. The goal in active listening is to develop a clear understanding of the speaker’s concern and also to clearly communicate the listener’s interest in the speaker’s message [18]. The *CareerWISE* team specified the following four sub skills for active listening and defined them as indicated in Table I: asking open ended questions, listening for critical information, communicating via nonverbal cues, and perception checking. Items in the instrument were specifically included to assess each of these four elements.

The STEM-ALSA is comprised of three unique scales. The Knowledge Assessment scale measures the respondent’s self-reported current knowledge of active listening. The following are two sample items from this scale: “I know how to restate a speaker’s message to verify my understanding” and “I know how to convey nonverbally that I am interested in what the other person is saying.” Response options for this scale are arrayed on a 5-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*).

The Self Efficacy Assessment scale is designed to measure an individual’s confidence in her own ability to use active listening skills in an academic setting. Two sample items from

this scale are: “I can detect the important messages in a conversation with professors,” and “I can ensure that I have understood the speaker’s message.” Response options for this scale are also arrayed on a 5-point Likert scale, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*).

TABLE I. DESCRIPTION OF ACTIVE LISTENING SUB-SKILLS

| | |
|------------------------------------|---|
| Asking open-ended questions | Questions that are broadly framed to encourage elaboration and allow for responses other than yes or no. |
| Attending to nonverbal cues | Observing the speaker’s nonverbal cues (e.g., facial expressions, hand gestures, posture, etc.) for information about the meaning of the speaker’s message. |
| Listening for critical information | Identifying the main points of a speaker’s message. |
| Perception checking | Ensuring that the listener understands the speaker’s message by paraphrasing the listener’s interpretation of the speaker’s feelings and message content. |

The third scale, Skills Assessment, measures the participant’s ability to actually apply her active listening skills. Skills are often measured using an observation rating approach [24]. However, actual observation can be costly and time intensive. To get around this issue, the STEM-ALSA uses a self-report format to measure skill application. In this section of the instrument, a series of scenarios is presented, modeling situations that could realistically occur for a female doctoral student in STEM. Each scenario includes a stated goal for the student. Following each scenario are four responses, each corresponding to a particular course of action that could assist or hinder the student in achieving her desired outcome. Participants are asked to rate the likelihood of achieving the desired goal for each action on a five-point Likert scale with response options ranging from 1 (*very unlikely*) to 5 (*very likely*). Figure I gives a sample scenario and its corresponding items.

A month ago, Dr. Simpson asked Sarah to organize an informal bi-weekly meeting at which graduate students from the department would present their research to each other. Today is the first of those meetings, and Sarah is presenting her own research to kick things off. During her presentation, she notices that Dr. Simpson appears to be falling asleep and is not paying attention to what she is saying. For each of the following actions, indicate how likely it is to assist Sarah in getting his attention.

1. Pause for a moment to convey nonverbally that she is waiting for his attention.
2. Talk as usual while ignoring his lack of interest.
3. Catch Dr. Simpson’s gaze when he looks up.
4. Speak with more animation and address him by name.

Figure I: Sample item from the Skill Assessment scale

IV. INSTRUMENT DEVELOPMENT METHOD AND RESULTS

The STEM-ALSA instrument was developed in three phases. The first phase consisted of initial item development and expert feedback, the second phase involved piloting and then modifying the instrument based on expert feedback (pilot study #1), and the third phase included a second pilot and associated modifications (pilot study #2).

A. Phase 1 – Initial Item Development

Initially, 16 items were written for the Knowledge Assessment scale, 32 items for the Skills Assessment scale, and 8 items for the Self Efficacy Assessment scale. Items were developed using the literature on active listening and were examined by an interdisciplinary research team consisting of students and faculty from the disciplines of counseling psychology, engineering, and educational technology. To assess content validity, three experts in psychological measurement and interpersonal communication provided open-ended comments on the original items in each of the three scales. The experts rated each item on content appropriateness and clarity/readability using a 5-point scale that ranged from 1 (*not at all appropriate or clear*) to 5 (*very appropriate or clear*). Based on their feedback, several items were revised for clarification. Two of the original content experts then re-evaluated the three revised measures for appropriateness and clarity.

B. Phase 2 – Pilot Study #1 Methods

The purpose of pilot study #1 was to examine the initial factor structures of the items in each of the three scales in the STEM-ALSA instrument. During the pilot, undergraduate women majoring in mathematics, sciences, and engineering at a large southwestern public university were recruited through university organizations and contacts within the departments. Participants in the study were given a short online introduction to communication skills and then were presented with the instrument so that their active listening skills could be assessed. Demographic information was also collected from participants.

A total of 72 participants (primarily juniors and seniors with an average age of 21.6) completed the anonymous online pilot study. The majority of participants reported that they were US citizens with English as their primary language, and over 90% of those who responded stated they had an advisor with whom they interacted. Participants who completed the study were given a \$25 gift card redeemable at the university bookstore.

Using the participant responses, a principal-components analysis was performed on the items in the STEM-ALSA instrument. A separate analysis was performed for each of the three scales. Of note is that the responses in the Skills Section were scored in a unique way. First, three experts were asked to score each item for how likely it would be to produce the desired outcome. The mean of those values was recorded as the final “best answer.” Participant scores, then, were recoded based on this best answer. Participant responses that were in the same direction as the best answer (i.e., above or below the score of “3”, the midpoint of the scale) were scored as “1,” and those that were not in the direction of the best answer were scored as “0.” For example, if the best answer based on for an item based on expert scoring was 4.33, and a participant’s score was 5 (also above a score of “3”), then the participant’s score was recoded to be a “1.” On the other hand, if the participant’s score was “2”, which is in opposite direction of the best answer, the participant score was recoded to be a “0.”

C. Phase 2 – Pilot Study #1 Results

Analyses of each of the three scales in the STEM-ALSA indicated that a one-factor solution was most interpretable. In the Knowledge Assessment scale, the factor structure accounted for 33.31% of the variance. All 16 items loaded at or above 0.40, and the internal consistency of the scale was good, with a Cronbach’s alpha [25], of 0.84. In the Self-Efficacy scale, three of the eight items were deleted, as the factor only accounted for a small amount of their unique variance. After excluding these three variables, the structure of this scale was reanalyzed. The revised structure accounted for 62% of the total variance and was comprised of five items that loaded above 0.70. Cronbach’s alpha [25] for the total score of the one factor solution in the Self Efficacy scale was found to be 0.85. The results were not quite as good for the Skills Assessment scale. The one-factor solution in that scale, while most interpretable, only accounted for 14 % of the total variance. The Cronbach’s alpha coefficient [25] for the total score of the one factor solution in the Skills Assessment scale was also only 0.38.

D. Phase 3 – Pilot Study #2 Methods

After completing pilot study #1, the three experts in the areas of interpersonal communications and psychometrics were again consulted to examine the items of the three scales, paying particular attention to the Skills Assessment scale. Based on their analysis, items in the Skills Assessment scale for which the experts disagreed on the general direction of the best response were dropped (e.g., when two of the three experts thought it was generally a good course of action, and one didn’t).

Following the expert input, a second pilot study was conducted to further examine the factor structure of the revised STEM-CSA. For this pilot, undergraduate students in an introductory computer informatics course at a large southwestern public university were recruited. As in the first pilot study, participants in this pilot were given a short online introduction to communication skills and then were presented with the instrument so that their active listening skills could be assessed. Demographic information was also collected. Students’ majors included liberal arts and communication, as well as computing. A total of 27 participants (primarily sophomores and juniors, with an average age of 21.3) completed the second pilot study. The majority of participants reported that they were US citizens with English as their primary language, and over 76% of those who responded stated they had an advisor with whom they interacted. Participants who completed the study received course credit for their participation.

E. Phase 2 – Pilot Study #2 Results

Analysis of the Knowledge Assessment scale in pilot study #2 supported the one-factor solution. However, the factor solution accounted for less than 50% of the individual variance for four of the 16 items. Consequently, these four items were excluded from the instrument. The revised structure accounted for 56% of the total variance and included 12 items that loaded above 0.50 (See Table II.). Cronbach’s alpha for the total score of the one factor solution was found to be 0.93.

A one-factor solution in the second analysis of the Self Efficacy Assessment was also robust and conceptually sound. The measure accounted for 69% of the total variance, and included 5 items that loaded above 0.70 (See Table III.). The alpha coefficient for the total score of the one factor solution was found to be 0.88.

Based on expert suggestion and the statistical results of pilot study #1, a number of items were deleted and/or revised in the skills-assessment section. Analysis of the revised, 25 item STEM- Skills Assessment indicated that a one-factor solution again yielded the most interpretable solution. This factor structure accounted for 16% of the variance. The alpha coefficient for the total score of the one factor solution was found to be 0.52. Factor loadings ranged from 0.04 to 0.72. Therefore no support was found for this scale. As such, further revision is necessary.

V. CONCLUSION

The development and initial validation of the STEM-ALSA is an important preliminary step in filling the gap of empirically-validated instruments for measuring active listening. The scales, Knowledge Assessment, Self Efficacy Assessment, and Skills Assessment were designed to measure a respondent's perceived knowledge, self efficacy, and ability to apply active listening skills respectively.

The results indicated that two of the three scales in the instrument, Knowledge and Self Efficacy, demonstrated high internal consistency and fit a unidimensional factor solution. STEM-ALSA also contained a unique section for measuring the application of active listening skills. In this section, a scenario based approach was used, representing a novel approach for measuring the ability to apply active listening skills. However, the analyses suggest that this section of the instrument needs further validation and examination of the factor structure. In future work, we plan to further assess the scenario based approach of the Skills Assessment scale and examine the construct validity of the STEM-ALSA scales.

Finally, of note is that although the STEM-ALSA was developed for use in the context of a specific study, further studies can evaluate the usefulness of the instrument for measuring academic communication skills in other populations (e.g., STEM undergraduate students) as well as within other professions.

TABLE II. STEM-KNOWLEDGE ASSESSMENT ITEMS, FACTOR LOADINGS, MEANS, AND STANDARD DEVIATIONS FOR STUDY 2

| Items | Factor 1 loadings | M | SD |
|--|-------------------|------|------|
| 1. I know how to quiet my own thoughts in order to listen carefully. | 0.57 | 3.93 | .96 |
| 2. I know how to listen and watch for the main points of a speaker's message. | 0.71 | 4.37 | .69 |
| 3. I know how to identify the overarching message even when other topics come up. | 0.81 | 3.63 | 1.08 |
| 4. I know how to ask a question that doesn't give away the answer I'm hoping to receive. | 0.70 | 3.96 | .90 |

| | | | |
|---|-------------|------|------|
| 5. I know how to ask questions that will encourage the other person to elaborate. | 0.76 | 3.85 | 1.20 |
| 6. I know how to find out more about the other person's perspective. | 0.75 | 4.19 | .79 |
| 7. I know how to ensure that I have understood someone's point of view. | 0.78 | 3.96 | 1.09 |
| 8. I know how to restate a speaker's message to verify my understanding. | 0.82 | 4.19 | .92 |
| 9. I know how to check whether what I heard is what the speaker meant. | 0.87 | 3.81 | 1.04 |
| 10. I know how to convey nonverbally that I am interested in what the other person is saying. | 0.73 | 4.11 | 1.05 |
| 11. I know how to recognize when someone I am conversing with is distracted. | 0.72 | 4.26 | .984 |
| 12. I know how to be consistent in what I'm saying and how I'm saying it. | 0.71 | 3.70 | 1.10 |

Note.. Scores on individual items in the STEM- CSA Knowledge Assessment scale ranged from 1-5. Total scores ranged from 5-60.

TABLE III. SELF EFFICACY ASSESSMENT ITEMS, FACTOR LOADINGS, MEANS, AND STANDARD DEVIATIONS FOR STUDY 1

| Items | Factor 1 loadings | M | SD |
|---|-------------------|------|------|
| 1. I can detect the important messages in a conversation with professors. | 0.86 | 3.93 | 0.92 |
| 2. I can identify the intended meaning of a verbal message even when it is phrased ambiguously. | 0.88 | 4.04 | 0.85 |
| 3. I can behave in a manner that is consistent with how I am feeling. | 0.72 | 3.78 | 0.97 |
| 4. I can verify my perceptions of what the other person is telling me. | 0.90 | 3.81 | 0.88 |
| 5. I can ensure that I have understood the speakers' message. | 0.77 | 3.78 | 0.85 |

Note.. Scores on individual items in the STEM- CSA Self Efficacy Assessment scale ranged from 1-5. Total scores ranged from 5-25.

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Implementing an Outcome-Based Assessment Technique in Applied and Theoretical Courses

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Abstract— This paper presents experiences with implementing a grading technique to closely couple student performance on specific course outcomes with student grades. The course selected for this technique is an undergraduate computer modeling and simulation course, which required an individual research component in addition to assignments and in-class tests. This class tested a technique whereby assignment of aggregated numerical scores for homework or tests was replaced by pass/fail feedback on individual course outcomes. Each assignment or test enumerated which specific course outcomes potentially satisfied within the assignment. Outcomes loosely correlate to Bloom's taxonomy levels of recognition, understanding, application, and creation. Student feedback reported that the technique enhanced learning, though an increased tendency towards procrastination was also reported. Instructor experiences were positive, with the assessment technique integrating easily with course design and delivery.

Keywords—Assessment, Criteria Based Assessment, Outcomes Based Assessment, Learning Outcomes

I. INTRODUCTION

This paper presents experiences with implementing a grading technique that closely coupled student performance on specific course outcomes with student grades. While instructors have access to a wide range of assessment techniques, effective techniques should strive to be formative, learner centered, ongoing, and align closely with course syllabus [1][2][3]. Additionally, the technique should measurably support an institution's goals and be an integral part of the planning and teaching processes [4][5][3]. This class tested a technique whereby student performance was assessed using pass/fail feedback on individual course outcomes.

Two courses were selected for this technique. The first is an undergraduate computer modeling and simulation (M&S) survey course. Course material covered a wide range of M&S concepts, followed by in-depth presentation of the critical challenges currently confronting the M&S community. In addition to assignments and in-class tests, students were required to design, implement, and document a unique simulation experiment that investigated a topic of their choice.

The project provides students with opportunities to display mastery of course topics, and affords an opportunity to reinforce technical writing skills ancillary to the core course topics. The second course is a computer science organization of programming languages course. This course provides a comparative study of programming paradigms, and the content has more emphasis on theoretical concepts than the modeling and simulation course. Formal language concepts are introduced, related to real world programming paradigms, and reinforced through language design and programming assignments.

Traditional assessment techniques do not necessarily tie mastery of course topics to a final grade. A typical process may loosely be described as identifying a desired skill, creating an activity to demonstrate the skill, assign a numeric value to the demonstration, and assign a letter grade based on numeric totals. This process potentially encourages students to focus on numeric scores or letter grades while losing sight of course learning objectives.

Some educators advocate techniques that employ criteria based assessment of outcomes as indicators of learning [2]. Learning outcomes are a set of distinct and well defined set of skills or knowledge that students should be able to demonstrate as a result of the course [6][7]. Measurement of outcomes must be based on some observable event [7], so the measurement criteria provided to students contains actions words such as "define," "distinguish," "solve," or "design." Instructors implementing an outcomes based assessment technique should use the outcomes as a focus during course preparation. The instructor must shape course content and assessment opportunities such that students understand what they are to learn, and understand how they are to demonstrate their knowledge. A focus on the outcomes during the planning period facilitates this goal [8]. Introduction of outcomes alone does not modify the assessment process described above. The technique described in this paper was to express desired skills as learning outcomes, develop activities in which students may demonstrate those skills, and assess each outcome on a pass/fail basis. Course letter grades were assigned based on the number and complexity of the outcomes demonstrated as described in Section III.

The outcomes utilized in this study loosely correlate to Bloom's taxonomy levels of knowledge/recognition, understanding, application, and analysis/creation [7]. The highest level of mastery assessed was the ability of students to create and analyze their own working examples. The inclusion of higher levels, such as synthesis, was not deemed appropriate for this undergraduate survey course. The Bloom taxonomy levels as presented to the students are:

- Level 1 (Recognition): Students demonstrate recognition by simply providing a working definition of a glossary term.
- Level 2 (Understanding): Understanding is demonstrated through correct usage of a term, or identification of the principle, while providing feedback on reading material. The student must justify the usage by referencing the key attributes that make the reference appropriate.
- Level 3 (Application): Application level outcomes were satisfied by using a concept or analytical technique to solve a problem provided on test or assignments.
- Level 4 (Analysis): Students demonstrate the ability to create new material for outcomes through completion and documentation of a large or small project.

For example, the term *dynamic verification* refers to any technique in which the correctness of a simulation model is assessed by running the simulation. The student demonstrates completion of the outcomes for *dynamic verification* by supplying a definition for the term (Level 1, Recognition), justifying why a described verification technique is or is not dynamic (Level 2, Understanding), describing how a dynamic verification technique could be applied to an example problem (Level 3, Application), and creating a dynamic verification plan for their course project (Level 4, Analysis).

II. IMPLEMENTATION

A detailed list of course outcomes was drawn up by the instructor as part of course preparation. This list was provided to students as part of the introductory course materials (Table 1). Explanatory material as to how each outcome level may be satisfied was also provided. Each assignment, test, and project deliverable enumerated which specific course outcomes were potentially satisfied within the assignment. The instructor found it most useful to explicitly tie an outcome to a test or assignment question. For example, one exam assessed a portion of the outcomes listed in Table 1. A short functional description of a notional simulation named "The Altruism Game" was presented to the students with the following questions.

1. Sketch out how this simulation could be created using a CFD model. (Level 2 CFD, Level 3 CFD)
2. Sketch out how the Altruism game could be created using Agent Based techniques. (Level 2 Agent Based, Level 3 Agent Based)
3. Sketch out how the Altruism game could be created using a Discrete Event Model. (Level 2 Discrete Event, Level 3 Discrete Event)

Each question requires that the student demonstrate that they know **why** their solution was of the requested simulation type, (Level 2 outcome), and then **create** a high level design description of a simulation. Students received feedback via a tracking sheet noting all outcomes demonstrated thus far. This feedback acted as a formative assessment, as students were allowed to re-visit missed outcomes during future assignments in order to gain credit for them later in the semester. The ability to repeatedly attempt the same outcome was viewed by the author as in keeping with the goal of outcomes being an ongoing part of learning [1][5].

Each course assessed students via homework assignments, tests, and projects. Level 1, 2, and 3 outcomes were assessed primarily via homework and test questions. Level 4 outcomes required the students to display a capability to deeply analyze an aspect of the topic. This was accomplished in the modeling and simulation course via the course project, which required that the student design, implement, and report on a relatively sophisticated and in the programming languages course through course assignments where the class wrote language requirements documents, and designed small programming languages.

Table 1: Partial List of course Outcomes

| | Level 1 | Level 2 | Level 3 | Level 4 |
|----------------------------------|---------|---------|---------|---------|
| Model (1) | 1 | 1 | | |
| Simulation (1) | 1 | 1 | | |
| Finite Element Modeling (2) | 1 | 1 | | |
| Computational Fluid Dynamics (2) | 1 | 1 | 1 | |
| Discrete Event Simulation (2) | 1 | 1 | 1 | |
| Agent Based Simulation (2) | 1 | 1 | 1 | |

III. IMPACT ON COURSE PREPARATION AND PRESENTATION

The use of this grading scheme presented several benefits and challenges. The presence of clearly defined learning objectives or outcomes is believed to assist in course organization, lecture presentation, and creation of assignments [7]. Overall course preparation time was not significantly affected from previous semesters offering the same course. The organization of topics, lecture schedule, and lecture content were assisted by the unity of the process. The instructor was cognizant of the need to provide opportunities to obtain credit for specific outcomes, which drove the design of assignments and tests. Since outcomes were equally weighted, the issues of how much weight to assign to a specific skill, or aspect of problem solution, were avoided. Grading student work on a pass/fail criterion resulted in a reduction in time to grade student work. The percentage of course outcomes achieved in each of the outcome levels was used as the basis for computing overall course letter grades (Table 2). Thus, the goal of removing the potentially arbitrary assignment of traditional 0 – 100% grading schemes was not fully achieved. However, the

grading scheme did result in a concise record of attainment of specific outcomes at all levels to serve as grade justification if needed. Therefore, student performance was tied to course grade in this fashion.

TABLE2 – COURSE GRADE BASED ON ACHEIVEMENT OF OUTCOMES

| Level | 1 | 2 | 3 | 4 |
|-----------|----|----|----|----|
| Available | 84 | 59 | 38 | 24 |
| A | 76 | 36 | 32 | 16 |
| B | 76 | 32 | 28 | 8 |
| C | 68 | 28 | 24 | 4 |
| D | 64 | 24 | 16 | 0 |

IV. IMPACT ON STUDENT EXPERIENCES

Boud proposes seven principles to keep in mind when designing and performing effective assessments [3]. Among these are that assessment and feedback should actively improve learning, engage students in learning that is productive, and allows students and teachers become partners in learning [3]. The focus on demonstrating skills based on a specific outcome, and the existence of multiple opportunities to demonstrate those skills appears to contribute to those results.

Students reported less test anxiety, citing two reasons. First, students knew that outcomes not achieved on a specific test may be achieved later. This contrasts with a traditional setting where each test serves as the only opportunity to capture a fixed percentage of total points available in a course. Second, since students were made aware of what outcomes they had not yet achieved in the course, they were able to target parts of the test that would potentially yield the highest results.

The most prominent negative aspect of this grading scheme during the initial trial was that students demonstrated an increased tendency to procrastinate. This trial occurred during the modeling and simulation course, and affected student completion of the course project. Two mechanisms were identified to encourage students to perform timely work in the future. The first is to enforce due dates after which certain outcomes would no longer be accepted. This technique was implemented in the programming languages course and eliminated the tendency to procrastinate. The second technique is specific to courses having a lengthy course project experience. This technique would require students to obtain permission from the course instructor to proceed from one project phase to the next. Since the project should provide a significant opportunity to obtain level 4 outcomes, this would encourage timely completion of project goals.

Students participate in an online course evaluation survey at the end of each semester. Students were encouraged to provide feedback on the use of outcomes in the course assessment. Positive responses were as follows:

“Providing us with learning outcomes to complete is a lot less stressful than raw grades. We have multiple opportunities to complete these outcomes so it's a very fair class setting.”

“Learning [sic] outcome style of assesment [sic] made it easy to identify what needed to be learned & eliminated the pressure of tests by not emphasising [sic] a time coonstraint [sic] on knowing the material.”

“No stress tests due to the grading system”

“The grading system really requires the students to know and understand the course material to succeed in the course. It doesn't [sic] require memorization and promotes learning.”

“A decrease in pressure due to the grading system allowed for flexibility in time management. “

“The outcomes were clearly addressed during class and gave multiple ways to achieve those outcomes. Many other classes try to implement this method but fail because the outcomes were not clearly addressed. In this class the professor made the material understandable. He made sure that we achieved the outcomes.”

Negative responses focused on the need for timely feedback on their progress in completing outcomes. For the programming languages course, instructor feedback was not as timely as the system required, resulting in the following negative student feedback responses:

“The grading system was difficult in determining were [sic] you stood during the semester but I still like the grading system.”

“Not enough assessment. I liked the new grading scheme but it would have been nice to get opportunities to get points.”

“no feed back on our work”

“The lack of feedback for the entire course made many of us uneasy.”

These responses highlight the need for timely and continuous feedback from the instructor in order for students to self-assess their progress and manage their time effectively.

V. SUMMARY AND FUTURE WORK

The author tested a technique whereby student performance was assessed using pass/fail feedback on individual course outcomes. This technique was attempted in two courses having a mixture of theoretical and applied course material. This technique was seen as consistent with current trends in assessment techniques [1][2][4][5], and arguably tied student performance more directly to assignment of course letter grades. The instructor viewed the experience favorably, and experienced no additional workload while reporting a deeper alignment of assessment with other course activities. Student

feedback was positive for the most part. Student's identified the focus on outcomes as an enhancement to the learning process, while reporting an increased tendency to procrastinate. Offering multiple opportunities to demonstrate achievement for a single objective must therefore be coupled with a firm "last chance" date in order to reduce the tendency to procrastinate. Student feedback made it clear that timely feedback is an essential part of this process. Feedback allows the students to self-assess and manage their time effectively.

The author intends to continue to utilize and refine this assessment technique for future courses. Students identified the focus on outcomes as an enhancement to learning. Since learning objectives were clearly identified, effort applied to learning was consistent with effort applied to obtain a grade. This was consistent with assessment intent and good practices [1][2][5].

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Application of item response theory (IRT) for the generation of adaptive assessments in an introductory course on object-oriented programming.

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Abstract— Assessment process in one of the most important issues in the learning process and in many cases it is the process that define the sequence of the instruction because it measures the performance of the student in the educational process. In last decades the inclusion of TICs in teaching-learning process has facilitated to address the diversity of students and teachers features. Learning technologies enhance have permitted to adapt the different ways of learning and teaching that coexist in the educational context through the generation of adaptations process as well as user modeling process. This paper describes the item response theory and how it can be applied in a test scenario of an online course for the generation of adaptive assessments within a course of introduction to Object Oriented Programming from items (assessment questions), which are available in online repositories. Being a probabilistic theory the article describes the variables to consider and how to calculate the probability that a student answers correctly a specific item, which is known as the student proficiency level or theta, based on a skill test and their previous answers. In other papers write for the authors it is described the experience of working with fedora commons repositories, which are distributed across a network, in order to have enough questions to be applied properly normalized in the adaptation process. These questions are described under the Dublin Core standard.

The main contributions of this project are the implementation of a probabilistic theory in the generation of adaptive assessment and use of distributed repositories that allow the reusability of items properly parameterized. A second phase of the research includes the implementation of the project (APIP) Accessible Profile Portable Item, allowing standardization of assessment items in a suitable format in the LOM. (*Abstract*)

Keywords—component; IRT (Item Response Theory), Adaptive Assessment, Items and Items Repositories.

I. INTRODUCTION

Information and communication technologies (ICT) have allowed the work done within the classroom can be complemented by using virtual learning environments that

involve a number of tools to enhance teaching and learning in extracurricular work. However, it should be a work of the academic community aim at improving the services provided by information technology, to enhance the services of teaching-learning that provides students and teachers, who are the end users of tools of this type.

For that reason and with the intention of making a contribution to improving the tools used in the field of teaching, this paper presents an research work into the process of adaptation assessments in a course of OOP in the university “Universidad Distrital Francisco José de Caldas” by using the item response theory (IRT). The article presents the main statements of the IRT and how it was applied to an online course for the generation of adaptive assessments, based on the student proficiency level.

Additionally, the last section of this paper presents an explanation of the use of learning repositories and how they enhance the generation of an adaptive assessment and in a general way on learning management systems.

II. BACKGROUND

Previous works [1] [2] [3] deal with the problem to measure student competence level based on the Classical Test Theory (CTT). Assessment Structures in the IMS Learning Design (IMS LD) [2] have been automatically generated using planning techniques [3]. These structures are organized in different level of competences according to a particular scale of measure based in the Bloom’s taxonomy [4]. The structures also define the course sequence, i.e. the student growth in his/her competence level through the different Bloom knowledge levels.

In this paper, we are focusing on the automatic generation of Item Response Theory (IRT) based adaptive tests in the contexts of a Unit of Learning (UoL). ITR offers us the opportunity to alleviate the workload for designers of adaptive courses on the complexity task of authoring adaptive test that

takes into account the demonstrated performance of student in the virtual environment.

Despite the fact that there are many works related to IRT the present research has decided to work with distributed repositories, which are going to be discussed in other paper, because these one is focused on the application of IRT.

The items retrieval system is supported by distributed items repositories of which the most suitable items are selected according to the temporal student model. Student temporal user model is based on competence level and it is update each time that the student response an item in the system.

As long as this project was developed within a research group, the IRT selected methods were choose at random, so that other research teams in the group had the opportunity to taste other methods. Then, as future work it is quite necessary to compare the efficiency of each method.

III. ITEM RESPONSE THEORY (IRT)

Test theories offer validated frameworks to conceptually link unobservable variables with observable variables.

Item response theory is a general statistical theory about examinee item and test performance and how performance relates to the abilities or traits (in our case, competence levels) that are measured by the item in the test. Within the general IRT framework, many models have been formulated and applied to real test data [5]. This article will be considered the models that apply dichotomously scored data.

The most general and accepted IRT model is shown in (1):

$$Probability(\theta) = c + \frac{1}{1 + e^{-a(\theta - b)}} \quad (1)$$

This model defines the probability a particular Item has to be correctly answered given a proficiency level (θ) using the logistic function $Probability(\theta)$. The model assumes the relation between item performance and the competence is given by a logistic function described by one-, two-, or three parameters. Parameter a , tells us how the item can discriminate between highly proficient students and less proficient students; parameter b , indicates the difficulty level of the item; and parameter C indicates how likely the examinees are to obtain the correct answer by guessing [6].

In our case, the unobservable variable (θ) is referred to the competence level of student. Some important formulas associated to the model are:

A. Item Characteristic Function

Birnbaum's three-parameter model states that the probability of a correct answer to an item, given a value q of the knowledge level, is defined by (2) [2].

$$P_i(\theta) = c_i + (1 - c_i) \frac{1}{1 + e^{-1.7a_i(\theta - b_i)}} \quad (2)$$

B. Calculate student proficiency level

Maximum likelihood method (Lord, 1980): This consists of finding the value of θ that maximizes the likelihood function, as it is show in (3).

$$L(u|\theta) = \prod_{i=1}^n P_i(\theta)^{u_i} (1 - P_i(\theta))^{(1-u_i)} \quad (3)$$

In equation (3) $u = (u_1, \dots, u_n)$ is the vector of the examinee's answers, that is, for $i = 1, \dots, n$, u_i is 1 if the answer to the item is right and 0 otherwise.

Bayesian methods, (Owen 1975): which compute the ability level for which the posterior distribution is maximum. This posterior distribution is proportional to the product of the likelihood function and the a priori density function.

Neural Networks Methods. (Benitez,2000): Alternatively to the classical methods it have been proposed using competitive neural networks and Kohonen neural networks for sorting, since theoretically, it has been shown, in general terms the results obtained by competitive neural networks similar to those obtained with Bayesian classification [7].

C. Item Selection Methods

Test Information Function: Consists of selecting the item that maximizes the item information for the provisional estimate skill level so far (θ). Is given by the following function (4) [2]:

$$I_i(\theta) = \frac{2.89a_i^2(1-c_i)}{\left[c_i + e^{1.7a_i(\theta - b_i)}\right] \left[1 + e^{-1.7a_i(\theta - b_i)}\right]^2} \quad (4)$$

Bayesian methods: Select the question that minimizes the expected posterior variance of ability distribution.

Method based on the level of difficulty: Selecting the question of which level of difficulty is close to the current estimate of the student's skill level.

IV. DESCRIPTION OF IRT FUNCTIONALITY

This section describes the functionality of IRT in the development of a tool that presents to the students items based on their proficiency level, taking into account the theory explained before.

A. General Description

As was mentioned before, .IRTT was thought as a tool to support teachers in the difficult task to deliver adaptive test to students. In this order of ideas, the role of the teacher is, actually, control the definition of assessment process. In particular Teacher: 1) provide to system an initial sample of items for the item difficulty definition; 3) define the parameters for the initial sample and 3) provide new items and its initial parameters. Teacher also provides and initial level of competences of her ser of students.

The students are the object of assessment. They login into dotLRN learning management system to present the adaptive test. They are interested in verify their performance in the system and the system offers they the possibility to follow their advances through an open learner model.

Figure 1, shows a general vision of IRTT.

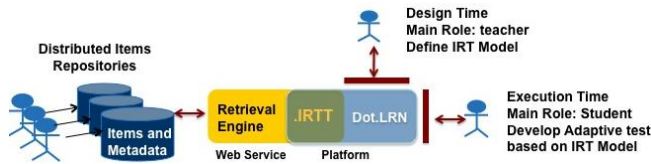


Figure 1 General Framework of IRT in adaptive assessments

IRT consists in two important components. The first component .IRR Retrieval Engine offer a web service client to connect with some based web service items repositories and also an intelligent mechanism to select the most suitable items according to the student model. The second component .IRT package upon .LRN integrates in the learning platform, the necessities users interfaces to support the teachers and student actions.

At the execution time, when a student request for a particular test, .IRT package verify the achieved and desired level of competence of this particular student and then, recovery system of items, select the most adequate repository of items (according with the available number of items) and look there an appropriate item and returns it to the interface of the student to begin your test.

According to her response, IRT infer the new competence level of student and taking into account the desired competence level and the finalization criteria will consider for delivering a new item. This process is repeated until the application decides to terminate the test.

Teachers could define how many times the student could present the test and the finalization criteria.

While items are stored in a Distributed Repositories its necessary a traffic analysis in order to optimize the process of selection the most suitable items. This process includes the study of the busiest times and the number of service requests, it means the number of users attempting to access the system simultaneously.

B. First Parameter estimation

As was mentioned in the first section the .IRT model assumes the relation between item performance and the student competence is given by a logistic function described by one-, two-, or three parameters.

In order to define the estimation of the, a student sample and a sample of the items were defined.

The test scenario was created in the context of an object-oriented programming course, where the students resolved a test in a traditional manner. In this way the Difficulty (b), considering an average value of the results of all students to an item.

Considering the experience of different teachers we asked, Discrimination parameter (a) was defined depending of the type of question:

| Classification of item | Value |
|------------------------|-------|
| Definition Questions | 0,2 |
| Intermediate Questions | 1,2 |
| Application Questions | 2 |

Table 1 Discrimination

Finally and taking into account [2] Guess (c) was defined. c was based on the number of alternatives available to the question as follow:

| Classification of item | Value |
|---|-------|
| 2 alternatives | 0,50 |
| 3 alternatives considering the options yes / no | 0,33 |
| 3 alternatives | 0,33 |
| 4 alternatives | 0,25 |
| 5 alternatives | 0,20 |
| 6 alternatives | 0,16 |

Table 2 Guessing parameter

C. How the items are selected and how the competence student level is update?

From the results of this initial test, we identified the probability of a correct answer to an each item in the sample, it means we generate each Item characteristic curve using the equation 01. The a, b, c parameter values correspond to the parameters of item i and the value of θ is equal to an estimated average of all responses of a particular student and then taking these results on a scale between -3 and 3.

Based on the probability value of each item for each student, he obtained a student's competence level more optimal (θ), for which use the maximum likelihood method according to (2), where u is the result of each item ($1 = \text{success}$, $0 = \text{failure}$) and $P =$ probability of success of each item (estimated above).

For selecting the next question, we used the method of maximum information in (3), where all values are defined as explained above parameters.

V. METHODOLOGY IMPLEMENTED

In order to construct .IRT we identify some necessary steps to follow:

- 1) Conduct an assessment test to a group of students as statistical sample for the b parameter inference.
- 2) Identifies a level of proficiency for each student, based on his or her correct answers.
- 3) Identifies a level of difficulty for each item.
- 4) Perform a calibration of the items from an iterative process involving the student attempted competition and the difficulty of the item.
- 5) After having the item parameters estimated, they are used to model the response pattern of an item, with the mathematical function CCI (Item Characteristic Curve).
- 6) To implement adaptive testing, initially you must select a method of estimating the level of competence (θ), which is not directly observable and must be estimated for each student from her response to items.
- 7) You should choose a method of items selection.

- 8) From her response, the system calculates a new level of competences, which takes into account to apply again the method of selection of items.
- 9) Carried out this last step until the stopping criterion implemented to establish the final competence level.

In table (3) is presented the methodologies to frame the development of this research project:

| Methodology | Description | Systems/modules |
|--|---|--|
| IRT (Item Response Theory) | Allows calibration of the data, identify the ranges of the parameters a, b and c and thus make the selection of items. | Items Recovery System |
| RUP (Rational Unified Process) | So that this project is a software development, selected the RUP development methodology. | Items Recovery System Web Service Integration |
| MEC (computerized educational materials) | Moreover, the methodology for the development of computerized educational materials (MEC) developed by Alvaro GalvisPanqueva [8], the project relates to computer material that is available to perform an online course. | Repository Development |
| METHADIS | Methodology METHADIS (Prieto, 2006), defines the activities to be performed when we implemented adaptive learning systems in the table presented below specifies the activities to be undertaken during the project. [9] | Web service to automatically generate Items. |

Table 3 Methodology

VI. DISTRIBUTED REPOSITORIES

Virtual repositories of learning objects are used to store Learning Management Objects and then be sought by different people all over the world. Some of the learning repositories are MERLOT, CARE, CLOE, these repositories are software systems that have the functionality to store educational resources and their metadata, a search interface, either manually or automatically [10].

In this project it was used geographically distributed repositories of items and IRT provided the steps to select the appropriate item to be presented to the student.

CONCLUSIONS

In this paper we deal with the problem to relieve teachers' design work when they have to create adaptive test in the context of a virtual learning environment using 3 parameter model of item response theory as a strong and highly utilized tool for adaptive testing.

At the design time, teachers need to provide only few amount of information while the system provides a transparent interface with items distributed repositories to reuse.

At the execution time, adaptive tasks are delivered to users in the context of a virtual learning environment using an .IRTT based.

Although the production of items repositories and their semantic characterization require an initial extra effort for the teachers, this effort decreases as the possibility of reutilization grows. One of main issues of our proposal is the integration task. Actually, the integration task is progressing and a layered evaluation has been defined for the validation process of the proposal. This validation includes real-time courses development with more than 500 students. Future works also are oriented to take into account other types of questions to construct more performance-oriented tests.

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Pedagogical architectures to support the process of teaching and learning of computer programming

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Abstract— This paper presents pedagogical architectures designed specially to support the process of teaching and learning of programming in engineering and computer science courses. A pedagogical architecture is a pedagogical approach and the technological resources required to implement it, i.e., it is defined in two levels: the level of educational strategy and the technological level that establishes the set of technological resources used.

The professional programmer needs to have special skills. Based on the human learning theory of Piaget and on the researches in computers in education, this paper presents the research results on the development of these skills in students of undergraduate courses in Computer Science and in Computer Engineering, during the first programming course.

This paper presents pedagogical architectures (pedagogical approaches + technological resources) specially designed to develop these skills in students and the evaluations of these architectures made by students of programming, in undergraduate courses in Computer Science and in Computer Engineering, in the second semester of 2011.

Keywords- *pedagogical architecture, problem solving, learning of computer programming, cooperative authoring, CSCL*

I. INTRODUCTION

The difficulties encountered in the teaching-learning of the initial programming disciplines are related to the development of various skills needed to program computers, which generally are not treated before students enroll in the University. Among these skills are:

- domain of a methodology for problem solving, specific, focused on the construction of the artifacts that satisfy a set of requirements;
- domain of a methodology for assessing the quality of programs produced;
- skill to solve problems cooperatively;
- using the syntax, semantics and pragmatics of a programming language;
- domains of different computational tools to support the development and evaluation of programs.

In the current pedagogical practices, the teacher presents the methods, elements of the programming language and submits lists of exercises to be solved individually or in groups. Subsequently, the lists are delivered and corrected with respect to the operation of the programs produced. In this approach there are no major concerns regarding the use of strategies to

support the development of the skills mentioned above, which implies the inadequate training of programmers.

From the context presented, were investigated pedagogical approaches and technological resources that can effectively support the teaching and learning of programming to make good programmers. So, we started to use the concept of architecture pedagogical.

A pedagogical architecture is a pedagogical approach and the technological resources required to implement it, i.e., it is defined in two levels: the level of educational strategy and the technological level that establishes the set of technological resources used.

A good programmer needs to have professional especially developed skills. Based on the human learning theory of Piaget and on the researches in computers in education, this paper presents pedagogical architectures specially designed to develop these skills in students to enhance and facilitate learning of computer programming, with the aim of graduating good computer programmers. The use of digital resources to support the teaching and learning of engineering in technology courses is defended by several authors [7,11]. Now it is necessary to emphasize the importance of using more constructivist pedagogical approaches. Therefore, in this research is used the concept of pedagogical architectures.

II. THE CONSTRUCTION OF KNOWLEDGE ACCORDING TO GENETIC EPISTEMOLOGY

To understand the learning process of the freshmen in computer courses, we use Piaget's theory on learning as a reference. According to this theory, reported by Ramozzi-Chiarottino [2], the individual undergoes a process of cognitive development which begins with the manipulation of concrete objects, includes the use of mental operations (reversible actions) applicable to the objects until you can develop the ability to formalize, allowing you to ignore unimportant details in order to generalize the characteristics of the objects, etc. Finally, the formalization allows you to construct hypotheses about the world and infer results (knowledge items) based on such assumptions. This evolution involves the discovery of the laws governing the observed world, ie, the laws needed (needs) to the organization and operation of this world. The possibilities of organization and operation of this world, ie, the "possible solutions" to a problem are inferences made from the "needs".

In the model of cognitive development proposed by Piaget [2], students (teenagers) from introduction to programming may not yet have fully developed the cognitive capacity of formalization, which could cause difficulties for the student to solve programming problems, either in analysis of errors, either in creating / proposing new programs.

The development of these formalizations can be favored by interactions and challenges posed to students. These challenges are not just to achieve a goal, or to succeed in terms of practical actions, but must reach the understanding, the reasons for things, meanings, the whys. The understanding is not limited to the here and now, she coordinates what is general (constructive generalization) and that applies to a range of situations. In this sense, the error corresponds to a gap in knowledge or failure in the hypothesis of the subject that seeks to explain some phenomenon or situation [1].

As in many situations, the student has no awareness of the means employed to achieve an end and thus can not be anticipated errors (he does not realize the errors, the errors are not observable to the subject). From the undesirable results, it initiates the resumption of his actions and he reaches back to discover the causes of this result and seek corrections.

In order to construct knowledge, an error corrected is more important than a success, since it requires the intervention of self-regulatory mechanisms that are responsible for reconstructions. These self-regulations allow individuals to achieve the ability to solve problems in a formal level [2].

The resolution of challenges can contribute more effectively to student learning, if it occurs in groups. The system of cooperative work (in teams) contributes to the development of the formalism since it encourages awareness of the student's own thinking, so he can get arguments to express it and defend it, as well as enhances learning by allowing exchanges of views on the object of learning [6]. Still on the cooperative work, Piaget [6] states that "... cooperation is essential for the development of reason. The method of teamwork seems to be based on the essential mechanisms of child psychology."

To accompany the student and understand the level of his development, we can use, as strategy, monitor him closely while he solves problems, seeking to record the process of resolution used by him [3]. This record provides the basis for a detailed analysis of the cognitive process used by the individual during the construction of the proposed solution. We are referring to Piaget's clinical method, which involves the recording, analysis and understanding of how an individual learns [3].

Piaget [5] noted that in the period of 11 or 12 years until he was 14 or 15 years, the individual, positively stimulated, develop formal thinking which allows you to "think hypothetically and deduce the consequences that are implications of the assumptions (independent of the intrinsic truth or falsity of the premises)". In some individuals who live in cognitively unfavorable contexts, the development of formal thinking can be completed only at age 20.

III. THE USE OF DIGITAL RESOURCES IN TEACHING - LEARNING OF PROGRAMMING

There is a growing amount of experience with the use of digital resources to support the teaching-learning programming. Some of these experiments use digital resources to facilitate access to educational material from initial programming disciplines (videos, manuals, texts, exercises, programs, etc.). Others report the use of digital resources (forums, FAQs, etc.) to access information that will help resolve doubts [7]. Many works investigate the influence of cooperative/collaborative work on learning [8].

There are researches that emphasize that the computer programming requires the use of problem-solving techniques [7] [9] [10]. The lack of mastery of these techniques makes it difficult to learn programming.

More recent studies propose digital resources to inform the learner about the program code built by him, ie, an automatic feedback on the program code built by the student [11], [12]. This feedback is being called, in many studies of automatic regulation [11] [13] [12].

Researches strongly supported in learning theory of Piaget, as is the case of the research reported in this article, use digital resources to socialize the programs developed by students [7]. Thus, they encourage learning through observation and comparison of several possible solutions [7] [11].

More recent research [7] [4] have sought to emphasize the importance of the pedagogical approach when using digital resources to support learning through the application of the concept of architecture pedagogical. Thus, the use of any digital resource needs to be backed by an appropriate pedagogical approach, since architecture pedagogical = pedagogical approach + technological resources.

IV. CURRENT PRACTICES IN THE PROGRAMMING DISCIPLINES

Tavares et alli [4] reported problems in current practices of pedagogical approaches used in introductory programming disciplines, where:

- The teacher presents the methods and elements of the programming language and model programs fully ready;
- Submit to class lists of exercises to be solved individually or in groups;
- The lists are delivered and corrected with respect to the operation of the program code produced.

In this approach there are no major concerns regarding the use of strategies to support the development of skills of the programmer, such as:

1. domain of a method for solving problems especially directed to the construction of artifacts satisfying a set of requirements;
2. domain of a methodology for assessing the quality of programs produced;
3. easy to solve problems cooperatively;
4. use of syntax, semantics and pragmatics of a programming language;

5. domain of different computing resources to support the development and evaluation of programs.

This implies an incomplete formation of the graduates of the discipline.

Aiming at the development of these skills, needed for the programming, in the freshmen of the undergraduate courses in computing, Tavares et al (2010) conducted a research on pedagogical architectures that can minimize these problems. The design of an overall pedagogical architecture for this purpose is presented below.

V. TEACHING-LEARNING PROCESS OF PROGRAMMING (TLPP)

From our previous experiences, we structured the TLPP with the following steps:

- 1) understanding the problem;
- 2) planning of the test of the solution;
- 3) specification of a solution;
- 4) manual testing of the solution;
- 5) encoding the solution;
- 6) automatic test of the code;
- 7) analysis of the solution;
- 8) publication of the solution to the class;
- 9) visit to the solutions of colleagues;
- 10) contributions and comments from colleagues about solutions;
- 11) reanalysis of the own solution and
- 12) construction of other possible solutions.

For each of these steps can conceive pedagogical architectures that can help the learner acquire the skills necessary to carry out activities related to the step.

VI. PEDAGOGICAL ARCHITECTURE PA1

This section details the pedagogical architecture PA1, designed to support the development of programming projects by students of a discipline of programming.

A. Principles

The pedagogical approach adopted in this initial class schedule was based on the following principles:

1. Authoring of solution: encourage students to develop solutions, reflect on the results and on the process of development of the solutions and create a custom method of building the programs;
2. Cooperation: cooperating with classmates to enhance learning and motivate students to participate more actively in the learning process;
3. Critical thinking: build many possible solutions for each proposed problem and compare them with each other and with the solutions built by other students.

B. Objectives of the PA1

We seek to build architectures to support the educational training of students to:

- solve problems - to challenge students to solve problems and reflect on the process used to resolve them, through the exploration of all possible solutions in order to build their own method to solve problems;

- assess the quality of programs produced - to motivate the student to build multiple solutions to each problem and compare these solutions in order to reflect on metrics for comparing the quality of the programs produced;

- handle errors - instigating the student to resolve the errors detected in the process of building solutions, with proactive actions that may involve individual reflections, consulting of manuals or texts, exploratory interactions with colleagues, tutors and teacher, but never with the expectation of receiving the solution of the error;

- solve problems cooperatively - to exercise cooperation in solving problems;

- know the computer model programming - developing the student theoretical and practical knowledge about computer model programming (syntax, semantics and pragmatics of programming, performance and program implementation);

- use computational tools for the development and the evaluation of programs – to create conditions for students to learn how to use a programming environment with editor, interpreter, code debugger, web spaces to access information of the discipline and of the programs produced by the student individually and by groups, web resources to interact with colleagues, tutors and teachers.

C. Indicators of learning

With respect to verification of student learning, we sought to evaluate the individual development of each student through the course, with respect to learning indicators used especially for that purpose. The learning of each student has been checked in each classroom, in each session of interaction in each laboratory practice, each exercise solved at each presentation of resolutions made by the student on each question raised. We tried to record as much information as possible through records on the web made by each student and each group of programming project. These records were made on the web by the student or group, but were visited and commented on by peers and teachers in the classroom.

Other learning checkpoints were questionnaires applied to each student, student interviews with the teacher, individual and group presentations made to socialize the problem solving and individual and group reports on the development of programs (model presented by teachers).

The teachers of the discipline elaborated, during the execution of the research project, the learning indicators used here.

Following, skills needed to program computers are presented as indicators of student learning, in addition to pedagogical activities used to increase students' skill with respect to each indicator:

1) the skill to solve problems indicates the effectiveness of the methods used by the student to solve problems. The lists of problems to be solved by the students are proposed to encourage the development of this skill;

2) the skill to handle errors is related to the effectiveness of the method used by the student to resolve errors that occur during the development of the program. As an error may have different causes (understanding the problem, test plan, the logical solution, encryption etc.), the heuristics used by the student to identify the cause of the error are related to maturity, security, independence and pro-activity of the student in developing a program. Specially designed exercises should be proposed to allow the student to develop this skill. A model of exercise that can be used is to challenge students to identify types of error that may arise during the development of the program;

3) the skill to solve problems cooperatively indicates the student's skill to work in groups, interacting with colleagues, finally, to learn and teach. The programming project developed within group allows the development of the skill to develop programs cooperatively. The report's analysis of group programming project and a personal interview between students and teachers allow the identification of how cooperation has occurred in the group;

4) the skill to use the syntax, semantics and pragmatics of a programming language is related to the student's knowledge about this language. The coding of the programs developed by students during the resolution of the proposed lists of problems, among other objectives, increases the knowledge (knowledge = information + experience) of each student of using the programming language;

5) The skill to use computational tools for development and program evaluation indicates the student practical experience in developing these programs with computational resources. This practical experience is developed during the preparation of programs to compose the lists of exercises proposed by the teachers and monitors;

6) the skill to understand problems is related to the student experience in addressing the problem properly in order to understand it correctly. This skill increases with special exercises of interpretation of problems descriptions. And it also increases when the student represents the problem in a high level language.

7) the skill to plan the test for each solution is related with the understanding that the student has of the problem domain. This skill is developed with exercises in which the student must test programs of various authors, apparently correct, but fail to deal with data from all relevant subdomains;

8) the skill to specify a solution allows the student to make the description and composition of the transformations provided in

the test plan on the input data. Exercises about description of transformations of input data on expected outcomes help develop this skill;

9) the skill to manually test the specified solution allows students to simulate the mapping done by the program between each data of the domain of the function and its image. The type of exercises to develop this skill is one that presents the specification of the program (in a high-level representation. Eg.: Mathematics, logic, English text, flowchart etc..), and the domain of the function represented in the program. So, it is asked the student what is the image set of the function and also to relate possible errors in the treatment of domain data;

10) the skill to code a solution: it is not just enough the student to know the programming language. He/she must learn to use it in order to encode the specification of each solution, ie, to represent in the appropriate programming language the same function described in the specification of each solution. The coding, in the target programming language, of functions, represented in high level language, serves to increase this skill;

11) the skill to automatically test the code allows the student to use the features of the programming environment for test codes. To exercise this skill you can ask the student to test code, previously prepared, in the programming environment used in the discipline. Optionally, it can be delivered to him data of the coded function to be used in the test. The student may be encouraged to prepare a report with the results of each test;

12) the skill to correct errors reflects the knowledge of the student to correct errors that exist in the program code. Exercises specially prepared with program code including different types of error, are recommended to enhance this skill in the student;

13) the skill to evaluate a program is important for a programmer and can be developed in the apprentice through the comparison of different programs that solve the same problem. As the student performs these comparisons, it develops criteria of comparison that will serve as criteria for evaluating programs. The skill produced to evaluate the quality of programs is related to the efficiency of the heuristics used by the student to assess the quality of programs. Exercises for the comparison of equivalent programs (representing the same function), prepared by different authors, allow the student to develop criteria for comparison and evaluation of program quality.

14) the skill to publish the solution to the classroom causes the student to appropriate technological resources for publication and presentation of programs and interaction with his/her classmates. This skill reflects on the importance of presenting the results of the solution constructed by him/her;

15) the skill to review the colleagues solutions indicates the easeness of the student visit, suggest contributions, and comments on the solutions of the colleagues. With these activities, students develop criteria for comparing the solutions developed by them and the solutions of other classmates;

16) the skill to build other possible solutions allows the student to seek alternative ways to construct solutions to each problem. This quest leads him/her to solve the problem in different ways and to a deeper understanding of the process of building program;

17) the skill to cooperate with the project group allows students to exchange ideas with partners in their group, to understand and evaluate other ways of addressing the problem and to explain, defend, and evaluate their own ideas. The students are encouraged to participate effectively in the construction of the solution prepared by the group in order to get full benefit from the opportunities that arise in this activity.

D. Pedagogical approach of the PAI

We present the following conditions created to allow the student to achieve the goals of the pedagogical architecture. We will focus on the conditions created for the implementation of pedagogical architecture AP1 designed to support programming projects in a classroom of programming, of the semester 2011/2, consisting of 16 students beginning courses in Computer Science or Engineering.

This group was organized in groups of two or three members. Each group chose a problem to which the project should develop a program that solves the problem.

Each group created a web space, shared it with the classroom, which included the description of the problem and reports on the solutions produced, according to the following model:

- 1) problem description (caption on the context of the problem and a precise identification of the passage chosen to tackle the project);
- 2) proposed solution (including data organization, the main algorithms used and how is the interaction between user and program);
- 3) evidence of correction:
 - a) explanation of the conviction that the critical parts of the program works;
 - b) planning and carrying out the tests (with which data the program has been tested? what was expected, was it obtained?)
- 4) program performance (brief consideration of the memory consumption and computational effort);
- 5) evaluation of the project by the group (managed to achieve the desired goals with the solution: What are the main difficulties? What were unable to be achieved and what were the reasons?)
- 6) source code (with comments).

The web spaces of each group were visited by classmates and received comments.

Each group has prepared a presentation of the results achieved, has published in the web, and presented it to the classroom.

The comments posted on the classroom web space and those received during the presentation were used to produce new versions of the solution constructed by the group.

Doubts could be raised in the classroom or shared with peers and teachers via digital resources.

E. Digital resources PAI

We used the following digital resources to implement the pedagogical approach described: wikis, emails, forums, chats and videos.

On the home page of the wiki of the course there is a list of programming project of the groups. The themes of the projects were proposed by the groups and approved by teachers. Each group built a wiki with: a group presentation, a description of the problem, the final solution, the peer review, the assessment made by the group on the solution, the alternatives produced by the group, the presentation (ppt) of the project made by the group and the presentation to the classroom on video.

VII. ASSESSMENT OF EDUCATIONAL ARCHITECTURE

To raise the students' opinions about the pedagogical architecture adopted, at the end of the semester (2011/2), to each student, was asked a report covering topics related to: individual work, group work, the use of technology, the learning achieved versus his expectations.

Analyzes made by the researchers on the students' responses are presented below:

1. to challenge the student to learn how to build solutions is a good way to help him/her to achieve autonomy in learning;
2. the need to present the results of the programming project for the classroom requires an additional effort to articulate the program code in order to make easier the presentation of the solution;
3. autonomously after constructing solutions to the problems posed, all students testify in favor of the pedagogical approach adopted in the discipline;
4. the majority of students reported on the importance of considering several possible solutions, in order to gain familiarity with the problem and its solutions;
5. students realized the importance of developing programming projects for learning in the class;
6. some students emphasize the importance of understanding the problem before seeking to resolve it;
7. the students testify in favor of group work, emphasizing the acquisition of much knowledge and experience, during the programming project (developed in pairs) and the skill to work together, "essential skill in today's job market."
8. group work significantly increases students' interest in solving the problem;
9. group work is a way to expedite solutions and enhance creativity and performance;
10. difficulties of group work are related to reconciliation of spaces and times to schedule meetings;
11. the student becomes more involved with activities in the classroom when he/her is called constantly to expose his/her ideas, make suggestions and raise questions during classroom;

12. there were reports of increased learning due to the procedure of making the student independently seek to solve their own doubts;

13. problem solving and collective reflections on the solutions developed by students were considered as potential factors of learning.

14. some students are motivated to continue the programming project even after completion of the semester;

15. One of the difficulties highlighted "the need to pay attention to several disciplines simultaneously, which hinders their dedication to the discipline of programming";

16. all reports considered appropriate and sufficient the digital resources used in the pedagogical architectures adopted in the discipline.

VIII. FINAL CONSIDERATIONS

This article presented the results of research on pedagogical architectures to support the teaching-learning process in initial programming disciplines.

The pedagogical architecture studied shows a constructivist pedagogical approach, emphasizing the learning to learn, the autonomy of students, the student as the author of the programs (solutions to problems), the doing as the predecessor of understanding, cooperative work, socialization of the results (programs), the search for generating several possible solutions, all of this, seeking greater awareness of problems and their solutions.

The digital resources of the pedagogical architecture allowed the proper implementation of the pedagogical approach and were well accepted by students.

The pedagogical architecture presented in this paper allowed the following gains:

a) students are involved in the choice of a problem which leads them to think of real-world problems, rather than being focused on solving problems lists;

b) there is an intellectual effort to specify, design, implement and present a problem that makes the student more familiar with the activities of a "programmer";

c) living with a significant amount of problems raised by the group enriches the experience;

d) socializing in small groups and the exchanges that they do go beyond what they may experience in conventional classes, since they are engaged in seeking information;

e) the socialization of issues through a workshop in which students present their solutions, with recordings and support for the continuation of discussions, puts them in a position of problem solvers, similar to what is expected of them when formed, rather than mere solvers of artificial problems.

We expect to have produced results that collaborate with the adoption of pedagogical practices in early programming courses, which promote greater motivation among students in learning to program machines.

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Work in Progress: Help in Finding Evaluation Instruments for Engineering Education Innovations

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Abstract— This paper describes the first-year progress of a TUES Type 2 project funded by the National Science Foundation (NSF) that supports scholarly innovation in engineering education. The project, known as the Appraisal System for Superior Engineering Education Evaluation-instrument Sharing and Scholarship (ASSESS), builds on a precursor NSF CCLI Type 1 project, the Inventory of Evaluation Tools for Engineering Education Projects. The paper reports on the process and framework for developing ASSESS as a sustainable library of superior evaluation instruments that promote scholarly innovation in engineering education. The online database supports information storage, retrieval, and input as well as expert review and user feedback. Adoption research currently being conducted will determine factors that influence broad utilization of the database. Feedback is invited from the community to produce a user-friendly website that enables engineering educators to locate and implement tools that can be used to credibly evaluate the impacts of engineering education innovations.

Keywords—evaluation, engineering education, evaluation capacity building

I. INTRODUCTION

Growth and improvement in the field of engineering education depends on effective evaluation of impacts of innovations designed to enhance student achievement. While several engineering educators utilize innovative methods of student assessment [1-3], identifying instruments and evaluation processes to determine the impact of such innovations for adoption by others is challenging.

The purpose of this paper is to document the processes used to develop an online repository of engineering education evaluation tools known as the Appraisal System for Superior Engineering Education Evaluation-instrument Sharing and Scholarship (ASSESS). ASSESS was created in response to a call from a national panel of 30 engineering education and evaluation professionals for a resource that would enable effective project evaluation and that would help build the evaluation capacity of engineering educators.

The online database supports information storage, retrieval, and input. Users can search for instruments of interest using keyword searches and selected item characteristics based on their evaluation needs (e.g., content, instrument type, technical specifications). The web interface will also support expert review and user feedback. Because the project is designed to build the evaluation capacity of engineering educators [4],

adoption research is currently underway to determine factors that influence broad utilization of the database. User needs and adoption preferences will then be used to guide the final deployment of the ASSESS system.

As the database becomes fully operational by the end of 2012, it will undergo extensive review by members of the user community. Feedback is invited from the community on the usability of the database, which will positively impact the adoption of best practices for improving student achievement and will, ultimately, advance the field of engineering education.

II. PROJECT GOALS AND OBJECTIVES

The ASSESS project is a TUES type 2 project funded by the National Science Foundation (NSF), DUE 1065486. The project builds upon previous proof-of-concept work conducted through a precursor NSF CCLI type 1 project: Inventory of Evaluation Tools for Engineering Education Projects [5]. The overall goals of the present project are to create, thoroughly test, and strategically communicate the ASSESS system to engineering educators and to encourage future adoption of ASSESS by the engineering education community.

Two sub-goals guide project development, including:

- 1) **Instrument utilization.** Enable engineering educators to locate and effectively deploy superior evaluation instruments to enhance engineering education project discoveries and successes.
- 2) **Instrument development.** Support the engineering education evaluation community in the identification and refinement of evaluation instruments with potential to become major assets to the profession.

In addition, four objectives are vital to achieving the project goals. These objectives include: (1) Developing an evaluation instrument database and user interface that support users in accessing desired instrument information and in providing feedback on instrument and system features; (2) Establishing an appraisal process that identifies, reviews, certifies, and supports refinement of superior evaluation instruments for engineering education; (3) Documenting the performance of the integrated software system and instrument appraisal process to ensure desired value added to the

engineering education and evaluation community; and, (4) Conducting communication, vetting, and adoption research of the ASSESS system needed to establish its value and to define steps essential for broad adoption by the engineering education community.

III. FIRST-YEAR ACTIVITIES

The core ASSESS project activities began with a meeting of project consultants to review and revise the project team's understandings of the requirements for an evaluation tools database that can best support the engineering education community in building its evaluation capacity. Project consultants reviewed the team's proposed set of parameters for characterizing the instrument, reviewed prototyped web interfaces for the evaluation instrument database, provided exemplar evaluation instruments and critiques of instrument characterizations, and suggested additional resources to support the work. The consultants also helped refine software and database requirements.

IV. SOFTWARE DEVELOPMENT AND INSTRUMENT IDENTIFICATION

The software development process included three phases:

- 1) Needs analysis produced software specifications to guide programming
- 2) Integration and coding of database and user interface to define and demonstrate desired functionality
- 3) User testing (by project team) to test the software and associated evaluation instrument data.

Suitable evaluation instruments were defined for inclusion in the ASSESS database using a three-pronged search strategy, which included: searching peer-reviewed journal articles, using branching techniques from reference sections of papers and reports, and identifying innovative projects that may have developed and employed evaluation instruments. In addition, certain tools identified in the type 1 project, such as the Thermal and Transport Concept Inventory, were incorporated into the ASSESS database. Instrument quality was rated based on a team-defined appraisal process that evaluated the available psychometric evidence for each instrument as non-existent or limited, emerging, or strong.

V. STAKEHOLDER NEEDS AND ADOPTION

A variety of individuals with multiple backgrounds and perspectives is expected to utilize the ASSESS database. To better guide development of the database and interface and to get a clearer picture of prospective users, project leaders developed a survey that was administered to thirty workshop participants who attended the precursor Inventory project's national workshop. The survey was followed up by interviews with prospective users using a combined 'push' and 'pull' approach to obtain a richer data set based on user needs and to make the ASSESS system more adoptable and broadly used. More specifically, the pull questions focused on users' current approaches to gathering instruments as well as users' visions on how to better acquire information. The push questions, on the other hand, focused on feedback regarding the database.

VI. DATABASE STRUCTURE

The Engineering Work Group developed a series of prototype templates for characterizing evaluation instruments based on recommendations from the consultants and from the Measurement Work Group. Five different templates were prepared over the course of the year as trial mock-ups. Each template was reviewed and refined by the leadership team. At the end of the first project year, the template presents instrument data in the form of: summary, technical description, technical specifications, reviews, and links.

VII. NEXT STEPS

To date, the ASSESS project website prototype includes information for viewing details of different instruments and a search page for locating the instruments within the database. These functions are not only critical for the usability and adoption of the website but also drive the structure of the database.

The next steps in the development of the ASSESS online database will be to:

- Add other prototypical instruments to the database to span the types of instruments that are of interest to our customers and to exercise the full range of the database structure.
- Refine the instrument data model based on experience with more data.
- Build administrative pages to support instrument entry, review and editing functions.
- Add home page and other informative pages to guide users.
- Build a system for registering with the site, logging in and out, and managing user roles.

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Work in Progress: First Year Engineering Women:

A Qualitative Investigation of Retention Factors

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Abstract— Many universities face disturbing trends in the retention, underrepresentation and socialization of women students in engineering. The focus of this present study is the retention of first-year women students currently enrolled in a large state college of engineering in the Rocky Mountain region. Eight hour-long focus groups were conducted consisting of four to ten first-year women in a first-year engineering design projects course. Participants were asked a structured set of questions to investigate several topics. These focus groups were video-taped and later transcribed for analysis.

Six research questions were posed for the current study:

- Do women express a loss of interest during the first year of the program?
- Is there a chilly climate for first-year women in the college?
- Do women's self-efficacy levels change during the first year of the program?
- Do academic performance levels play a role in women's retention in engineering during the first year?
- Do women have adequate support structures in the college during the first year?
- Does the structure of the academic program instill career awareness in the first year?

Implications for strategies to boost retention and an explication of the themes from the qualitative analysis will be discussed in the paper.

Keywords: Gender, Retention, First-year programs

I. BACKGROUND

Across the nation, and in our own university, disturbing trends have been observed in the retention, underrepresentation, and socialization of women in undergraduate engineering programs. Among first-year undergraduate students, women are much less likely than men to enter the field of engineering, and only 20% of the Bachelor's degrees earned in engineering are held by women. The presence of women continues to decline in the STEM work place [1]. Women are often socialized to enter other more "feminine" fields as many are often stigmatized for strong abilities in engineering and other STEM fields, causing doubts about entering a STEM field in the future [2]. Anderson-Rowland acknowledges that many women are raised to believe it is not "cool" to succeed in STEM fields,

and many women are not aware that they can help others by following an engineering career, causing them to select other career choices [3].

While the recruitment of women into colleges of engineering is increasing by about 1% per year in most universities, the retention of women is still below that of men [2]. This trend of decreased retention of women was observed at our own university. Figure 1 below illustrates the six-year graduation rate of men versus women in our college.

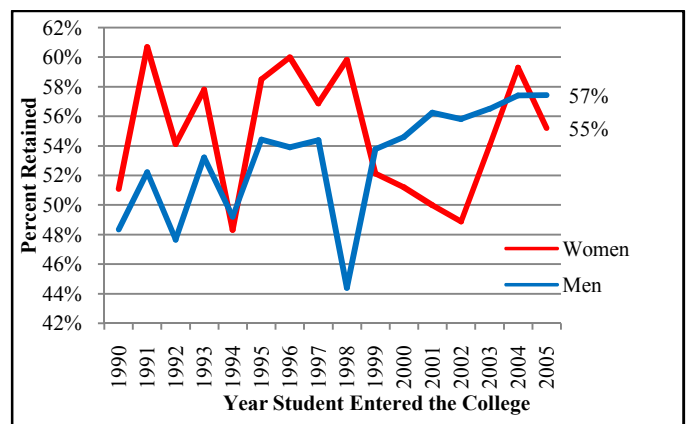


Figure 1: Six-year graduation rate of men compared to women in our college

To investigate this drop in retention, six research questions were formed for the current study:

- Do women express a loss of interest during the first year of the program?
- Is there a chilly climate for first-year women in the college?
- Do women's self-efficacy levels change during the first year of the program?
- Do academic performance levels play a role in women's retention in engineering during the first year?
- Do women have adequate support structures in the college during the first year?
- Does the structure of the academic program instill career awareness in the first year?

II. LITERATURE REVIEW

Investigation of the literature revealed self-efficacy as a significant factor in the retention of first-year engineering women [4]. According to Anderson-Rowland, self-efficacy is built through past performance, accomplishments, learning through female role models, encouragement, support, and lowered anxiety. She reports that there is a lack of information and female role models for women to build this self-efficacy causing a dramatic separation between men and women in their self-confidence. She also noted that while men blame the teacher or test for poor performance, women tend to blame their abilities, further decreasing self-efficacy [3]. Despite the pre-qualifications of women entering the college, many tend to enter with higher anxiety and lower confidence than their male peers [5]. Hutchison reported that women also tend to have lower confidence in their overall engineering skills after their first-year than male students as well and found this change in efficacy to be related to understanding of the material, students' motivation and team experiences [6].

Several other factors have been reported by the literature to affect the retention and enrollment of first-year women in the engineering program [2, 7]. Many women are discouraged by male students and faculty members who truly believe engineering is a male field, creating a chilly climate for the students. Similarly, international students can create this discouragement for women due to the presence of a patriarchal society in other countries and different rights and social roles for women [3].

Besides the presence of a chilly climate, the lack of support structures has been shown to have an effect on the retention of women in engineering. Findings by Groll reported that persistence in engineering for women in their senior year had a positive correlation with strong advisors and positive interactions with said advisors [8]. It has also been shown that women who are retained tend to take better advantage of these support groups, indicating their importance in retention [3].

III. METHOD

Eight hour-long focus groups were conducted for this study with a range of four to ten students resulting in a total of 55 participants. Participants consisted of first-year women enrolled in an engineering design projects course. Each focus group was video-taped and transcribed to ensure quotations were captured properly and no information was missed. Students were asked six questions with various probes for each question. At the end of the discussion, participants were also asked an open-ended question to see if there was anything else they wished to discuss. A detailed list of these questions and probes can be seen in the Appendix.

Analysis of the data was done using Krueger and Casey's "long table method" [9]. In this method, quotes from each focus group were coded into various themes under each

question [9]. These themes were then compared to our research questions.

IV. RESULTS AND DISCUSSION

Results will be discussed in order of the six research questions.

A. Research Question 1: Interest

In the second focus group question (see Appendix), women were asked how they defined success. One of the three major themes that arose during this discussion was enjoyment of the subject. Participants who defined success in this manner were adamant that "if you don't enjoy it and you are just trying to get by... you are not going to survive." This definition of success implies that women who are encountering a loss of interest in the curriculum may feel they are not successful in the college of engineering, and thus select a new major or college.

The fifth focus group question dealt with specific courses and professors that have had an impact on the women's decisions to stay in the college of engineering. Many students stated that the professor can greatly impact their interest in class as well as their interest in engineering. Students had positive reactions to professors who were passionate and involved in the class and felt like they retained more information. Students also felt like they had more support and were encouraged by the professor's involvement with the students. One student stated regarding her Physics professor: "He keeps me coming back to class every single day and he makes me want to like Physics... it gives you a purpose to going." These results acknowledge the importance of a professor in keeping women interested in their course material and indicate that professors of first-year courses should be engaging and able to capture the attention of students during lecture to increase the retention of women.

B. Research Question 2: Chilly Climate

The third focus group question asked women how welcoming the college of engineering has been to them as women. When asked if they had ever felt treated differently due to their gender, most students stated they did not. One woman commented "I knew going into it that it was supposedly supposed to be less girls, and you always hear how it's a male dominant field... But I can honestly say that since I've been here I have not been reminded of that... I can't think of a time where I've been reminded that I'm a minority in this specific college." However, one theme that arose indicated some women felt they were treated differently not by their professors, but by their male peers. In the engineering projects course, some of the women felt they were placed into stereotypical female roles in their teams such as developing presentations or writing reports. One woman also felt she was underestimated, saying "people ask me excessively if I understand stuff that is fairly simple, which is frustrating."

Overall, this discussion showed a generally warm climate for most women in the college. Women who reported a chilly climate were more likely to acknowledge its presence among teams. These results imply special attention needs to be placed on team experiences to ensure women are being given the same opportunities as their male teammates and enjoying their team experiences.

C. Research Question 3: Self-Efficacy

While first-year women in the engineering program may have a high self-efficacy regarding their school work, their self-efficacy for succeeding in engineering decreases when extracurricular activities are considered. Extracurricular activities emerged as a theme in the first focus group question. While all students showed a strong desire to participate in more their outside interests than they were currently, most women agreed that the engineering curriculum and work load were preventing them from joining the extracurricular activities they desired to participate in. One student stated “I am scared to do something else... they give a lot of pressure like you have tons of things to do.” However, most understood it as the “price” of being an engineer. These results imply the need for a mentor program that can assist women with balancing their outside interests with school and keep women thinking positively about their ability to succeed in engineering and still participate in extracurricular activities.

A second theme that emerged during the discussion regarding success was the understanding of concepts taught to students in class. Many women stated that they wanted to apply the knowledge gained in the college of engineering to their degrees in the future so they wouldn’t have “a degree that doesn’t mean anything.” One student commented on this definition of success, stating “if you don’t comprehend it then you don’t know what’s going on after college.” This definition of success may reflect the lower self-efficacy of women who may not feel successful if they do not fully comprehend everything they learn in class, leading to a decreased retention.

During the discussion of courses and professors, most core classes were shown to have little impact on the students’ self-efficacy and resulting desire to stay in engineering. However, one course, general chemistry, had a negative impact for a large majority of students due to the large lecture size. Many students did not feel like they were learning the necessary concepts. One woman spoke regarding chemistry, saying “you could give me a chemistry problem and I could spit it back out to you and give you the calculated answer which is all the midterms are, but I feel like I don’t necessarily understand the concepts.” This lack of understanding in such classes as chemistry could lead to a decrease in self-efficacy large enough to cause students to leave the college of engineering. These results imply women need to understand the concepts being taught in first-year classes to obtain the confidence to succeed.

D. Research Question 4: Academic Performance

A third theme that emerged during the discussion of success was academic performance. Many of the freshman women defined their success in the college of engineering by their academic performance, whether by beating the average, obtaining a high GPA, or improvement in their grades. This definition of success indicates the large stress many women place on their academic performance and the effect a lower GPA may have on the retention of women who hold themselves to high standards. Regarding her goals for academic performance, one woman stated “I want to get a 4.0, even though I probably won’t but I just want to do really well”. In other words, our women students might fail *themselves* out by holding themselves to higher GPA standards than the college. This is due to the fact that many of these high performing women view a B as unsuccessful, and in turn may select another major in which a 4.0 GPA is more obtainable.

E. Research Question 5: Support Structures

The third focus group question also explored the participation in women-supportive groups available on campus. While some of the women had attended meetings once or twice, most were not very involved in these support structures. Those who participated more actively found it beneficial and a great networking opportunity. One theme that arose was that many women did not feel these support groups were necessary, and further singled out women in the engineering field. One woman stated “I don’t need a support group as a woman, more a support group as an engineer in general.” This discussion implied that while women do need and appreciate the presence of support structures, gender-specific support structures may be further emphasizing women as the minority and reflecting the stigmatization that many women wish to avoid.

The fourth focus group question focused on the participants’ experiences with mentors both before and during college. Some students had experiences with mentors in high school through peer mentoring programs, teachers and their parents. Many students also had similar experiences in the college of engineering using advisors and mentoring programs. However, some students shared their struggle to find a mentor in college due to the large amount of students in classes or assigned to each advisor. One such student described her struggle, saying “I was trying to develop that relationship with my advisor (name deleted) but she quit I guess recently... we were both kind of left out there trying to fend for ourselves. Like who do we talk to? What do we do?” Some women also described the awkward interactions with their assigned faculty mentors, leading them to question their value. These comments brought to light the fact that some women are not receiving the support they need from their advisors and that women desire a more personal advising experience.

The concept of a new mentoring program was also discussed. Many of the women acknowledged that mentors participating in this program would need to have experience in the college of engineering and would like the mentors to have similar majors and interests. The gender of the mentor, however, was not important to the majority of the women. Many students also shared that they found the presence of a mentoring program to be important and beneficial. Some women stated that they would not find the program beneficial because they desired to be independent and solve their problems on their own. However, this discussion revealed the importance of a personalized mentoring program to many women as a support structure.

The final focus group question asked women how supportive their current living situation was to their studies. Many women lived in the honors engineering dorm, and reported it as a very supportive environment due to the various study locations, the large engineering community, and the presence of older engineering students. One resident spoke regarding the honors dorm, stating "There are always people I'm studying with and we can always find somewhere eventually to study because there are just a million classrooms there. And then if I always have questions on my homework and people I'm with aren't in the same classes as me I can walk around and find somebody." Many women living in the honors dorm desired to live there again in succeeding years. Similarly, students living in other engineering dorms found them to be very supportive due to the presence of an engineering community. However, these women felt like it was socially unacceptable to live in the dorms in succeeding years since residents were primarily freshman.

While many women found their living environment to be supportive, those who lived in non-engineering dorms found the opposite to be true due to the lack of fellow engineering students and the noise levels. One student stated "I requested to live in [a non-engineering dorm] for a healthy balance... I made the worst choice by not being in the engineering quad where it's like, not only do I not have people on my floor I can go to for help for say like a problem... but also what I'm surrounded by instead is detrimental to what I'm doing." Clearly, the engineering residence halls serve as an important support structure for first-year women, and an unsupportive environment is creating additional stress for these women.

F. Research Question 6: Career Awareness

While many of the core classes in the first-year did not seem to promote career awareness due to the technical nature of the curriculum, the introduction to engineering courses taught students how they could apply their knowledge to their future careers and gave them an opportunity to see what they could do in the future with their degrees. Participants stated these introduction courses were helpful in defining their majors and helping them decide if it was an appropriate choice for their interests. The guest speakers were said to be the most beneficial aspect of the course. The first-year engineering

design projects course was also enjoyed by all students because it opened their eyes to what they would be doing after graduation and gave them the opportunity to experience it beforehand. One woman spoke regarding the course, stating "you know if I just had calculus and chemistry I'd really be questioning, but we get a taste of what we are going to be doing, like after we learn all that stuff, and that's really encouraging." These results suggest the need for more classes that promote career awareness in the first-year to give women the desire to push through the core classes and increase retention.

V. SUMMARY

The underrepresentation, socialization and retention of women in undergraduate engineering colleges have been issues nationally [2, 7]. In a large state college of engineering in the Rocky Mountain area, the retention of women has dropped below that of men. This drop in retention was investigated through the conductance of eight hour-long focus groups with four to ten participants (n=55). Participants consisted of first-year women enrolled in a first-year engineering design project course.

Overall, the interest of first-year women was demonstrated to be greatly affected by the professors of first-year courses. Engaging professors were stated to have a positive impact on the interest of students, indicating the importance of having such professors to keep first-year women interested in the course material. Most women reported a warm climate in the college of engineering. However, women who reported a chilly climate indicated that male peers in project teams were the source, implying the need for special attention on project teams to ensure a positive environment for female members. The self-efficacy of women in the college was found to be relatively high. However, many women expressed doubts about being able to perform well in school while maintaining outside interests. These results imply the need for a mentoring program to help women understand how to balance their extracurricular activities with school work. Academic performance was demonstrated to have a large impact on how women defined their success in the college and, with the high standards women set for themselves, illustrates the potential for women to fail themselves out of the college due to personal standards higher than those imposed by the college. Support structures in the college were found to be very important to the women of the college. However, many women reported they felt uncomfortable that gender-specific support programs tended to emphasize women as the minority and singled them out. While career awareness was not instilled in most core classes, the introduction classes and first-year engineering projects course were reported to help students understand what they would be doing in the future and give them something to look forward to while taking "weed out" classes. These results indicate a need for more courses that promote career awareness in the first-year curriculum.

This study demonstrated that all six of the posed research questions can have an impact on the retention of first-year women. To further investigate these research questions, the focus group questions will be revised to further focus on the research topics, and more focus groups will be conducted.

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APPENDIX

Focus Group Questions:

1. Warm-up Question (~5 min): How have you found friends so far in the college of engineering?
 - *Probe:* Do you do extra-curricular activities with your friends? If you had infinite time on your hands, what sorts of things would you do? What is preventing you from doing these things now? What about a job during school?
2. Defining "Success" Question (~10 min): What does "success" look like in engineering to you or your friends?
 - *Probe:* How do you feel about that definition of success? Do you think your definition of success is different from other people's
3. Climate Question (~10 min): How welcoming has the college and/or your department been to you as a woman?
 - *Probe:* What kinds of groups are you involved in which are supportive of you as a woman? How important is it for you to have groups which support you as a woman? Have you ever felt treated differently because you are a woman?
4. Mentor Question (~10 min): What is a mentor to you as an engineering student?
 - *Probe:* Describe mentoring experiences you have had since entering college or before college? What do you talk about with them? How did you find them (e.g. university, family, industry)? If the university were to initiate a mentorship program for women in the college, what kinds of qualities would be important to you for matching you with a mentor (is gender an important quality)? How important or not important is it for you to have a mentor?
5. Course-Specific Question (~10 min): Are there any courses or professors that are currently impacting your decision to continue in your program.
 - *Probe:* What aspects of the course or professor were most impactful? What about the intro to engineering courses, (GEEN 1400, Departmental intro courses, math, science, computing)? In particular, what are your opinions about the Calculus courses? What about the women's manufacturing/skills workshop? Discuss any impact of your courses on the development of your knowledge of the engineering profession?
6. Supportive Housing Question: Tell us about your current housing situation.
 - *Probe:* How would you compare yourself to your roommates? Where, in terms of location, do you like doing your school work?
7. Open-Ended Question (~10 min): Is there anything we did not cover that would you like to talk about?

definitions in the college? What do you think success looks like for students in other fields or colleges?

Perceptions of Engineering Identity: Diversity and EWB-USA

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Abstract - Currently, the engineering community faces shortages. These shortages can be conceptualized as both literal shortages of numbers, particularly females, and a more conceptual shortage of engineers who are trained and qualified to handle the transitioning global context of the profession. With its rapid growth, high female involvement, and global vision, Engineers Without Borders-USA (EWB-USA) stands as a prime research model for the larger engineering field. During a series of five regional EWB-USA workshops, participants were asked to respond to six open-ended questions dealing with identity and gains from their involvement. Thousands of unique responses were coded into emergent themes to identify the most common responses and to compare response themes across questions. Results suggest that EWB-USA members identify strongly with the organization, which may increase their identity with and motivation to remain in the profession. Results also show that EWB-USA members are filling significant education gaps from their organizational involvement and are gaining the desirable global engineering qualities required within the field. These results help unpack the motivations driving EWB-USA members and gains from their membership that may help, through future curriculum development, attract and retain a diverse engineering population able to handle future challenges required by the profession.

Keywords: *Engineering Identity, Motivations, EWB-USA*

I. INTRODUCTION

Today, the engineering field faces significant challenges. Recognizable shortages of young professionals have been reported by the National Academy of Engineers [1] and female engineers are drastically underrepresented in both universities and the workplace [2]. Current numbers state that 20% of the engineers in the university and 11% of the engineers in the workplace are female [3]. To combat this shortage against the rising demand for engineers, recruitment and retention efforts are prevalent topics in engineering practice and research.

In addition to the shortage of engineers, the engineering profession must also confront demands for new skills and attributes of future engineers. In particular, NAE identified a need for globally aware and prepared engineers ready to navigate the world of 2020; the identified qualities of these future engineers are often not taught inside the typical engineering curriculum [4]. Engineers are now being asked to obtain these attributes while the universities and workplaces adapt their educational goals.

In the midst of these challenges, the engineering organization Engineers Without Borders-USA (EWB-USA) has witnessed rapid membership growth since its origin ten years ago. It currently has over 12,000 members, which includes both student and professional membership. These members have worked on over 350 community-driven engineering projects in over 45 developing countries [5]. Additionally, this organization reports that roughly 40% of its members are female, which provides a much more gender-balanced ratio than the typical engineering setting [6]. Due to the success of EWB-USA, this research aims to unpack its success to better understand the motivations attracting its volunteers to join and remain in the organization. With its rapid growth, high female involvement, and mission of global service projects, EWB-USA may serve as an ideal model for the challenges facing the larger engineering profession.

II. LITERATURE REVIEW

Current literature regarding the shortage of engineers, particularly female engineers, offers many factors impacting retention. Social cognitive theory proposes that behavioral, cognitive, and environmental factors simultaneously influence an individual's actions [7,8]. In applying this theory to vocations, social cognitive career theory suggests that expected outcomes and self-efficacy, or the belief in one's own ability, are the foundations for professional interests and goals [9,10]. Because of its extensive application to education and career choice, this theory provides the framework used for this research. Examining the interests, identities, goals and motivations of EWB-USA members, can help us determine the expected outcomes and self-efficacy these members hold. Appreciating all four key theoretical components for EWB-USA involvement will aid our understanding of the organization as a model for recruitment and retention. Although the literature assessing involvement in professional organizations is scarce, one study found that undergraduate women involved in professional organizations (such as ASME, IEEE, ASCE, SWE etc.) had higher academic achievement and commitment to engineering when compared to women without professional organization involvement [11]. To further unpack these trends using the lens of social cognitive theory, this phase of the research focuses primarily on the identity and motivations of EWB-USA members as retention factors.

A. Identity

Work by Matusovich et al. shows that aligning engineering with one's sense of self is an important factor for persistence in the field [12]. Additional research confirms that a sense of inclusion and finding "people like me" assists female engineers in identifying with and persisting in STEM disciplines [13,14]. Formal and informal mentoring serves as a way for female engineers to find role-models to identify with and learn from; however, with limited resources of similar mentors, female retention may be hindered [15,16,17]. Other research shows that most engineers are assumed to be Caucasian men [18], which restricts the identity of the overall engineering profession. In contrast, EWB-USA may provide supportive career scaffolding in transition from university to workplace because of its formal and informal mentoring opportunities, which may lead to an improved and diversified engineering identity and may encourage female retention.

B. Motivations

Motivation is another important factor for retaining engineers. In a survey of over 3,600 individuals, students reported that "making a difference" was a significant motivation for joining the profession [1]. Seymour and Hewitt (1997) found similar results in their study of gendered STEM data. They found that over 90% of students reporting altruism as a reason for majoring in a STEM field were female [19]. The mission and vision of EWB-USA aligns with these findings: "*Our passion is to make a difference*" [5]. If EWB-USA helps its members connect engineering and their motivations, including a place where they can help others to feel their altruistic intentions, the organization may help retain both male and female engineers in the profession.

Understanding motivations may also help give insight to areas in which educational gaps can be filled. A diversified engineering profession may be achievable by attraction to both male and female motivations. Some research suggests that men prefer to work with things while women prefer to work with people [20]. As Schreuders et al. conclude in their study of women in engineering, "An emphasis should be placed on the direct human benefits of engineering practice..." (p. 16). If engineering curriculum can be transitioned to include more humanitarian or societal emphasis, which is naturally present in the field, female retention may improve. With the natural humanitarian component of EWB-USA projects, this educational gap, along with other recognizable gaps, may be fulfilled through organizational involvement.

The current research aims to build on these two retention factors, identity and motivations, to unpack the success of EWB-USA. This research is part of the first phase of a three-year, multi-method NSF funded project that seeks to understand why the organization enjoys a balanced gender membership. Answering this larger question requires that the research question is broken into smaller, more manageable, and, as a result, more thorough parts. At this initial phase of research, the questions of interest ask how involvement with

EWB-USA affects a sense of identity, and how participation in EWB-USA supports, sustains, or diminishes motivation to enter and stay in engineering.

III. RESEARCH METHOD

This research aims to unpack the success of the EWB-USA organization by using a multi-method approach. This larger approach begins with a qualitative portion of open-ended responses, focus groups and interviews followed by a quantitative questionnaire. At this phase of the project, the initial qualitative portion is underway. Eventually, quantitative surveys will be delivered to memberships of a number of engineering organizations, including EWB-USA, the American Society of Civil Engineers (ASCE), the American Society of Mechanical Engineers (ASME), and the Society of Women Engineers (SWE). For this paper, we report results from one phase of the qualitative portion of the research. We refer to this phase as the "Sticky" notes.

During the fall of 2011, seven regional EWB-USA workshops were held for student and professional members across the country. In total these conferences brought together 1,005 engaged EWB-USA members, which represented 8.4% of the organization's total reported membership. At each of these workshops, members were asked to answer six open-ended response questions. These questions were delivered via a sheet of paper that contained 6 blank colorful boxes that resembled "Post-its"® with demographic data, including gender, professional status, professional training, organizational membership, and year of birth at the bottom of the paper. During the workshop, the workshop facilitator asked willing participants to answer a question in a colored box, rotating through the questions during the talk. Five of the conferences asked the same six questions and have been analyzed together, while the other two conferences asked unique questions that will be used in future research. The five conferences with identical questions will be analyzed for this research, resulting in 505 respondents.

The six questions for this phase of research asked:

1. How do you describe yourself?
2. How do you describe a typical engineer?
3. How do you describe a typical EWB-USA member?
4. What do you think an engineer needs to know?
5. What, if any, are the gaps in your engineering education?
6. What are your biggest gains from your experience with EWB-USA?

These six questions were chosen to gain preliminary insight into the identity and motivations of EWB-USA members. The first three questions aim to answer identity questions while the last three intend to unpack the motivations driving EWB-USA members. Instead of asking for motivations outright, these three questions looked at the gains experienced by members from their involvement and whether

or not those gains were beneficial for their expected outcomes of being an engineer (i.e. needed for engineering or to fill an educational gap). In order to distinguish these questions from explicit motivations questions posed during interviews and focus groups, these were deemed ‘*awareness*’ questions as they referred to the respondents’ awareness of their engineering needs, educational gaps, and EWB-USA gains.

Collecting such large quantities of data allowed for greater breadth of data than interviews, and the open-ended format permitted unrestricted responses. Because of the nature of open-ended questions, participants had freedom to write any format of response, which generated a range of response types including paragraphs, sentences, and bullet points. This format often led to multiple unique answers per question per person and gave a total of 7,661 unique responses to analyze. Each response was transcribed and imported into the program QSR NVivo. This software package allows researchers to manage and analyze qualitative data by grouping responses into emergent themes and comparing and contrasting trends.

Throughout the process of coding responses, we kept a descriptive coding dictionary for each emergent theme in order to maintain consistency between responses and between periods of analysis. For example, the word *motivated* was a common descriptor of self and therefore became its own theme. In the dictionary, this theme also included words such as *driven*, *focused*, *hardworking*, etc. The dictionary was shared with the research team to check for validity and to ensure inter-coder reliability. Responses to each of the six questions were initially coded separately for their unique trends, and once patterns were found, themes between questions were aligned to allow for cross-question comparisons. In general, themes for questions one, two, and three—the identity questions—were matched, while themes for questions four, five, and six—the awareness questions—were matched. Each question primarily generated responses in the main, matched themes; however, each question also generated a few unique themed responses. Once the themes and definitions were established, the relative frequencies of each response were compared and analyzed.

IV. RESULTS

Responses to open-ended questions were analyzed from the following five regional EWB-USA conferences: Great Lakes (n=118), Midwest (n=71), Mountain (n=62), Northeast (n=188), and Southeast (n=66). These 505 responses represented 68% of total conference attendance. For those respondents who reported their gender, 41.5% were female and 53.3% were male. These statistics follow the gender-balanced trend that EWB-USA claims. Additional demographics showed that 74.4% of respondents reported being student members, while 16.2% reported being professional members.

Analyses of the coding results were based upon relative frequencies of responses to the open-ended questions. We calculated relative frequencies based on the number of responses coded to a theme in comparison to the total number of responses for each question. This allowed us to compare the relative frequency of unique themes for each question and the relative frequency of equivalent themes between questions.

Because the questions were open-ended, many unique themes emerged, which resulted in themes with relative frequencies under roughly 25%. In order to reduce the results to a manageable amount, only the top twenty themes for each set of questions are reported and compared. For all six questions, the top twenty themes hold at least 80% of the responses. A category labeled *other* collected themes with low relative frequencies or unique responses for each question. The *other* category differed by question but generally contained between five and ten unique or smaller frequency themes. For instance, the *other* category in the identity questions includes themes such as *traveler* and *nature lover*, while the awareness questions included *humility* and *professional development* in the *other* category.

A. Identity

Results for the relative frequencies of responses to the first three questions of the study are shown in Table 1, which lists the themes ranked in descending order based on responses to question 1, the description of self. The top five most common descriptors of self were *motivated*, *humanitarian*, *passionate*, *creative*, and *goal-oriented*. These top results are highlighted in Table 1 in bold along with the top five results for the other two questions. *Motivated* is the only theme that appeared in the top five categories for all three descriptive questions, while four of the five top responses between the descriptions of self and the descriptions of the typical EWB-USA member matched.

Table 1 holds two dominant responses: an EWB-USA member is typically *humanitarian* (19.2%) and an engineer is typically *analytical* (24.2%). The table also indicates that there was not one single dominant trait for the descriptions of self—where the relative frequency was significantly higher than the other two questions. Interestingly, for twelve of the top twenty themes, the relative frequencies of the response themes for describing self are in-between those of the engineer and an EWB-USA member. These results suggest an emerging trend that EWB members often identify themselves as someone with combined traits of an engineer and an EWB-USA member.

This trend was also noted in reading responses to all three identity questions from individual participants. For example, one participant described herself as, “*analytical, driven to serve others and make a difference.*” She then described a typical engineer as, “*educated, problem solvers, strategic, analytical, innovative,*” and a typical EWB-USA member as, “*wants to make a difference, thinks of others, wants to use own knowledge to help others.*” This response is illustrative of

TABLE I. IDENTITY RESULTS

| Relative Frequencies of Response Themes (%) Ranked by <i>Self</i> | | | |
|---|-------------|-----------------|----------------|
| | <i>Self</i> | <i>Engineer</i> | <i>EWB-USA</i> |
| Motivated | 15.4 | 9.6 | 13.8 |
| Humanitarian | 12.3 | 3 | 24.2 |
| Passionate | 6.2 | 1.3 | 9.4 |
| Creative | 5.8 | 9.1 | 4.2 |
| Goal-oriented | 5.7 | 4.7 | 4.3 |
| Analytical | 5.3 | 19.2 | 1.6 |
| Curious | 5.2 | 3.1 | 2.7 |
| Outgoing | 5 | 0.3 | 3.5 |
| Smart | 4.6 | 10.8 | 3.7 |
| Organized | 3.3 | 4.1 | 1 |
| Adventurous | 3.1 | 1 | 2.6 |
| Global Perspective | 2.4 | 1.3 | 8.3 |
| Problem Solver | 2.2 | 8.7 | 1.1 |
| Respectable | 2.2 | 1.1 | 1.5 |
| Well-rounded | 2 | 0.5 | 2.5 |
| Confident | 1.9 | 1.3 | 2.2 |
| Optimistic | 1.9 | 0.1 | 1.4 |
| Narrow | 1.5 | 9.5 | 0.8 |
| Introvert | 1 | 3.3 | 0.1 |
| Adaptable | 0.9 | 0.6 | 0.5 |
| Other | 12.1 | 7.5 | 10.6 |
| n | 1467 | 1431 | 1550 |

typical responses where the participant's description of self consists of traits included in her descriptions of both the engineer and the EWB-USA member. Looking at the results in this way—based on the individual—further supported the results based upon relative frequency alone, suggesting the individual often identifies as both an engineer and an EWB-USA member.

Additional results from the identity questions showed that three quarters of the top themes for the descriptors of self are found in frequencies closer to the EWB-USA member than to the engineer. Although members often describe themselves with traits of an engineer and an EWB-USA member, the descriptive responses for self tended to lean closer to the identity of an EWB-USA member than that of an engineer. This further suggests that EWB-USA members commonly identify with this engineering organization. Since the literature states that better aligning personal identity and engineering increases retention, the data provides strong

evidence to the claim that EWB-USA is supporting its members to persist in the engineering field.

B. Awareness

Results for the relative response frequencies of the last three questions of the study are shown in Table 2 and are ranked in descending order based on responses for question 4, what an engineer needs to know. The top five most common themes identified included *technical skills*, *interpersonal skills*, *problem solving*, *societal awareness*, and *awareness of engineering impact*. These top results are highlighted in Table 2 in bold along with the top five results for the remaining two questions. None of the top five themes match across the three questions; however, three of the top five themes match across the responses for gaps in education and gains from EWB-USA.

Two prominent responses are seen in Table 2: an engineer needs to know *technical skills* (25.2%), and a major gap in engineering education is *experience and application* (25.9%). As with the dominant identity responses, these results are somewhat natural or expected, although in this case the extreme response rate to *experience and application* as an education gap is noteworthy.

Six of the top twenty response themes reported for these questions are responses limited to one question. These responses were given with high enough frequency to merit consideration. *Problem identification* and *ability to learn* were highlighted as unique responses for question 4, what an engineer needs to know, and *personal awareness*, *sense of fulfillment*, *confidence*, and *enjoyment* were frequent response themes for question 6, gains from EWB-USA. These last four unique responses to question six illustrate that EWB-USA members are gaining much more than standard curriculum from their membership. For example, two members wrote about their personal gain from their involvement that, “*It has helped me define what I want in my career*,” and “*I learned where I fit, and figured out why I get out of bed every morning*.” Clearly some of these personal gains are very significant and impact motivations.

The most interesting response themes for the awareness questions were those where the trait or skill was needed for an engineer. Some responses may be interesting, such as finding *relationships* as a top gain from EWB-USA involvement; however, without a present engineering need for this theme or additional knowledge of how this leads to a specific gain, the gain might not have much application. The themes that we focus on here are those with an existing need, a present education gap, and a comparable gain from EWB-USA involvement. Several themes fall into this pattern, specifically *global perspective*, *project management*, *teamwork*, *experience and application*, and *humanitarian emphasis*. Based on the recognized need, tangible gap, and significant EWB-USA gain, these five themes stand out as significant progress made by the organization. If students and professionals are aware of their needs and their knowledge

TABLE II. AWARENESS RESULTS

| Relative Frequencies of Response Themes (%) Ranked by <i>Gains</i> | | | |
|--|--------------|-------------|--------------|
| | <i>Needs</i> | <i>Gaps</i> | <i>Gains</i> |
| Technical Skills | 25.2 | 4.4 | 3.3 |
| Interpersonal Skills | 12.9 | 10.2 | 3.3 |
| Problem Solving | 7.8 | 3 | 3 |
| Societal Awareness | 7.6 | 3.3 | 2.6 |
| Awareness of Engineering Impact | 5.3 | 4.4 | 2.9 |
| Global Perspective | 5.2 | 6.9 | 11.6 |
| Project Management | 4.3 | 6.1 | 9.6 |
| Experience and Application | 4.1 | 25.9 | 9 |
| Teamwork | 4.1 | 3.8 | 4.3 |
| Humanitarian Emphasis | 3.3 | 3.9 | 6.3 |
| Creativity | 2.4 | 1.3 | 1.1 |
| Non-technical Subjects | 1.9 | 5.6 | 0.4 |
| Networking | 0.5 | 1.7 | 3.7 |
| Relationships | 0.3 | 1.1 | 9.4 |
| Problem Identification* | 3.5 | - | - |
| Ability to Learn* | 2.7 | - | - |
| Personal Awareness** | - | - | 6.6 |
| Sense of Fulfillment** | - | - | 5.1 |
| Confidence** | - | - | 3.7 |
| Enjoyment** | - | - | 2.6 |
| Other | 9 | 18.3 | 11.5 |
| n | 1315 | 787 | 1111 |

* limited to Question 4; ** limited to Question 6

gaps, and then are able to fill them through involvement with EWB-USA, the organization is benefitting the profession.

Additionally, based on the agreed upon theme definitions, EWB-USA members report *global perspective* as their highest gain from EWB-USA involvement. These members also report *global perspective* at the third largest gap in their education. Because this theme is among the top responses, the results suggest that the organization is having a strong impact on the global awareness of its members. EWB-USA is creating more globally aware engineers and extending the typical engineering skill set further than the traditional curriculum.

In its report *The Engineer of 2020*, the National Academy of Engineers highlights nine unique attributes that the engineer of 2020 should have: strong analytical skills, practical ingenuity, creativity, good communication, business and

management skills, leadership, high ethical standards or professionalism, resiliency and flexibility, and a desire for lifelong learning [1]. Based on this research, EWB-USA members are explicitly gaining at least seven of these attributes from their experience with the organization. *Technical skills, problem solving, creativity, interpersonal skills, project management* (which includes *leadership*), and *humanitarian focus* are comparable emergent themes that EWB-USA members report to be gaining and match with the engineer of 2020 attributes. With these seven gained attributes and the additional gains of *global awareness, personal awareness, teamwork, and experience and application*, EWB-USA members are becoming well-equipped current and future engineers.

With such significant gains experienced by the members of EWB-USA, the larger engineering profession can benefit by applying the EWB-USA model in the classroom. As Schreuders et al. suggest, educational institutions can help engineering retention by incorporating more of the motivational factors driving diverse engineers, such as making a difference [20]. With EWB-USA reporting a population with atypical engineering demographics, the top gains found in this research would be valuable to incorporate into engineering curriculum as they may lead to similar trends found within the EWB-USA membership: fast growth, diversified population, and increased global awareness.

V. CONCLUSION

Based on these initial results, EWB-USA members identify themselves with characteristics consistent with their descriptions of both other engineers and other EWB-USA members, suggesting that their identity is complete through the combination. As the literature states, identity as an engineer and with the engineering profession is a key factor in recruitment and retention of engineers. As EWB-USA members are identifying strongly with this engineering organization, their identity alignment to the profession are likely increasing, which other research would suggest improves their likelihood of persisting in engineering. Results also show that these members gain valuable engineering and personal attributes desirable for the engineer of 2020. Further research will help us determine if these gains are the underlying motivations of organizational involvement; however, if these gains are allowing EWB-USA members to connect engineering to their motivations, literature says that the desire to remain in engineering should increase. Based on the literature and these two primary findings, EWB-USA appears to have significant impact on engineering retention.

Some limitations of this study stem from the data collection methods. With such large amounts of data collected from volunteers, the depths of responses were significantly limited and gave primarily only a few words for each response. This limits understanding the identities and motivations of EWB-USA members to phrases rather than richer, deeper explanations. The research team is expanding these findings

through interviews and focus groups, with students and professionals to gain richer insight to the organization. This depth of data will also allow us to better understand how a member's level of EWB-USA involvement changes their responses. Another limitation of the data collection method was that the data was gathered at EWB-USA conferences, which limited the respondent population to only EWB-USA members. Ideally, equivalent amounts of data could be collected from engineers not involved with EWB-USA for comparisons. As part of the future focus groups and interviews, engineers not involved with EWB-USA will be included. Comparative analysis between members and non-members will allow us to better determine differences between identities, motivations and gains. After we feel theoretical saturation has been reached, a survey is planned for the memberships of EWB-USA, ASCE, ASME, AGC, and SWE to validate the findings across multiple students and professionals and compare EWB-USA with other professional organizations. These future steps will continue to support the aim of the research to understand why EWB-USA is enjoying gender-balanced ratios and determine how these results can be extended to engineering curriculum and workplaces to recruit and retain a larger, more diverse, and more globally prepared engineering population.

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Work in Progress: Understanding the Experiences of Women of Color in Engineering

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Abstract— This qualitative study aims to understand the experiences of undergraduate women of color in engineering; specifically how their gender, race, and ethnicity shape their construct of an engineering identity. For many of the students, engineering identity was only understood along with gender and race/ethnic identities.

Keywords—identity, women of color, diversity

I. INTRODUCTION

In 2008, the percentage of women who graduated with an engineering bachelor's degree in the United States was 18.5% [1]. In other traditionally male-dominated fields such as business the percentage of women awarded degrees in 2006 was 49.2% nationwide [2]. In a population where the percentage of women is 50.7% [3], gender disparity in engineering is intolerable. These disparities are similar, if not worse, for women from racial and ethnic minorities in engineering.

In a changing U.S. population, it is critical to understand the experiences of women of color in science, technology, engineering, and mathematics fields in order to improve the campus climate and curriculum in higher education. This study builds on previous literature about undergraduate student identity development by looking at women of color and their engineering identities. As [4] suggests, studies of women in engineering through a feminist theory lens can be enriched by the parallel studies of identity formation. In previous literature, researchers have studied professional engineering identity [5,6] science identity [7], student social and academic engineering identity [8,9] and engineering identity of students working in a research environment [10]. As emphasized in [11], there is a great need to expand on qualitative studies of underrepresented people in the field of engineering. The focus of this study is on the intersection of racial, ethnic, gender identities and engineering identity.

II. RESEARCH METHODS

The research questions posed in this study were (a) How do the race or ethnic identities, gender identity, and engineering identity play a role in the experiences of undergraduate female students studying engineering? (b) How does engineering identity intersect with other identities, specifically racial, ethnic, or gender identity?

After receiving Institutional Review Board approval, I conducted 35-50 minute, semi-structured interviews with nine undergraduate female students at a large, public, predominantly white university. All of the participants were majoring in an engineering field and self-described as African-American, Black, Hispanic, or Latina. The students were recruited via a mass mailing list and through snowball-sampling. The interviews were audio recorded, transcribed, and coded using induction [12] and iterative methods [13].

After several iterations of data analysis, the themes presented below were constructed. Next, specific occurrences of identity understanding and/or construction as it related to the model of multiple identities presented by Abes et al. [14] were coded. Finally, occurrences of "engineering identity" – that is anything related to how students understood themselves as engineers were also coded across all interviews. All of the names presented are pseudonyms.

III. PRELIMINARY FINDINGS

Using the research questions as guides, the following three prevalent themes were found.

A. Being Recognized as an Engineer

The idea of being recognized in a positive way as an engineer was a key element in the students' experiences on campus. The students discussed instances of recognition from staff, faculty, family, and friends. Ana described the warm welcome from staff in her department as a positive experience that reinforced her goal of attaining the engineering degree.

I remember going to the head of the department for funding for a [National Conference], and we got into the topic...[The staff said] "Hey you should come around more often, we do recruiting, we would love to see more female Hispanics here." They're very excited about having females in [Engineering Major] especially Hispanics because I think I'm the only one. I like it. They embrace it and I appreciate the way that they treat me in the department. (Ana, 3rd year)

B. Feeling like a "Minority"

Even though the word minority was not used in any of the communication with the participants, it was voiced by all of

the students in different ways. Some discussed the idea of being the only one, with respect to their gender or race/ethnicity on campus, others discussed seeing more opportunities because they are a minority, and experiencing stereotypes.

Kiara talked about seeing more opportunities because of her race and gender. Her representative quotation below illuminates the idea of how being a minority had positive and negative consequences.

I've been getting a lot of opportunities just because of my gender and race. I get the double shot. It's like they're both working against me and for me at the same time, so it kind of breaks even... I was discussing with the [administrative staff] about reapplying, he's like Kiara, you have three things going for you right now...you're Black, you're female, and you're transferring from out of state. Use it, use it, use it! That really broke my heart. (Kiara, 2nd year)

C. Perceptions

The students discussed situations where others' perceptions of them as engineers mattered or had a role in their experiences. In a lot of ways, "perceptions" is opposite to positive recognition – when talking about perceptions students referred to negative experiences they encountered at the university. Jessica shares her encounter with fellow engineering students in the beginning of the semester when student organizations set up booths to recruit other students. This story was in response to my question about what kind of a role her ethnicity plays in her experiences as an engineering student.

I got completely ignored by engineering societies I walked up to them and asked a question and they said "hmmm, this is for engineering students" and I looked at them and said "I'm an [Engineering Major]" (Jessica, 3rd year)

Ana shares a similar story with regards to how she might be treated in the classroom, a story I have heard from other women I interviewed as well.

You see it in your classes, when you ask a question and [male classmates] kind of role their eyes like "How could you not know that? It's probably because she's a girl" Or when I'm trying to explain something and they don't listen. (Ana, 3rd year)

IV. CONCLUSIONS

For many of the students, engineering identity was only understood along with gender and race/ethnic identities. In other words, students' identity as a woman of color was crucial to their construct of an engineering identity.

Participants' engineering identity was understood through

contextual influences in the student's lives such as family and climate. Abes, Jones, and McEwen's [14] dynamic and fluid model of multiple identities helps illuminate the experiences of women of color in engineering. Contextual instances play a major role in understanding the experiences the women talked about especially with regards to gender and race/ethnicity. The next step in this study is to conduct follow up interviews with the nine students. The follow up interviews will focus more transparently on a discussion of engineering identity.

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Critical Questions of Engineering Students by Gender and Ethnicity

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Abstract— Engineering and computer science careers are not well known to the general public. Most students studying these majors also have limited knowledge and information about their chosen area of study. In working with students over many years, the authors have experienced many questions from these students. As part of the evaluations for Academic Success Meetings, the students have been encouraged to ask questions about areas that they need to know more about. The questions tend to repeat themselves and fall into general categories. Not all students have mentors to answer these questions. Starting with the most important, the answers to all of these questions will go on a website that has been developed especially for transfer students under a National Science Foundation Step Award # 0836050.

An initial 136 questions were presented to over 100 students. The students were asked to choose the 20 most critical questions to them. From this data, in an earlier paper, the top five questions were determined for students over 21 and the top five for students 21 and under, as well as by academic level.

In this paper the similarities and differences in these critical questions by gender and by race/ethnicity are considered. The males and females in this study had two questions in common for their top five: “Why should I consider getting a PhD degree in engineering?” and “How do I choose a job?” The three race/Ethnicity groups of White, Hispanic/Latino, and Other/Unknown had only one question in common: “Will there be a job for me when I graduate?” Each of the three two-pair combinations had one question in common. The differences in critical questions by gender and ethnicity will also be discussed.

The information determined here will help educators and advisors encourage potential and actual students in engineering and computer science. With this information they can focus their message by honing in on the critical questions of their particular audience. These questions and their answers can also be used for intentional advising.

Keywords— *critical engineering questions; ethnicity, gender, intentional advising, recruitment, retention, survey.*

I. INTRODUCTION

Women and minority students have always been underrepresented in engineering. Even now, after years of attention on the matter of recruitment and retention and the establishment of women in engineering and minorities in engineering programs, although the percentages are better, the

number of women and minorities are still far too low as “Engineering by the Numbers” shows in Table 1. The 17.8% for women Bachelor’s degrees is the lowest since 1995. This may mean a decrease in the percentage of women’s graduate degrees in the following years. Henceforth in this paper, the term “engineering” shall include computer science.

Table I. Degrees in Engineering and Computer Science 2009. Source: Engineering by the Numbers by Michael T. Gibbons.

| Degrees in Engineering and Computer Science 2009 | | | |
|--|-------|-----------|-------------------|
| Degree | Women | Hispanics | African-Americans |
| Bachelor’s | 17.8% | 6.6% | 4.6% |
| Master’s | 23.0% | 5.3% | 4.7% |
| Doctorate | 21.3% | 3.8% | 3.8% |

Much attention has been paid to the retention of women in engineering; however, recent studies have shown that women are retained as well as or better in engineering than men [1, 2]. The first study also concluded that engineering students are very much like other students, but more of them need to be attracted to engineering [1]. Although retention rates certainly are not ideal, with less than half of all students who begin engineering graduating in engineering, the major problem with the scarcity of women in engineering is that not enough of them begin engineering in the first place. The percentage of both women and men who expect to have their career in engineering is low (less than 12%) [3]. In addition, few students switch into engineering often because the student would need to do catch up work in mathematics. Therefore, one way to have more students switch into engineering is to have more students well-prepared in mathematics and science in high school or during the first years at a community college. A major conclusion from this research is that most young girls do not know about or learn about engineering in their early years. Cosentino de Cohen urges “School teachers – and in later years career counselors – need to encourage girls to become engineers by exposing them to engineering professions [2].” Another action urged by this study is to provide women with a better understanding of different ways to get an engineering degree. This action fits in well with our research

that shows many community college students do not know what they want to major in [4] and need someone to spark in them an understanding of and interest in engineering.

The reasons that more women do not choose engineering have been much debated. There are no easy answers, but there are several plausible theories. Eccles believes "There are two key factors women face in their decision-making process: how much they believe in the ultimate utility of mathematics and how much they value working with and for people [5]." This leads us back to the facts that if you do not take very many mathematics classes you do not realize the ultimate value of mathematics and if you know nothing about engineering, you will not know that engineering is really about working with and for people.

A second cause for few women in engineering proposed by research is that their self-efficacy, the fundamental perception of one's ability to succeed at a task or in an environment, is often low without cause. For example an internship or co-op can change the self-efficacy of students about their ability to perform well in an industry environment [2]. Women often feel that they are not "good" at math when they do just as well as the boys and often have a higher GPA and retention rate.

Not much has changed in the past 18 years. In 1975 only 3 percent of engineering graduates were women. This was increased to over 10% in the 1980s. By 1994, over 17% of engineering graduates were women; however, in 2009 the percentage of engineering degrees earned by women was 17.8%, a 15-year low [6]. So what is the answer?

Tietjin asked this question in 2004 [7]. She wondered why, after 50 years of working on this issue, it had not been solved. Her conclusion was that "If we really knew the answer, we would have solved it already." Her conclusion is that "Engineering in the United States suffers from a huge image problem [7]." Until it is "cool" for girls to like and do well in mathematics and science, we will struggle as a nation to have a good representation of women in engineering [8]. A 1998 Harris Poll revealed that most Americans do not understand what engineering is and what engineers do: "The Harris Poll survey revealed that 45 percent of Americans feel that they are 'not very well informed about engineering and engineers' while another 16 percent stated that they are 'not at all well informed about engineering and engineers.'" Among women, however, the percentages increased to 55 percent and 23 percent, respectively. While education level correlated positively to the respondents' level of informedness, the majority of college graduates (53 percent) still reported that they are "not very well informed or not at all well informed" about engineering and engineers [9].

It seems clear that young women do not know about engineering in general and what they do hear is not very inviting. Phrases such as "math is hard" are commonplace. Women often want to interact with others, to help others, to make things better: however, this is not the usual engineering message. Change was called for. In 2007, the Committee on the Public Understanding of Engineering Messages was tasked by the National Academy of Engineering to do something about this. The result was the publication, "Changing the Conversation: Messages for Improving Public Understanding

of Engineering [9]." This committee talked to people and ran studies to determine messages that could make a difference. A few of these messages are: Engineers are Creative Problem Solvers, Engineers Help Shape the Future, Engineers Make a World of Difference, Engineering is Essential to our Health, Happiness and Safety, and Because Dreams Need Doing. This new style of conversation is already having results. The National Academy of Engineering website [10] has case studies of how using these messages have increased enrollment by women and underrepresented minority students, with the University of Colorado as a prime example.

II. THE SURVEY

The authors are the PI and co-PI on four National Science Foundation (NSF) grants which are leveraged to increase the recruitment and retention of engineering students in order to produce more engineers. An emphasis of the programs is to recruit and to retain women and underrepresented minority students and also to have students go right on to graduate school full-time after receiving their Bachelor's degree. These programs have been described elsewhere [11-14]. As a part of the work the authors are doing under their National Science Foundation (NSF) STEP grant which targets five non-metropolitan community colleges (CCs), they are concerned with the conversations that they have with potential engineering transfer CC students, as well as with some 160 engineering students each semester in Academic Success Classes sponsored by three NSF S-STEM grants (# 0728695, 0807134, 1060226), and additional engineering students who use their Motivated Engineering Transfer Students (METS) Center. Since many of these students know little about engineering even if they have chosen it for their major, the authors receive many questions. Of great concern is the lack of women engineering students coming from rural CCs.

A website has been developed as part of the STEP grant activities. Included on this website are 136 common questions that students ask. The list is being expanded and answers are being added to the questions [15]; however, 136 questions are a lot of questions and the authors wanted to know which questions were the most important to the students. Knowing which questions were the most important, it would make sense to answer those questions first and to emphasize this material to the students. To determine this, the authors surveyed the students in their academic success classes with 103 respondents to select their top 20 questions. At the same time the students were asked to note the questions and to let the authors know of additional questions that should be added.

After receiving the survey results, the authors noted the top 5 questions selected by various groupings: gender, ethnicity, over 21 or 21 years of age and under, academic class standing, and others. The number of students in each category who had selected a particular question was noted. In a previous paper [11] the authors reported and analyzed the results for the students divided by age (over 21 and 21 years of age and under). The only common "top five question" between these groups was "How do I choose a job?"

The top five questions were also analyzed by academic class. Freshmen and sophomores shared two questions in their top five: "Will there be a job for me when I graduate? Will it

pay well? Will it be challenging/boring? Will it require travel?" and "How is my engineering school viewed by industry?" Juniors shared two questions with sophomores: the question on the industry view and "What is the engineering work environment like?" Juniors also shared two questions with seniors: "How do I pay for graduate school?" and "How do I choose a job?" Seniors and graduate students shared two questions: "Why should I consider getting a PhD degree in engineering?" and "How do I weigh the factors that go into choosing a job?" Interestingly, freshmen also chose this last question on weighing job factors as one of their top five.

The 13 major categories of questions, with the number in parentheses identifying how many questions were in that category, were as follows:

- BS in Engineering (5)
- Why Engineering? (8)
- Choosing an Engineering Discipline (13)
- Financing My BS in Engineering (8)
- Why Pursue a BS in Engineering at ASU? (27)
- Importance of a Mentor (6)
- Importance of Research: Figuring Out What I Want to Do (14)
- Important Skills (24)
- Importance of Graduate School (9)
- The MS Thesis (6)
- Getting a PhD (8)
- Starting a Company (6)
- Choosing a Job (2)

The survey results for gender and ethnicity are given and analyzed in the next section.

III. SURVEY RESULTS AND ANALYSIS

Seventy men and 33 women selected and ranked their top 20 questions from the Critical Engineering Questions list. The two groups had two questions in common in their top 5. The women were more united as group on their choices. The most important question for women was "Will there be a job for me when I graduate? Will it pay well? Will it be challenging/boring? Will it require traveling?" Of the 33 women, 60.6% of them chose this as one of their top 20 questions. Their fifth most popular question (selected by 42.4%) was "How do I choose a job?" On the other hand, the most popular (42.9%) question in the men's top 20 was "How do I pay for graduate school?" The men's fifth most selected question was "How is the ASU Ira A. Fulton Schools of Engineering viewed by industry?" This question was in the top 20 for 38.6% of the men. The two questions that were shared by the men and the women in the five questions most often selected were: "How do I choose a job?" and "Why should I consider getting a PhD degree in engineering? What will it offer me over an MS in engineering? Advancement opportunities? Flexibility? Responsibilities? Salary?" See Table II for the top five questions by gender.

Since these students are all in Academic Success Classes where going to graduate school is emphasized, it is not surprising that both the men and the women had questions about getting a Ph.D. Since the Ira A. Fulton Schools of Engineering has a 4 + 1 program allowing students to double-count three courses for the BSE and the MSE, many students come to the conclusion that getting a Master's degree, if at all possible, is a "no-brainer". The question that remains then is

Table II. Top Five Questions by Gender

| Gender | Category | Question | Sample Size |
|--------|--|--|-------------|
| Women | Why Engineering | Will there be a job for me when I graduate? Will it pay well? Will it be challenging or boring? Will it require traveling? | 20 (60.6%) |
| | Getting a PhD | Why should I consider getting a PhD degree in engineering? What will it offer me over an MS in engineering? Advancement opportunities? Flexibility? Responsibilities? Salary? | 16 (48.5%) |
| | Important Skills | What professional organizations should I join? What do they offer? | 15 (45.5%) |
| | Importance of Graduate School | What is a fellowship? | 14 (42.4%) |
| | Choosing a Job | How do I choose a job? | 14 (42.4%) |
| Men | Importance of Graduate School | How do I pay for graduate school? | 30 (42.9%) |
| | Choosing a Job | How do I choose a job? | 29 (41.4%) |
| | Getting a PhD | Why should I consider getting a PhD degree in engineering? What will it offer me over an MS in engineering? Advancement opportunities? Flexibility? Responsibilities? Salary? | 28 (40.0%) |
| | Choosing a Job | How should I weigh each of the following: engineering/technical responsibilities? Flexibility? Choosing what you work on? Flexible work hours? Working from home? Day Care? Work conditions? Work group dynamics? Opportunities for advancement? Location? Traveling? Benefits? Retirement plans? Bonuses? Salary? | 28 (40.0%) |
| | Why Pursue a BS in Engineering at ASU? | How is my Engineering School viewed by industry? | 27 (38.6%) |

if they should go for a PhD. For those who aspire to go into academia the answer is easy, but for those who plan to go into industry, the answer is not as transparent.

Both women and men are concerned with how to choose a job. The students are urged to do internships with different companies to see how they fit with that company. An internship experience can give the student good feedback on what type of job they want. The students are also urged to look around during an internship and to note what engineers with a Bachelor's, Master's, or PhD degree are doing. This information can then help them decide what type of work they want to do and what final degree they should obtain.

The women were concerned with being able to get a job as one of their top five questions, while the men were not. The reason for this is an area that needs more research. Related to this question, however, is the men's concern about how ASU is perceived by industry. This last topic is discussed in the Success Class, but obviously needs to be talked about further. ASU has been ranked by recruiters as the fifth best school in the nation for recruiting [16]. Since many women want to know more about fellowships, this is an area that needs to be clarified and emphasized more.

Paying for graduate school is a concern for the men. This is a topic that is often discussed in the class. The students are urged to become involved in leadership and volunteerism, and especially to participate in research. Most students do not know what research is and are quite sure that they do not want to do it. The students are told that if they can begin research as an undergraduate and find a good mentor, this research can carry into graduate school and they will be paid to go to graduate school and continue the research. Students are also told that not having money is not a good excuse for not going to graduate school. Students have proved that taking out an extra loan to get a Master's degree is a good investment both in terms of job opportunities and in terms of pay. The payback on this investment is usually only a year or two and at that point the person has a higher salary that is compounding. The authors emphasize with the students that choosing a major and a job are not commitments for life. As engineers they are being taught to solve problems and that process applies to all fields. The authors have brought in speakers from industry who have changed their job situations several times to accommodate family constraints or other interests at the time.

Since the ASU programs have an emphasis on both women and underrepresented minority students, the authors are also concerned that the needs of underrepresented minority students are being met. Typically, 60% of the scholarship students attending the Academic Success Classes are women and/or underrepresented minority students. In Arizona, the largest minority group is Hispanic/Latino. In 2010 nearly 30% (29.6%) of the population was of Hispanic or Latino origin compared with 16.3% in the nation [17]. This percentage is likely to increase given that since 2000, the Arizona population has increased 24.6%, the second highest increase in the nation [18]. At the same time, the percentages of Blacks (4.1%, USA 12.6%) and American Indians (4.6%, USA 0.9%) are very

small. The "Other" category" for this study includes Blacks, unknown, and foreign national students who are not scholarship holders, but who do attend the Success Class

Table III shows the top five question choices of the major ethnic groups at ASU. As can be seen from the table, there is one question that was common to all three groups: "Is there a job for me when I graduate? Will it pay well? Will it be challenging or boring? Will it require traveling?" This question was the most popular or tied for top spot for both the Hispanic/Latino and Other groups. It ranked fourth for the Whites. It is possible that the groups other than the Whites feel that they may have more trouble finding a job than Whites. Interestingly, each set of two groups had one question in common in their top five. Both Whites and Hispanics/Latinos are concerned with getting a PhD, with a rank of third for Whites and tied for first for Hispanics/Latinos. Again, this is good news for the authors who are encouraging the students to consider both a Master's degree and a PhD. It is possible that since some of the students in the Other group, which did not rank this question in their top five, know that they will return to their country with a BSE or MS and are not concerned with a PhD. This topic warrants further investigation. The Hispanic/Latino and Other groups shared the question, "How is my engineering school viewed by industry?" As mentioned earlier, although the authors have discussed this point in the past, it is a topic that apparently needs more explanation. This question ranked tied for fourth for the Hispanic group and was ranked third by the Other group. Lastly, the Whites and Other groups shared the question, "What professional organizations should I join? What do they offer?" This question was tied for fourth with the Whites and in fifth place for the Other group. A possible explanation why more Hispanics may not have chosen this as an important question is that the student organization of the Society of Hispanic Professional Engineers as well as the Society of Mexican American Engineers and Scientists, are quite prominent on the ASU campus and so Hispanic/Latino students know that they will continue with these organizations.

Each ethnic group chose two questions in their top five that were not chosen by the other two groups. The Whites were alone with their top two questions: "How do I pay for graduate school?" and "How do I choose a job?" Further study is needed to understand if Whites feel there is less money for them to attend graduate school than for the other ethnic groups. The questions tied for first and fourth for Hispanic/Latinos were unique to their top five: "How do I weigh the factors in a job?" and "What is a fellowship?" The weighing of factors in a job choice is similar to one of the top questions asked by Whites, "How do I choose a job?" These questions will be revised in the future. It is interesting to note that more information on fellowships was on the top five lists for both women and Hispanics. The Other group's unique questions were: "What is the engineering work environment like?" and "How do I pick a research topic?" These questions may have been more important to this group because they had less internship experience among them. The research topic question will be investigated further. This question may have

Table III. Top Five Questions by Ethnicity

| Ethnicity | Category | Question | Sample Size |
|---|--|--|-------------|
| White | Importance of Graduate School | How do I pay for graduate school? | 20 (44.4%) |
| | Choosing a Job | How do I choose a job? | 20 (44.4%) |
| | Getting a PhD | Why should I consider getting a PhD degree in engineering? What will it offer me over an MS in engineering? Advancement opportunities? Flexibility? Responsibilities? Salary? | 18 (40.0%) |
| | Why Engineering | Will there be a job for me when I graduate? Will it pay well? Will it be challenging or boring? Will it require traveling? | 17 (37.8%) |
| | Important Skills | What professional organizations should I join? What do they offer? | 17 (37.8%) |
| Hispanic/Latino | Why Engineering | Will there be a job for me when I graduate? Will it pay well? Will it be challenging or boring? Will it require traveling? | 17 (44.7%) |
| | Getting a PhD | Why should I consider getting a PhD degree in engineering? What will it offer me over an MS in engineering? Advancement opportunities? Flexibility? Responsibilities? Salary? | 17 (44.7%) |
| | Choosing a Job | How should I weigh each of the following: engineering/technical responsibilities? Flexibility? Choosing what you work on? Flexible work hours? Working from home? Day Care? Work conditions? Work group dynamics? Opportunities for advancement? Location? Traveling? Benefits? Retirement plans? Bonuses? Salary? | 17 (44.7%) |
| | Why Pursue a BS in Engineering at ASU? | How is my Engineering School viewed by industry? | 15 (39.5%) |
| | Importance of Graduate School | What is a fellowship? | 15 (39.5%) |
| Other/Unknown (than White or Hispanic/Latino) | Why Engineering | Will there be a job for me when I graduate? Will it pay well? Will it be challenging or boring? Will it require traveling? | 12 (60.0%) |
| | Why Engineering? | What is the engineering work environment like? | 12 (60.0%) |
| | Why Pursue a BS in Engineering at ASU? | How is my Engineering School viewed by industry? | 11 (55.0%) |
| | The Importance of Research: Figuring Out What I Want to Do | How do I pick a research topic? | 10 (50.0%) |
| | Important Skills | What professional organizations should I join? What do they offer? | 9 (45.0%) |

been important to this group because they are concerned about graduate school or want to get into research as a way of getting support for graduate school.

IV. SURVEY DISCUSSION AND SUMMARY

The top questions chosen by the various groups seem reasonable. The women and men had two questions in common and then each had questions which seemed reasonable to be of importance to that group. The three ethnic groups had one question in common and then each of the three pairs had two questions in common. Similar results were found when comparing the 21 years of age and under with those students over 21: these groups had one question in common, “How do I chose a job?” [11]. Freshmen and sophomore students shared two questions: “Will there be a job for me when I graduate?” and “How is my engineering school viewed by industry.” Juniors also were concerned enough about industry’s view of ASU engineering to have it in their top five. The question, “How should I weigh each of the following engineering/ technical responsibilities (relative to choosing a job)?” is shared by freshmen, seniors, and graduate students. Juniors share “What is the engineering work

environment like?” with sophomores. Junior share just two questions with seniors, “How do I pay for graduate school?” and “How do I choose a job?” Seniors and graduate students shared two questions exclusively for these two groups, “Why should I consider getting a PhD degree in engineering?” and “How do I weigh the factors that go into choosing a job? [11]”

An addition interesting view of these results is to note that by selecting the top five choices by the two age groups and by the seven student academic standings, the list of 136 questions is narrowed down to 17 questions. Nine questions were determined by age and an additional 8 questions were determined by academic class. Eight top five questions were determined by gender and ethnicity added only two additional questions to that set for a total of 10. Further we note that 7 of the 8 questions noted in the top five due to gender are included in the top 9 questions defined by the age comparison. The one question that is not is included is, “What is a fellowship?” which was identified by women and Hispanic students. Eight of the 10 top five questions defined by gender and ethnicity are included in the 9 top five questions defined by age. The other question gender/ethnicity question that is not included in age is, “How do I pick a research topic?” selected by the Other

ethnicity group. The two age questions that are not included in gender are: “What is the engineering work environment like?” (included in ethnicity) and “How do I find a mentor?” The eight questions in academic class in addition to age do not include any of the gender and ethnicity questions. If we combine the gender, ethnicity, and age categories, we have reduced the list of 136 questions to 11 questions. If we include the academic standing category, then the list of 136 questions is reduced to 19. This summary can be seen in Table IV.

Table IV. Top 22 Questions

| Category | Question |
|-------------|---|
| Gender | 1. Why should I consider a PhD in engineering? |
| | 2. How do I choose a job? |
| | 3. How do I pay for graduate school? |
| | 4. How do I weigh engineering responsibilities? |
| | 5. How is my engr school viewed by industry? |
| | 6. Will there be a job for me when I graduate? |
| | 7. What professional orgs should I join? |
| | 8. What is a fellowship? |
| Ethnicity | 9. What is the engineering work environment? |
| | 10. How do I pick a research topic? |
| Age | 11. How do I find a mentor? |
| Acad. Class | 12. What are typical salaries for engineers? |
| | 13. What are the scholarship opportunities? |
| | 14. What exciting research is at my school? |
| | 15. What is a research proposal? |
| | 16. Master's thesis or comprehensives? |
| | 17. Unique support programs at my school? |
| | 18. How does one develop leadership skills? |
| | 19. What is a PhD qualifying exam? |
| | 20. What are exciting engineering problems? |
| Targ Trans* | 21. What should I do during summers? |
| | 22. I prefer to build stuff. Must I love math? |

- TARGETTED TRANSFER STUDENTS FROM NON-METROPOLITAN COMMUNITY COLLEGES

If we consider the categories for transfer status among the students who took the survey, only one group, 5 students from the targeted non-metropolitan community colleges, had top five questions in addition to the first 19 questions listed. Their questions have been added to Table IV as 20-22. It is good to note that the 23 non-transfer or graduate students in the class had no additional questions in their top 5, neither did the 31 transfer scholarship students from metropolitan community

colleges nor the 14 transfer students in the class who did not have scholarships

V. CONCLUSIONS

This survey identified 22 primary questions out of 136 that are of interest and judged “critical” to the students that we are serving through an Academic Success Class. The authors will first provide answers to these questions on the Motivated Engineering Transfer Students website. The identification of these 22 questions also gives guidance to the topics that should be covered in the Academic Success Classes, if they are not already and to the topics of interest for outreach. Additional research will be done.

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A Program to Increase Female Engineering and Science Enrollments Through NSF STEM Scholarships

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Abstract—This paper describes a scholarship and student mentoring program created to increase female enrollment and graduates in our Schools of Engineering and Science. This program was developed and administered jointly by both of the schools, and the admissions, financial aid, student life, career development, and learning resource departments. Scholarship recipients were required to participate in a mentoring program in which they met regularly with an upper-division peer mentor. Student participants also engaged in academic preparation activities to help develop study, organization, and test-taking skills for academic success. Further, social activities, such as field trips and dinners, were included to build camaraderie. A team of faculty was highly involved as academic advisors to all students in the program and as an advisory board for the grant overall. The program has been effective in increasing female enrollments and improving retention in both schools, particularly in engineering.

Keywords—female; engineering; science; enrollments, scholarships; mentoring

I. INTRODUCTION

The trends of STEM degree enrollments in the U.S. are well known and have been the subject of a number of NSF and National Academy of Engineering reports. The National Science Board of the NSF issued a 2003 report, The Science and Engineering Workforce: Realizing America's Potential [1], that addresses the need to increase STEM graduates. The report showed that the total number of engineering baccalaureate degrees in the U.S. has steadily declined since 1985, whereas the total number of baccalaureate degrees granted has increased. Today, engineering represents less than 5% of all baccalaureate degrees. The percentage of foreign-born baccalaureate scientists and engineers increased from 11% to 17% from 1990 to 2000. This represents a risk because the U.S.'s ability to attract foreign-born scientists and engineers is diminishing. The percentage of traditionally under-represented minorities in the U.S. is increasing, and the percentage of degrees awarded to women across all fields exceeds that of men and continues to grow, yet minorities and women have the lowest participation rates in pursuing STEM degrees. The report notes flat or reduced domestic student interest in critical areas, including the physical and mathematical sciences. It is

important to both attract and retain students in STEM fields, but less than half of the students intending to major in them currently complete a degree in these areas. Furthermore, underrepresented minorities drop out of these majors at a higher rate than other groups, and female college students in computer science are far more likely (69% in the late 1980s) to switch to another major than males (46%) [2].

Penn State Erie, The Behrend College is primarily a four-year and graduate college within a large land-grant and research university. The College enrolls approximately 4,700 students and has four schools: the Sam and Irene Black School of Business, the School of Engineering, the School of Humanities and Social Sciences, and the School of Science. The School of Engineering enrolls 1,300 undergraduates in nine degree programs, and the School of Science enrolls over 600 students in eight degree programs. Many of our students are of the first generations to attend college in their families, and many of them work while attending college to meet their financial needs.

In western Pennsylvania and our institution, female enrollment in engineering and science fields is lower than the national average. This has motivated us to develop a program, with an NSF S-STEM grant, to attract and retain female students in STEM fields. The NSF S-STEM grant program helps institutions provide scholarships for academically talented students with financial need to enable them to enter STEM careers. Furthermore, the grants provide support for curricular development, training, and retention. Many studies have demonstrated that building strong cohort groups is an effective way to retain female students. Other studies have shown that peer mentoring and use of role models does increase confidence level in lower division female STEM students [3]. Several studies have shown that this approach of using peer mentors can significantly benefit female STEM students [4]. Thus, retention was selected as an overriding theme in implementation of this program. The grant period ran from 2006-2011 and the results presented in this paper reflect that period of implementation.

This program has had a significant impact on increasing female enrollments in our STEM majors and our renewal application was funded by the NSF. Our purpose in presenting this work is to demonstrate exemplary NSF S-STEM program implementation and assessment processes for others to follow as they see fit. Furthermore, this article discusses the impact of the grant on our institution.

II. OBJECTIVES

The primary objectives established for this program were:

1. To provide scholarships to approximately 50 new STEM students in engineering and science who are academically-qualified members of underrepresented groups and who demonstrate financial need as per NSF guidelines.
2. To increase the female/underrepresented student enrollment in our engineering and science disciplines, putting us on a path to meet national averages.
3. To enhance the support structure for the scholarship recipients and increase their success rate in our engineering and science programs.
4. To improve the in- and out-of-class environments for females and underrepresented groups in STEM majors and to provide support for students' academic and social integration with a particular emphasis on interpersonal skills, leadership development, and other forms of student engagement.

III. PROGRAM IMPLEMENTATION

The cornerstone of this grant is the mentoring program, which was developed to retain STEM scholars, optimize their academic performance, and expose them to a wide range of opportunities. The program accomplishes these goals through a comprehensive system of academic support that begins prior to the College's student orientation program in the fall and continues through the fall and spring semesters.

The mentoring program focuses on students' academic and social integration. Each fall semester begins with an orientation meeting for the freshmen, followed by a meet-and-greet event for all STEM scholars. Throughout the fall semester, first year scholars meet in small groups or individually with peer mentors weekly to discuss, for example, time management, test taking skills, how to work with academic advisors, course scheduling, test anxiety, study sessions, and stress management. Some sessions are led by peer mentors and students, while others are led by staff from support offices such as the Academic and Career Planning Center and Personal Counseling or a faculty member. Group meetings addressed topics of interest to all participants and created an atmosphere of camaraderie and mutual support. Individual meetings enabled the mentors to provide targeted assistance on an individual basis and develop rapport with their mentees. During the first weeks of the spring semester, the first year students participate in a resume building program that also begins exploration of academic planning and career development topics. Program topics for the remainder

of the semester are driven by the interests and challenges that the students identify.

Second year scholars have a more individualized program. They are required to create an Individual Activity that is monitored by the supervisor of the mentoring program through meetings several times during the semester. They select from a variety of activities that include identifying topics for honors theses (for students who are also in the university-wide honors program), researching minors, graduate schools, internships, co-ops, and options for on-campus research. All scholars are encouraged to attend our undergraduate research and engineering design conferences.

There are annual field trips for all STEM scholars that foster interactions between scholars and build a stronger community. Trips have an academic focus and have included the Tom Ridge Environmental Center, the Erie Maritime Museum, the Carnegie Museums in Pittsburgh, the Cleveland Science Museum and Frank Lloyd Wright architecture in Buffalo.

Peer mentors are upper-division students in science and engineering and have all been female so far. They are selected based on strong academic records, interpersonal skills and demonstrated leadership skills. We wanted peer mentors who were examples of the kind of students we hoped our scholars would be in two years—with a good GPA, involved in academic activities, and with well-developed academic goals and career plans.

The mentors complete an application and are screened, interviewed and selected by the program faculty advisors, administrative coordinator and, in later years of the grant, current peer mentors. The first mentors were recruited from students who were recommended by faculty and then contacted by the committee. As the scholars became upperclassmen, they were encouraged to apply and were eager to be involved in the program from the "other side of the fence." For the last year of the grant the mentors were scholarship recipients, and this will continue into the renewal grant. They bring a unique viewpoint to the position, since they have experienced the program and are now helping to direct it. Each year brings a unique group of scholars with slightly different needs, so the creativeness and thoughtfulness of mentors in ongoing program development is very important to the program's success.

Peer mentors have also benefitted from participation in the program and have developed personally, academically, and professionally. They participate in a training program at the beginning of the academic year. Group meetings with their supervisor are held every third week during the semester to provide ongoing guidance. Discussions include the progress of their mentees, program planning, and address any immediate concerns. Support from faculty members is readily available as needed.

A Faculty Advisory Committee consisting of two faculty members each from the Schools of Engineering and Science,

the peer mentor supervisor, a staff member from the office of Student Activities and the director of the Learning Resource Center meets monthly, providing feedback on the progress of students and the program. Faculty members on the committee also serve as academic advisors to the students. Peer mentors often attend the meetings to provide information, participate in program activity development, and bring any immediate needs to the attention of the committee.

A. Student Recruitment and Selection

Penn State Behrend embarked on extensive outreach and publicity initiatives upon being approved for the original grant. A National Science Foundation STEM Scholarship brochure and Web site were developed that specified the scholarship and support program details. Targeted mailings were sent to prospective students who indicated an interest in STEM fields, encouraging them to look at Penn State Behrend and this unique opportunity. We also host numerous K-12 STEM outreach events on campus designed to attract students into STEM fields – over 2,000 K-12 students attend activities hosted through our K-12 Engineering Outreach Center annually. During these activities, we distributed information on the NSF STEM scholarship program. As students were offered admission, they were sent letters from the directors of our Schools of Science and Engineering, detailing the benefits of our STEM majors, faculty, facilities, and commitment to the STEM Scholarship Program. Lastly, potential STEM students were invited to a special on-campus breakfast with their parents where they learned about the program, opportunities in STEM careers, how to apply and personally met our STEM Team. Scholarship recipients and peer mentors also speak about their experiences and meet prospective students. They really provide the “peer to peer” touch that we hope will convey the uniqueness and benefits of pursuing a STEM major at Penn State Behrend. In our opinion, these outreach efforts had a significant impact on STEM enrollment.

Upon grant renewal, we were able to incorporate student testimonials in our recruitment activities. “Graduates” of our STEM Scholarship Program have been featured in our newest brochure. Interestingly, several STEM students who were offered admission for Fall 2012, but did not receive the scholarship, still chose to enroll at Behrend because we welcomed them into the mentoring/experiential learning

component of the program.

Scholarship recipients were chosen from women and minority STEM applicants demonstrating financial need. Secondary data used in selection were SAT scores, high school GPA and ranking, and predicted GPA. As our awarding process matured, we determined that we lacked a piece of valuable information from the applicants – their knowledge of and commitment to a STEM major. With the renewal grant, students are required to write an essay as part of their application that describes what they have done to prepare themselves personally and academically for a career in a STEM field. This additional information was extremely beneficial as we reviewed applications for the Fall 2012 class..

Independent sample T-tests found that STEM Scholars had significantly stronger entering academic qualifications and a higher first-year predicted cumulative GPA. Because Penn State uses a validated multiple regression model for science/engineering students’ predicted cumulative GPA that accounts for differing academic qualifications, one might expect scholars and non-scholars to achieve approximately their predicted GPA values. However the last variable in Table 1 shows Scholars’ mean first-year cumulative GPA significantly exceeded their mean predicted cumulative GPA (+.19), while non-scholars performed below their predicted GPA (-.03, not significant). This suggests that the STEM program positively influenced scholars and contributed to their first-year academic performance exceeding the expected level.

B. Student Monitoring

Academic progress is monitored regularly during the semester. Feedback is solicited from instructors, peer mentors and the students themselves. Students are evaluated at the end of each semester to ensure that they are making sufficient academic progress toward completion of a STEM degree; they must maintain a GPA ≥ 3.0 and complete courses for their stated major. Students who do not meet these criteria are sent a warning letter and are required to prepare an academic plan for the next semester that is monitored by the peer mentor supervisor. They are encouraged to consult with the Learning Resource Center to address academic problems and to meet with personnel in the Academic and Career Planning Center and Personal Counseling as appropriate. Students will have their scholarships renewed if they continue to participate in the mentoring program and make adequate academic progress.

TABLE 1. MEAN COMPARISONS: STEM SCHOLARS VS. STEM-ELIGIBLE NON-SCHOLARS

| | Variable | Group | Total Students | Mean | Standard Deviation |
|----------------------------------|---|--------------|----------------|-------|--------------------|
| Secondary Selection Criteria | SAT verbal score | Scholars | 61 | 561 | 90.00 |
| | | Non-Scholars | 397 | 502 | 95.92 |
| | SAT math score | Scholars | 61 | 593 | 73.32 |
| | | Non-Scholars | 397 | 533 | 97.58 |
| | High School GPA | Scholars | 61 | 3.78 | 0.33 |
| | | Non-Scholars | 398 | 3.47 | 0.54 |
| | Predicted Cumulative GPA | Scholars | 61 | 2.98 | 0.25 |
| | | Non-Scholars | 397 | 2.71 | 0.38 |
| Performance Evaluation Criterion | First year Cumulative GPA | Scholars | 60 | 3.17 | 0.55 |
| | | Non-Scholars | 387 | 2.68 | 0.71 |
| | Difference between first-year cumulative and predicted GPAs | Scholars | 60 | 0.19 | 0.49 |
| | | Non-Scholars | 386 | -0.03 | 0.67 |

Students will have their scholarships rescinded if their GPA is < 2.7 for two consecutive semesters.

IV. RESULTS

A. Objectives

The primary purpose of the grant was to provide scholarships and a mentoring program to support student recipients. A total of 61 students were awarded NSF S-STEM scholarships over the grant period: 57 students were female and 4 were male. Ten of the students were minorities.

The second objective was to increase female student enrollment in our engineering and science disciplines. Throughout the grant period, female student enrollment has increased steadily to over 60% (66 to 110 female students) in the School of Engineering and 10% (98 to 109) in the School of Science. Overall, enrollment in STEM majors in the Schools of Engineering and Science increased by 16%. Not all of these increases can be directly attributed to the STEM program. For example, other programs were put in place to increase female enrollment at the same time, and the female student increase exceeds that of the scholarships awarded. However, it is clear that the grant had a significant impact on the academic environment.

B. Student Retention

In terms of student retention in college and STEM fields, students in the NSF STEM Scholarship program have done well, greatly exceeding our institutional averages, which include all majors (STEM and non-STEM) as indicated by the following:

- The first-to-second-year retention rate in college for NSF STEM scholars is 96% vs. the institutional rate of 86%.
- The first-to-second-year retention rate in STEM majors for NSF STEM scholars is 93% vs. the institutional rate of 81%.
- The first-to-third-year retention rate in STEM majors for NSF STEM scholars is 83% vs. the institutional rate of 62%.

Beyond the quantitative results above, the grant has had a number of other impacts. The mentoring program has continually evolved (the types of activities and the ways in which they are delivered), based on survey feedback, to address the changing needs of the cohorts. In terms of impact on our students' careers, upper division STEM scholars are obtaining internships in their fields. The peer mentors hired to support the program have also been successful in obtaining STEM degrees and have obtained full-time employment or gone on to graduate studies in engineering and science.

C. Program Assessment and Evaluation

A series of assessment surveys were administered to measure student success and the effectiveness of mentoring activities. The surveys are summarized in Table II in the Appendix. Both the mentees (student scholar participants) and

peer mentors were surveyed. We used instruments from the AWE project (Assessing Women and Men in STEM fields, www.aweonline.org) beginning in the spring semester of the third year of the grant, when they became available. These assessment tools are validated and allow comparison to a national norm. AWE provides a comprehensive range of surveys. Prior to that time, we administered surveys we created for the purpose of guiding the development of the mentoring program into a support system that would be responsive to students' needs. AWE surveys were administered on-line via a class management system. Previous surveys were administered in paper format during meetings.

Mentees and mentors assessed the program in both pre- and post-participation surveys that included multiple choice and open-ended questions. Scholars indicated that the program helped their academic achievement in STEM majors. This is evident in the change in freshman response rate to the same question on pre- and post-participation surveys. The question asked scholars to indicate their goals for the program from among a list of eight options, with the opportunity to add additional items. 26.7% of scholars listed as one of their goals: *"Assist in doing well in my major"* in the pre-participation survey. In the post-participation survey, that response increased to 85.7%. A similar trend was found among sophomores, juniors, and seniors with a pre-response rate of 34.5% increasing to post-response rate of 75%. Thus, the program has had an impact on academic achievement for students enrolled in STEM fields, as exemplified by this scholar's comment about her mentor's effectiveness on an AWE post-participation survey: *"She [mentor] gave us her phone number the first day and told her (sic) to contact her with any questions. I did this on a regular basis. She helped with anything from school to how (sic) where things were on campus. She was a very reliable resource. Also when it came to scheduling she made sure that I as a freshman knew how to schedule properly. She was very enthusiastic about her schoolwork and this motivated me to do well like her."*

Additionally, based on responses to AWE pre and post participation surveys, the program has had an impact on student awareness of the importance of career and job search skills. On the pre-participation survey only 6.7% of freshman selected *"Help me with career and job search skills"* as one of their goals for the program. That percentage increased to 71.4% on the post-test survey. For sophomores through seniors, that percentage increased from 31.3% pre- to 85.2% post-participation. One scholar noted on an AWE post-participation survey question regarding whether or not she would recommend the program to a friend: *"I would recommend it because I already feel that I am ahead of my friends that did not participate when it comes to career choices and major decisions. For example even though it may not have been comfortable for me to attend a career fair as a freshman and talk to employers, being required to do so got me out there and I gained valuable experience from it."* Another commented, *"It is helpful for deciding if your major is right for you and how to find internships."*

First-year scholars were nearly unanimous in their opinion of the overall effectiveness of their mentors and program effectiveness. Ratings of effective/very effective were 85.7%

for mentor and 92.9% for the program overall. Satisfied/very satisfied was the same, 85.7% for mentor and 92.9% for the program overall.

The vast majority of scholars noted that the program met their goals for participating, with 85.7% of first-year and 82.1% of sophomore through seniors agreeing/strongly agreeing. Furthermore, 100% of mentors said their expectations were met. This suggests that the stated program objectives are being accurately communicated to participants, and also being achieved through the program's activities.

Finally, all scholars, freshman through senior, and all mentors, unanimously agreed/strongly agreed that the program should continue. All scholars would recommend participating in the mentor program to a friend starting college. One scholar said on an AWE post-participation survey *"It is very helpful because you get to know other students from your major and all the programs are very helpful also. The resume and interview programs and the research activities we did were very important in my success thus far in school and in my internship."*

D. Areas for Improvement

The program can benefit from additional programming for sophomore through senior scholars. Only 21.4% of these students noted being active/very active in the program, compared to 100% of first-year scholars. Several scholars noted more activities for upper-level students were needed, and one suggested on an AWE post-participation survey: *"I think it's good for underclassman (sic) to have mentors. Juniors and senior (sic) still need support I believe so I think there should be workshops to get them thinking about professional exams like GRE MCAT (sic)."* This confirmed the opinion of our faculty committee that the original grant was more relevant to first-year students, and upper-division students had fewer opportunities. This has been addressed in the renewal grant with the introduction of new experiential learning components to be completed during sophomore through senior years, with more faculty involvement.

In addition, 57.1% of sophomores, juniors, and seniors rated their mentors as effective or very effective, compared to the 85.7% rating by freshmen. Of the non-freshmen, 64.3% were satisfied or strongly satisfied with their mentors, compared to the 85.7% freshman rating.

Mentor responses were generally positive across the board, which makes it difficult to identify areas for improvement. Two that might bear reviewing are mentor training and mentor perceptions of scholar satisfaction with mentor performance. Both items received unanimous agree ratings, which is good, but no strongly agree ratings. Almost all other fields on the mentor surveys received some strongly agree responses, which

suggest that these two are "low" in a relative sense, even though their rating is still positive.

V. SUMMARY

This paper presented an implementation of an NSF S-STEM Scholarship program. The focus of this program was to increase female participation in our STEM majors, notably in our Schools of Engineering and Science. To achieve this, scholarships were awarded to students for up to four years for each student, and a mentoring program was developed for all participants. The mentoring program was intended to help students acclimate to the academic environment, improve study skills, explore career choices, and most importantly to develop student cohort groups. The program was assessed using nationally-normed instruments from AWE that allow for comparison to other program implementations.

The results of the program and grant are promising. Female participation increased in both of our schools, and the results in engineering were quite dramatic, with a 60% increase. Furthermore, the retention rates for students who participated in the program greatly exceeded our institutional norms. The overall assessment of the effectiveness of the program was quite high, with over 82% of all participants agreeing/strongly agreeing that the program met their goals for participation.

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VI. APPENDIX

TABLE II. OVERVIEW OF THE ASSESSMENT PLAN.

| Surveys | What it Measures | Time of Administration |
|---|--|--|
| AWE Mentor Pre-Participation | Ability to lead other students; ability to communicate effectively; ability to solve problems that arise during mentoring activities; ability to provide direction and offer productive suggestions | Annual Before mentoring program activities begin |
| AWE Mentor Post-Participation | Adequacy of support received to accomplish responsibilities; adequacy of training received; satisfaction with supervision; respondent's suggestions for improving the activity | Annual At the end of participating in the mentoring program |
| AWE Mentee Pre-Participation | Collects baseline data on each participant on students' preparation for a STEM study, confidence in preparation, and sense of inclusion in their academic environment, | Annual Before mentoring program activities begin. |
| AWE Mentee Post-Participation | Feelings of isolation/inclusion; impact of role models, influence on academic/social behaviors; satisfaction with the activities; extent that the respondent participated in the activities; overall satisfaction with the program; perceptions of the mentor; extent of contact with the mentor; suggestions for improving the activities | Annual At the conclusion of mentoring activities each semester. |
| AWE Student Persisting Survey | Reasons for deciding to persist in engineering/science, specifically: initial commitment to and preparation for studying engineering/science; impact of course workload, climate, advising, teaching, etc.; other factors /events that contributed to decision to persist; participation in academic and in extra-curricular activities; confidence in completing an engineering degree; post-graduation plans | Annual At the end of the second and fourth years. |
| AWE Student Leaving Survey | Reasons for deciding to transfer out of engineering/science, specifically: initial commitment to and preparation for studying engineering/science; impact of course workload, climate, advising, teaching, etc. ; other factors /events that contributed to decision to leave; participation in academic and in extra-curricular activities; retrospective confidence in finishing a degree in engineering/science; confidence in completing (another) degree; post-graduation plans | As soon as students leave the NSF STEM program or a STEM field. |
| In-House Freshman Self-Evaluation Survey | Self-evaluation of academic, math and writing abilities as well as self-confidence in academic and social situations. Expectations of a variety of aspects of college career including changes in major or career choice, activities, communicating with professors, etc. | Annual During Orientation and at end of freshman year |
| In House Program & Peer Mentor Evaluation Surveys | Feedback on programs, activities and mentors. Request ideas for activities for the coming semester. | End of each semester |

Science Bound: A Success Story for STEM Education

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Abstract—At the 2005 Frontiers in Education Conference, members of Purdue University and Indiana University Purdue University Indianapolis (IUPUI) presented the results of the first year of the Purdue Science Bound program. Science Bound was created to give young people from minority and low SES households an opportunity to pursue STEM careers in college. In cooperation with the urban Indianapolis Public School (IPS) system, candidate students with aptitude in math and science were selected and given the opportunity to participate in summer camps, enrichment activities, after school projects, and mentoring programs aimed at increasing their likelihood of acceptance to, and success in, collegiate STEM programs.

Analysis of summer camp results has shown that introduction of pre-engineering concepts, and exposing technology and scientific method to secondary school students can significantly enhance problem solving skills and prepare them for collegiate STEM careers. Researchers were also pleased to see that the pre-engineering curriculum modules help participating students improve understanding of associated mathematical concepts. The Science Bound program is now ten years old, and the original cohort of high school freshmen are graduating from college. This paper will examine the success of the program and provide insights into successful elements for STEM enrichment programs and approaches for engaging under-represented students in STEM careers.

Keywords- *Pre-engineering, Summer Enrichment Programs, Diversity, K-12 STEM*

I. INTRODUCTION

The projected job growth for STEM graduates is expected to be 22 percent while the National Science Foundation, predicts that only about 17 percent of US college graduates will earn a degree in subjects related to STEM. [1] That not only predicts a shortfall in college graduates prepared for STEM related careers, but it also falls well below the world average of 26 percent of college graduates earning STEM related degrees. [2] America is becoming more diverse at an unprecedented rate as shown by US Census Bureau projections that indicate underrepresented students will make up more than half the national collegiate population by 2050. Yet these students are significantly underrepresented in STEM fields. [3]

It is therefore imperative that colleges and universities find ways to increase the success rate of underrepresented students in STEM if America is to maintain a competitive edge in the global marketplace. [3] Chubin, May and Babco have pointed out that if American colleges and universities cannot meet the required demand for the quantity and quality of Engineering and Technology (E&T) graduates, then industry will be forced to increase the trend of outsourcing its engineering needs to countries outside the U.S., which may mean moving entire operations overseas. [4] One of the major ways that institutions of higher education can work to reverse this trend is to increase the number of minority students who pursue E&T educations that lead to these careers. Currently only about 10% [5] of students enrolled in E&T collegiate programs are from underrepresented households.

Regarding the shortage of women studying engineering, Cavanaugh indicates that girls have less confidence in their abilities in math and science and they also enjoy those subjects less than their male peers. [6] There are varying theories why young females are not pursuing engineering and technology plans of study. One theory is that they are put-off by engineering, which is stereotypically seen as a “guy” career. [7] Another theory is that young women lack self-confidence in their math and science abilities. Regardless of which is the cause, researchers say that if girls lose interest in STEM topics while in middle school, when social pressures and gender differences become more pronounced, they typically will not find their way back to those subjects. [8] A study of women in university engineering programs shows that this shortage of self-confidence is a major issue which follows them from their high school careers. [9] The Center for Pre-College Programs states that young women still avoid advanced mathematics and science related courses and careers because they underestimate their capability rather than because they lack competence or skill. [10] University outreach programs in conjunction with public school systems, similar to Science Bound, are intended to attack the issue by creating pre-engineering programs in middle school and high school. [11]

A second major shortage is African-American males in STEM. Ways need to be found to improve the yield and

retention rate of this tremendous resource. The Quality Education for Minorities Network's Final Report on African American Males in STEM documents that 67.9% of all STEM bachelor's degrees awarded by Historically Black Colleges and Universities in 2007 were female, but only 32.1% male. [12] The old adage that there are more African-American males in prison than college still rings true today. At the 2012 Best Practices for Students of Color Conference, Dr. James H. Johnson, Jr. presented a logic model for early intervention for boys of color that is consistent with the Science Bound program. Johnson stresses that boys of color are more likely to experience trauma/violence, less likely to have nurturing caregivers/parents, less prepared for school and more likely to receive inadequate/inappropriate educational services. [13] In numerous ways, Science Bound strongly parallels four of Johnson's suggested improved coping mechanisms: (1) parent focus (2) engaging students in high interest activities (3) using evaluation data to assess and improve future programming, and (4) leveraging corporate, community and university partnerships.

II. PURDUE'S SCIENCE BOUND INITIATIVE

Grose states that US engineering and technology schools are struggling to recruit, maintain, and graduate students from minority families. However, despite their best efforts, low income minority students can present a special set of challenges in STEM programs. They may have raw talent, but underrepresented students often suffer from inadequate academic preparation, particularly in math and science, which are two key requirements for engineering and technology students. Unfortunately, those who do make it to the university often are forced to drop out due to economic pressures and the need to begin earning a living early in life so as to help support their family. [14] Based on the data relative to females in STEM programs, there is a compounded issue for young ladies caught in this situation.

However, in Indiana, Purdue University partnered with the 40,000 student IPS public school system to form Science Bound, a program aimed at guiding urban students into STEM careers. The objective of Science Bound has been to locate IPS students who exhibit both an interest and aptitude for success in such careers. If located while they are still in middle school, then Science Bound can assist them, utilizing a program of science oriented classroom mentors, special activities, and enrichment programs. These all help to cultivate the student's STEM interests through the high school years, thus helping to prepare them for entry into the Purdue University program of their interest. These participants selected for the program are roughly evenly divided by gender, making Science Bound an excellent tool for evaluating both racial and gender minority issues.

In order to keep these students on track through their four year high school career, there needed to be a certain amount of incentive. Purdue President Martin Jischke established the objective that each student who completed the Science Bound program in high school and who was admitted to any Purdue degree program in one of the STEM related fields, would be

offered a full four year tuition scholarship plus additional support services such as tutoring, mentors, and professional development to help them succeed. This is an opportunity that few inner city students ever see as a possibility. So Science Bound opens new horizons for them.

In order to achieve this, a strong corps of local mentors, and a range of educational activities, summer camps and assistance programs were instituted during the high school years. Chubin, Babco and May have concluded that an effective pre-engineering program must (1) promote awareness of the engineering profession, (2) provide academic enrichment, (3) have trained and competent instructors, and (4) be supported by the educational system of the student participants." [4]

III. CORPORATE PARTNERS

There is a growing trend wherein both industry and academia have increased efforts to direct students into the pipeline leading for STEM programs. This requires reaching out to K-12 students in local school systems. Purdue's Director of Science Bound, Wesley Campbell, has had the task of recruiting corporate partners from the central Indiana area. Many businesses have become involved by contributing in a number of different ways. These businesses have supported the program financially, providing the funds for the scholarship offers made to students when they complete the high school program. The corporate partners have also provided the financing to provide the summer camps free to students, and to even offer small stipends to the mentors at various IPS high schools who volunteer to stay after hours and work with the Science Bound students on various after-school projects and investigations. However, corporate sponsor participation goes beyond the purely financial aspects of the program. They participate in career days, plant visits, and perhaps most importantly, they provided some of their employees for one-on-one mentoring and counseling.

One of the first companies to sign on as a corporate partner with Science Bound was Bowen Engineering, an Indianapolis based full service contractor that specializes in site-work, underground utilities, concrete, mechanical and process equipment installation, with over a million dollars in business annually. Company founder and president, Bob Bowen is a Purdue Civil Engineering graduate. Despite still being actively involved in the running of his company, Bowen himself is an active participant in the Science Bound program, often volunteering his time as a tutor to students at one of the local high schools. "You spend a lifetime building a corporation, an organization, and work hard to make it a success," says Bowen. "But when all is said and done, you consider it a privilege to give something back."

IV. APPROACHES

The Science Bound Office at Purdue has the responsibility for bringing together all the pieces necessary for the success of the program, coordinating with the IPS high schools to make sure that each school has at least one mentor working with the Science Bound students at that school. They arrange monthly

meetings for both students and parents, so that the entire family remains aware of the progress of the program, and both excited and supportive of their student's efforts in the program. This helps to keep the students focused on the goal.

A number of summer enrichment programs have been offered, and the Science Bound Office works to ensure that students get exposure to their specific areas of interest. Some of these summer programs serve a dual purpose of helping students improve the basic skills necessary for STEM careers and also exposing them to engineering type challenges that stretch their boundaries and help them learn to problem solve. One particular example of a successful enrichment program was a month long summer activity in which the students met in a modified classroom environment for four hours each day where they were exposed to simple engineering concepts. Examination of these concepts and solution of related problems required an understanding of math skills necessary to understand those concepts. None of the math skills were beyond the level that the students had already seen in high school. Nevertheless, when given a skills test at the beginning of the summer program, a majority of the students showed a definite shortfall in comprehension of some of the necessary algebra and geometry concepts.

Approaches used in this summer activity involved showing the students that the math skills they sometimes avoid in school have applications in the real world that do interest them. One example was showing students how mechanical advantage can be used to make their life easier, utilizing a number of common devices that students have seen in use in their everyday lives, such as pliers, wrenches, pulleys, or jacks. Means of determining and maximizing the mechanical advantage were discussed. However, in order to effectively use these new found skills to make their lives easier, the students had to know how to apply concepts of ratios and algebra. Similarly, one class involved a discussion of driving a car, and determining how fast the car could take a corner without sliding into the ditch. The analysis of this situation involved use of vectors and geometry. These two concepts were areas that the students were obviously struggling with, but applying them to real world situations increased their comfort level with the concepts.

The students were also involved in inquiry based learning. The final project of the summer session was to build a structure of balsa wood, capable of supporting a load using the least structural weight. The load which was successfully supported, and the weight of the structure, factored into a scoring rubric that also included appearance and sound use of engineering concepts. But before they began any construction, students were allowed to use different shapes and dimensions of balsa wood materials and a load application mechanism to determine what types of beams held the most load. Some teams even constructed composite beams of their own design to further analyze this relationship. Students and instructors then worked together to plot and analyze the data, extrapolating relationships that helped the students understand the optimum use of the available materials.

The construction of the final projects showed that it was obvious that the students had gained insight into how to choose their materials and how to optimize their structures. On the final day, some of them held impressive loads. Some of the Science Bound corporate sponsors sent representatives to the final day of the summer session, when structures were tested. An aerospace representative from Rolls-Royce Corporation had the following reaction, "The camp appeared to be received by the students with enthusiasm. This, despite their "giving" of a month of their summer to it. They definitely showed that they had learned a lot and were able to apply that learning and talk about it."

It has been suggested that females, more so than males, tend to seek careers where they can make a difference in society and apply less traditional solutions. Too often, engineering is not seen as one of those careers. To address this issue, one of the modules constructed for the summer enrichment camp focused on sustainable engineering and environmental impact, thus tying readily to current societal concerns. The students conducted a study of the environmental footprint created by one of their favorite devices: the cell phone. After learning the process by which cell phone circuit boards are manufactured, they examined the toxic waste byproducts that come from that process. They conducted chemical experiments on dilution, metal extraction from waste water and evaporative processes and even built and tested their own miniature version of a landfill, examining how dangerous chemicals leach into groundwater aquifers. These topics were always tied closely to the necessary mathematics, whether in calculating dilution concentrations, balancing chemical equations, or extrapolating laboratory sized experiments to the size necessary for an entire city.

V. RESULTS

By the end of the month long class, significant improvements in student performance were obvious. Not unexpectedly, there was an increase in comprehension of the engineering concepts, but there was also a surprising increase in accompanying math scores. The full data from the pre- and post-course assessments of one of the classes is shown in Table I.

Table I Results of Pre-Class and Post-Class Assessment Test Averages

| Subject Area | Pre-Class | | Post-Class | |
|----------------------|-----------|------|------------|------|
| | Female | Male | Female | Male |
| Mechanical Advantage | 30% | 16% | 63% | 94% |
| Friction | 50% | 33% | 57% | 83% |
| Structural Mechanics | 17% | 6% | 27% | 18% |
| Algebra | 80% | 60% | 83% | 74% |
| Ratios | 80% | 80% | 83% | 87% |
| Geometry | 70% | 16% | 90% | 73% |
| Chemistry | 20% | 16% | 30% | 26% |
| Problem Solving | 37% | 31% | 48% | 45% |

The instructors believe that this gain in math scores resulted from students overcoming the all-too-frequently encountered mindset of “I will never use this math.” Once they were shown simple engineering concepts that they could easily relate to, and which required the use of the math concepts, then there was a positive gain in math comprehension.

Perhaps the most promising aspect of the summer program was the qualitative gain that the instructors saw in student self-confidence. Several students who initially showed doubts in their own math and science abilities, were leading their teams by the end of the month, as well as speaking encouragingly about their fall math and science classes back at the high school. Data from that subsequent semester showed that 67% of the students from this summer program had improved grade point averages over the semesters prior to the summer camp.

The Purdue Science Bound program is currently in its tenth year of operation. Of the eighth grade students who were the initially selected for the first year of the program, seven have graduated from Purdue University and nine are in their fifth year of study, still on track for graduation. Participating students have been tracked since the summer of 2009 and the data reflect that a remarkable 98% of all program participants went on to college. Of these, 47% attended Purdue; 51% went to other institutions of higher learning, 1% enlisted in the military and 1% were unable to be reached. These results are summarized in Table II. The high school graduation statistics for the participating students are shown in Table III, indicating completion of high school and solid ACT and SAT scores.

TABLE II Where Science Bound Students Are Now

| Graduation Year | # of SB Seniors | Purdue | Other College | Military Or Unknown |
|-----------------|-----------------|------------|---------------|---------------------|
| 2007 | 41 | 28 | * | * |
| 2008 | 52 | 36 | * | * |
| 2009 | 27 | 11 | 15 | 1 |
| 2010 | 30 | 13 | 17 | 0 |
| 2011 | 32 | 18 | 13 | 1 |
| Totals | 182 | 106 | 45 | 2 |
| Percent | | 47% | 51% | 2% |

I. CONCLUSIONS

A number of things have brought about the success of the Science Bound program. These are not things that are unique to IPS or to Purdue. They, therefore, could be implemented anywhere. These key factors are:

1. Select students with both the aptitude **AND** the interest that is necessary for a career in STEM related fields. It is not enough to simply select students with strong test scores on math and science aptitude tests. If their desire is to be a musician or an artist, no amount of science aptitude will see them successfully

through the program. The selection process must find those students who *want* to succeed in STEM careers.

TABLE III Test and GPA Statistics

| Academic Year | High School GPA | SAT | ACT | Cohort Size | One Year Retention | | |
|---------------|-----------------|------|-----|-------------|--------------------|-----|------|
| | | | | N | N | % | GPA |
| 2007-08 | 3.35 | 1541 | 21 | 28 | 21 | 75 | 2.45 |
| 2008-09 | 3.42 | 1525 | 22 | 37 | 33 | 83 | 2.51 |
| 2009-10 | 3.40 | 1602 | 23 | 11 | 10 | 90 | 3.07 |
| 2010-11 | 3.38 | 1569 | 22 | 12 | 12 | 100 | |
| 2011-12 | 3.40 | 1589 | 23 | 17 | | | |

2. Provide mentors in the school system who are both active and involved. There needs to be someone active in each school who is working with the students participating in the program, meeting with them regularly and developing after-school activities that will develop their interest in pursuing STEM careers. These mentors, by virtue of their position in the student's school, will also serve as an early warning system to detect when one of the students is struggling.
3. Supply a support system that students and parents can fall back upon when the going gets tough. High school students experience a tremendous number of life changes. It is not surprising that a great many of them struggle at some point during their secondary school years. This problem is only exacerbated when dealing with minority students from urban. Low SES neighborhoods. For the program to be successful, there must be a safety net mechanism that the students can call upon when they feel themselves falling behind in a subject. The support system also should be one that the parents can access when they see their students struggling, or when they, themselves, do not know how to deal with a situation.
4. Offer interesting enrichment programs. These programs should provide the students a taste of what it would be like to be an engineer or scientist. This strengthens their interest in staying the course with the program, and also helps them refine their ideas of exactly which career path interests them.
5. Provide positive role models who are accessible to the students. Students need people in the industry that they can relate to, learn from, and call upon when they need help or advice. This also gives them a solid vision of what their life could be like if they

complete the program and reach their ultimate career goal.

The fields of Engineering, Science and Technology can only benefit from an increase in the diversity of students who chose STEM career paths. Programs such as Purdue's Science Bound that tie together university resources, corporate support, public school system participation, and parental involvement with the common goal of bringing more urban high school graduates into STEM related careers may present the best means of achieving the required numbers and balance of Engineering and Technology graduates in the coming decades.

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Work in Progress: A Multi-Strategy Model for Promoting High School Students Interest in STEM

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Abstract—In this paper we propose a new multi-strategy model for immersing students in STEM. Rooted in the current research and experiences, the new practices are being developed and implemented in a college-based hybrid STEM learning center that is geared to serve as a hub connecting high schools, higher education institutions, and industries bringing new and existing strategies together into one integral system with unique online features. The Hub model would serve as an educational research laboratory contributing to the knowledge base about STEM by investigating what strategies (or combination of what strategies) will best support student development for the STEM workforce. In addition, the model would illustrate the importance of interconnection between engineering education research and engineering education practice.

Keywords – *Multi-Strategy, Hybrid Learning, Hybrid LaGuardia Youth Center for Engineering Excellence (H-LYCEE), Online Learning Component, Research, Practice, STEM*

I. INTRODUCTION

The U.S. economy is currently experiencing a crisis in STEM education that can potentially cost the United States its leading position in most areas of engineering and affect our scientific and engineering workforce in the 21st century [1-3]. In order to address this issue, numerous research ideas on various strategies to stimulate STEM education are being generated and implemented [4-7]. Nevertheless, the STEM pipeline, especially in engineering, is deteriorating at significant rates over the last decade [2, 3], and the quest for new strategies promoting students' interest in STEM related careers continues.

The current educational research shows that attracting and retaining students in STEM fields is most effective when it is done in early stages of their educational path [2, 3, 8]. Moreover, research on learning in STEM disciplines suggests that students' problem solving ability comes from the creation of increasingly complex connections among diverse learning sources [12, 13]. Similarly, it is possible that various methodologies and approaches working together would better promote students' interest in STEM and help them in learning STEM disciplines. This paper discusses a novel idea of creating a college-based center that would serve as a hub connecting high schools (HS), higher

education institutions, and industries; the center, unlike most of the existing programs for HS students, would be an educational research laboratory where new and existing strategies for immersing students in STEM are interconnected into one integral system with unique online component. The center will design, implement, and evaluate new ways to promote students' interest in STEM careers and facilitate their readiness for it.

II. THE CENTER/HUB MODEL AND ITS IMPLEMENTATION

The HYBRID-LYCEE (H-LYCEE) center implementing the proposed multi-strategy model is currently being built on the basis of successes and experiences of LaGuardia Youth Center for Engineering Excellence (LYCEE) that was established in LaGuardia Community College of the City University of New York in 2009 to offer HS students various after-school and summer learning programs/activities (e.g., robotics, mechatronics, CAD/CAM design projects, math tutoring) designed to promote their interest in STEM-related careers [14]. The significance of the new model lies in the authors' effort to intertwine a wide scope of various approaches to the existing problem of attracting students in STEM and preparing future professional workforce in U.S. through the extension of LYCEE into H-LYCEE Center/Hub and to make different learning models work together as one in promoting the STEM-related careers.

The new and existing strategies for immersing students in STEM that can interlock and work together are as follows: (a) hybrid learning with face-to-face and online components; (b) learning through hands-on experience; (c) multidisciplinary learning; (d) teamwork; (e) contextualized learning; (f) professional development workshops for HS teachers; (g) college admission counseling; (h) talks by professional speakers; (i) creation of an Advisory Board, whose members are faculty, teachers, industry professionals, educational researchers, and parents, that will advise, guide, and help evaluate the center's work. Some particular activities towards the multi-strategy model implementation would include: creating a Robotics Academy; conducting robotics competitions for student teams from the NYC area; conducting professional development workshops for HS teachers on incorporation of H-LYCEE activities in high school curriculum; creating a new after-school program (H-

LYCEE Math Academy) where students will learn how math can be used to solve various engineering/science problems; and conducting information sessions on admission policies in STEM-related academic programs at the colleges and universities in the NYC area.

An innovative curriculum with an online component as well as an online chat platform would be key components of the proposed multi-strategy model which will provide the opportunity for any HS student from local area to join the center and get easy access to its resources. This will create a virtual world for HSs and colleges: students would be able to meet and interact with college professors and staff, while HS teachers and college professors would communicate via webinars around issues that affect STEM education.

The hub's specific feature would include a novel curriculum with an extensive online component, including online technical training on the Intelitek's LearnMate e-learning platform. The design of the new curriculum, both adapting existing hands-on projects and developing new projects, is currently being led jointly by LYCEE faculty and Intelitek. Some of these projects are as follows: the existing *Robotics Projects* will be completed using LearnMate and VEX components; the existing *CAD/CAM Design Projects* will be completed using LearnMate, CATIA, and AUTOCAD software; the *Electrical and Electronic Projects* use the Electrical Systems (Lab) module, that is already LearnMate-based; the *Biology Projects* will be offered in order to diversify the STEM areas covered in the Center.

H-LYCEE with its online component would make it possible to extend the participation of students from NYC area, especially from low-income and underrepresented groups, via newly created network/hub and, thus, will enhance and further promote STEM education.

III. EXISTING RESULTS. EVALUATION.

During the period of its existence as LYCEE, the Center has served 9-12 grade students from twelve high schools located in Queens. By the end of Summer 2011, 239 students had successfully completed the program which has shown a steady increase in the participation of minorities with Hispanic students constituting an average of 40% of all students each academic term. LYCEE was also successful in attracting female students (comprising 31% of all participants) to the program in a relatively short period of time. The Center is fostering an atmosphere promoting the development of mentoring relationships between high-school students, faculty, and current undergraduate engineering students. As follows from students' testimonials and reports, they are very appreciative of such learning environment [11]. College major choices of LYCEE participants were evaluated using a sample of 44 students who had made a college decision and had chosen a major (see Table 3). Out of 44 students, 36 (81.8%) had chosen a STEM major. Many students who attended LYCEE since Spring 2009 are still high school students and are not in the position where they can make a college major choice.

The evaluation of existing practices is not complete. In the future, in the process of implementing H-LYCEE and as more quantitative and qualitative data is acquired, we will be able to further analyze the Center's impact on college/major

choice of its participants while working on developing an efficient tracking system that will enable us to track H-LYCEE HS participants all the way to college. The project evaluation (internal and external) will employ a mixed methods approach to examine its implementation, effectiveness, and impacts. The formative and summative evaluations will capture participants' interest, engagement, and motivation.

TABLE I. MAJOR CHOICES OF LYCEE PARTICIPANTS

| Major | Number of Students |
|--------------|--------------------|
| Business | 5 |
| Engineering | 26 |
| Liberal Arts | 2 |
| Math | 1 |
| Nursing | 1 |
| Science | 9 |
| TOTAL | 44 |

IV. IMPACTS. BENEFITS.

The broader impacts of the project are multi-faceted. The proposed multi-strategy model can be duplicated for any higher education institution to facilitate STEM in general and, in particular, make engineering education accessible to as many HS students as possible. Thus, the audience that would be interested in the model is broad. The H-LYCEE will maintain, operate, and modernize shared education infrastructure and ensure that multi-user facilities serve as sites of mentoring for large numbers of underrepresented students from different racial, ethnic, and educational backgrounds. The online component would make it possible to extend the students' participation via newly created network and, thus, will enhance and further promote STEM education. The project's broader impact does not only involve immediate impact on participants but also leads to long-term outcomes. The strategy, by its design, advances discovery and understanding while promoting teaching, training, and learning. H-LYCEE can be seen as a learning/educational research laboratory contributing to the knowledge base about STEM by investigating what strategies (or combination of what strategies) will best support student development for the STEM workforce of the future. It would provide the research foundation that would feed inventive practices and, simultaneously evaluate new practices supporting the research. The results and outcomes of all activities will be disseminated broadly to enhance scientific and technological understanding. The current research and practices are in progress and have not been widely tested.

The proposed multi-strategy model is addressing a problem of growing demand for STEM professionals in the United States. The potential national benefits of the model can be found on a variety of levels; namely they can be seen through the chain starting from individual, going through the community, and expanding to the whole society.

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Work in Progress: Incorporating an Open-ended Systems Engineering Project in a Minority Middle School Outreach Program

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Abstract--Cultivating Adolescents in Systems engineering Habits (CASH) is an innovative STEM (science, technology, engineering, and mathematics) summer experience designed for middle school students (Grades 6-8). CASH participants are composed primarily of students from minority groups historically underrepresented in STEM fields. The main program goal is to stimulate and sustain interest in STEM majors and careers for these students. In CASH, participants are placed in a student-centered learning environment where they are given course instruction in several subject areas, such as math, engineering, financial literacy, in an effort to enrich them mainly with systems engineering basics and other concepts like research fundamentals, critical thinking principles, and team working skills.

For the program's first three years, projects given were devised to illustrate the fundamental concepts that were being imparted on students. This paper will examine the efforts being made to develop and incorporate an effective open-ended systems engineering-based project into CASH. The decision to do so was based on several reasons, such as the results of several studies that show that hands-on projects may be the best way to teach engineering concepts. In addition, the program's core subject of systems engineering is an interdisciplinary field that lends itself to a project that will incorporate the assorted topics that the students are taught in the program. Creating a culminating program project that is open-ended will allow participants to explore their imagination, utilize critical thinking principles and team working skills to creatively problem solve and present solutions for a challenge that require them to use the concepts they have learned during the program. This paper will explore CASH's history, its effectiveness, and its current status and development in constructing this new project for the program.

STEM industry is facing a diversity issue. Professionals in the STEM fields do not fully represent the variety of minority groups that exist in America. The CASH program was created in an effort to address these two challenges.

During the program, participants are placed in a student-centered learning environment and are given course instruction in math, financial literacy and the program's core area of systems engineering. Each day in the program is split into two sections-**Instruction** and **Lab**. The Instruction portion is delivered in a traditional classroom-setting and is the time period when the participants take the previously mentioned courses. Lab follows the Instruction portion, and begins after lunch. During this time, students work on hands-on projects in an out of the classroom learning environment. Since the summer of 2010, several of the projects featured have been based on NASA's Juno mission.

Juno is a five year cruise to the planet Jupiter, which was launched in August 2011. The mission is operated by NASA's Jet Propulsion Laboratory (NASA-JPL) in Pasadena, California. NASA-JPL has partnered with the CASH program for the past two years. They have provided CASH with solar-based and telecommunication-based projects centered on the Juno mission. This has given the program activities relevancy as they allow students to apply the lessons they are taught to real life experiences. The open-ended systems engineering project that will be developed and incorporated in the CASH program will also be based on the Juno mission.

I. INTRODUCTION

Cultivating Adolescents in Systems engineering Habits (CASH) is a summer program for middle school students (Grades 6-8). For the past three years, the program has been based in Baltimore City, Maryland and 100% of the participants to date have come from racial minority groups. The main program goal is to stimulate and sustain interest in STEM majors and careers, in hopes that these students will eventually join the nation's STEM pipeline and help to address the shortage that the country is currently facing. Additionally, the

II. CONTRIBUTION

CASH has proven to be highly effective in exposing and exciting participants about the world of STEM. However, each year the program is assessed and evaluated to identify which practices, projects, and methods can be improved or added. It has been decided that one of the more promising additions that can be made to the program would be to develop and incorporate a project that is open-ended and allow the participants to apply the system engineering concepts they learn throughout the program. In the development of this project, it was resolved that based on the research available a project would be compelling if it accomplished and contained the following objectives.

A. Open-Ended

An open-ended project will require students to explore their imagination, utilize critical thinking principles, and team working skills to creatively problem-solve. Projects and activities with pre-determined answers may serve to be more effective when dealing with a classful of students at different developmental levels and deadlines for class learning objectives. But a summer program that isn't constrained by those same requirements can be more conducive for projects that are open-ended, and as such the new project developed will feature this.

B. Authentic Learning

Authentic learning aligns with research into the way the human mind turns information into useful, transferable knowledge [1]. Tying the course lessons in CASH to projects that are based on the real life Juno mission allows participants to see the relevance of the activities they are completing. George Siemens suggested that learning to be a STEM professional is helpful when forging concrete connections [2]. By giving students an authentic learning experience in the program, it will serve to be more effective in helping them to see themselves as potential STEM professionals and members of the country's STEM pipeline.

C. Hands-On

Hands-on projects are useful when attempting to retain students' interest in a subject. The project developed will be one that is heavily hands-on and will allow the students to have fun while completing the objective. There may be a need for students to complete research, in order to successfully devise solutions for the project. But it will primarily be hands-on, as research has shown it is more effective when trying to teach engineering.

III. PROJECT DESCRIPTION

Systems engineering is an interdisciplinary that lends itself extremely well to an open-ended project that incorporates all of the assorted lessons and topics that students learn in the program. When students engage in complex, multidisciplinary projects, they learn how to ask other experts for assistance and how to manage collaborative relationships [3]. The main systems engineering concepts stressed to participants in the program include the importance of working in teams, understanding external and internal effects of decisions, and the engineering design-making process.

The project implemented will be a culminating one as students will have been given the opportunity to gain enough knowledge to competently complete the project objective. The project will be centered on NASA's Juno mission and will be based on one major challenge that may occur in the duration of the mission. The program will work with NASA-JPL scientists and engineers to identify a real-life challenge that the mission is facing and develop a program project based on this information. This major challenge will be broken into smaller segments and will be assigned to the students who will be broken up into groups. Each group will have to accomplish their mini-objectives, while remaining cognizant of the major challenge, as they will all be required to integrate into one central project at the conclusion of the program.

Initial methods of assessment will include pre- and post-surveys and compared to previous year's results to identify the effect, if any project may have had in accomplishing the program's main objective of stimulating participant's interest in STEM. As there are not pre-determined answers to the project, evaluations will be based on the extent to which the solutions and projects submitted by the students accomplish the main objective, individual team objectives, and integrate with other groups.

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Work in Progress: Developing Engineering Systems Thinking through the Modeling of a Complex Bioengineering System

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Abstract— Systems thinking is an important habit of mind that should be promoted in K-12 engineering education. This work in progress paper describes how systems thinking was introduced in middle school grades through the modeling of a biological system: the artificial heart. Preliminary qualitative results show that introducing systems thinking through modeling is both feasible and useful. Students demonstrated their knowledge of the heart as a system through the structural, functional, and behavioral components of their models.

Index Terms—K-12 engineering education, systems thinking

I. INTRODUCTION

The National Academy of Engineering [1] called for engineering education to promote the engineering habits of mind as essential skills needed for the 21st century. Systems thinking is an important habit of mind that enables students to recognize and think about the interconnectedness between parts of a system [1]. Most engineering design work represents a system or is part of a larger system, and as such, engineers must effectively be able to understand how systems work, how the parts are related, and what factors influence them. Thus, it is important that K-12 engineering education support students in developing systems thinking. The purpose of this effort is to determine ways to introduce systems thinking and effectively teach the content in a middle-school engineering curriculum. Modeling is one type of method used to understand a system and demonstrate systems thinking. Bioengineering provides useful inspiration for teaching modeling through systems thinking due to the complexity of the human body and designed engineering products that interact with it. Using the lens of design-based research methods and drawing upon the work of Hmelo-Silver and Kolodner [2,3], a systems thinking learning experience was developed to teach middle school students how to use engineering systems thinking by modeling a bioengineering complex system: the artificial heart. We describe the methods, outcomes, and challenges of the first design iteration of a design research methodology, in which a learning trajectory towards systems thinking and the support curriculum will be documented and analyzed. In subsequent design iterations we will revise, test, analyze, and modify our curricula based on data collected from multiple perspectives, that of the researchers, teachers, and students. The ultimate goal is to have a domain-specific, instructional theory for teaching systems thinking in a middle school classroom.

II. METHOD

22 (grades 6, 7, & 8) students applied and were accepted to participate in the systems thinking learning experience, entitled *Bioengineering: Design an Artificial Heart*. Arizona State University's Citizen Scientist-Engineering project listed this learning experience under their after-school course offerings, selected a local school from one of their partner school districts, and managed all student applications. Students were encouraged to come explore the complexity of a biological system, the human heart, by designing and building a model of an important bioengineering technology: the artificial heart. The program met once a week after school for 90 minutes for 10 sessions, with 2 additional optional sessions. The program was structured under the context of a design challenge that communicated the need for socially conscious entrepreneurial biomedical engineers (i.e. the students) to design a practical artificial heart and build a model of some piece of the design. Session 1 was designed to introduce students to each other through an activity where each student had a different part of a biological system taped to their back and other students gave the student hints until she/he ascertained the biological part labeled on her/his back. Session 1 also introduced students to the process of documentation in an engineering notebook and using personal sized whiteboards with markers/dry erasers to present their daily progress on the design challenge. During session 2, the design challenge was announced. The design challenge approach is beneficial to systems thinking because it plunges students into thinking about the system of the heart, as they are required to not only construct the structural components of the heart but also implement the more complex functional and behavioral aspects of the heart. The inherent iterative nature of engineering design also encourages students to reflect upon the heart as a system and then revise their models accordingly. Throughout the process, students were asked to use their engineering notebooks to describe and predict their models' structures, functions, and behaviors. At the end of each session, students were also asked to present their daily progress to the class on whiteboards. The researcher served as the classroom teacher and served as a facilitator of learning. The researcher/ teacher aided the students in identifying the problem through the design challenge, gathering information on the heart through books, hands-on heart models, and internet resources, guiding the students through imagining solutions and selecting a feasible solution, and managing the

students' progress in planning, building, and testing their models. Students worked in groups of two to three. The class was provided with an assorted mix of recyclables, such as bottles and containers, and materials from the home improvement store, including paint sticks, plastic tubing, and syringes, to design and construct the designs of their models. In session 3, students modeled the pumping action of a heart using siphon pumps and containers of "blood" and, in session 4, students modeled the one-way valve function of the heart using plastic gloves and tubing. These activities were used to demonstrate modeling techniques and provide tangible experiences with the functions and behaviors of the heart. This experience was used to demonstrate how students' increasing knowledge of the heart's structures, functions, and behaviors can be transferred to inspire design ideas for an artificial heart. In session 5, students continued to imagine solutions for their artificial heart and select a feasible solution. Over sessions 6-10, students planned, constructed, tested, and revised their models.

III. OUTCOMES AND FUTURE STEPS

Student groups had various foci in their approaches to designing and constructing an artificial heart. Some student groups focused on the valve function of the heart, while others focused on the pumping action. Of the nine student groups, six groups primarily focused on the structural components of the heart. These groups planned and constructed appearance-based models that had four chambers and other structural elements similar to the heart. The groups constructed components that represented the one-way valves and double pump of the heart, but these components did not necessarily function or behave as they were intended. Students in these groups gave consideration to the heart as a system with integrated parts, but only at a high level. During the design sessions, Jackie (grade 6) and Evan (grade 7), brainstormed how they would design the four chambers of the heart with the materials on hand. Jackie and Evan focused their discussions on selecting the materials that would help them simulate the ventricles and atria to hold and release blood and also to compress and expand. The one-way valves were a later consideration for Jackie and Evan, and were added in the passage ways between the atria and ventricles with little flaps made of duct tape. During the last design session, Jackie and Evan began to discuss the functionality of their design and how they would achieve the behaviors of the heart. Jackie proposed a question: how would they propel the blood from the left and right atria to the corresponding left and right ventricles to simulate how the right and left sides of the heart work in series. Jackie and Evan decided quickly that each of them would manually be in charge of a side of the heart and would forcefully compress the atria in sequence. The other five groups that created appearance-based models of an artificial heart were also primarily grade 6 and 7 students. The three groups of grade 8 students created more complex designs, including a design made by two male students that used basic circuits knowledge

to construct an operable motor-driven rotary pump. Another student group of three female grade 8 students designed an inertia-driven pump with an accordion-style pipe that functioned as a single pump. Grade 8 students gave more focus to one specific part of the system, such as a mechanism for moving blood through the heart. Their conversations early on in the design sessions focused on the behaviors of the heart, such as circulating blood through parts of the heart. These groups did not give consideration to the materials available until after their first design plan was completed. The three grade 8 groups revised their designs after seeing what materials were available. Two of the three groups sacrificed their original plan to have a motor-driven function and replaced this with materials that required transfer of energy by human force. Throughout the systems thinking learning experience, all class sessions were tape-recorded and, as preliminary assessment, students were qualitatively assessed through observation and interviews. With the exception of three students, the class began the program with limited knowledge of pumps and valves, and of the heart. Even though the human body is part of middle school science curriculum, these students did not learn about the heart in their science classes due to time constraints in their classrooms.

For the next design iteration of this systems thinking learning experience, ways to guide students to consider the structural, functional, and behavioral aspects of the heart will be modified. Students should be guided to integrate their growing knowledge of the heart as a system into their models, which includes the multiple parts of the heart and its interactions. Further, requirements for the models will need to be of appropriate complexity for the student's knowledge. Students will need to be given the opportunity for multiple iterations to design and re-design their models and to reflect on the parts and interconnectedness of the heart system. In the first design iteration, ten sessions led to a packed curriculum. For this reason, two additional, optional sessions were added. In the future, time constraints will have to be more carefully considered. Finally, even though the hands-on nature of the design process as well as the context of the design challenge was motivating to the students, the scope and broadness of the project was large. The learning experience will need to balance the opportunity for creativity and systematic exploration of the heart as a system.

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Work in Progress: *Grand Challenges for Engineering* in the Middle School Classroom: Preliminary Results

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Abstract—This paper presents preliminary results of implementing the *Grand Challenges for Engineering* (GCE) modules in math and science courses in 6 Wisconsin middle schools. Sponsored by the National Science Foundation (NSF), this project was designed to increase students' understanding of engineering careers and their appreciation for the societal impact that engineering can have. Preliminary results suggest gender differences in whether math and science are seen as male domains and in the types of work values endorsed.

Keywords—middle school; STEM; Grand Challenges; engineering education; program evaluation

I. INTRODUCTION

Fourteen *Grand Challenges for Engineering* (GCE) were identified by the National Academy of Engineering (NAE) [1]. These grand challenges highlight the needs of both local and global societies for which engineering will need to furnish answers. Themes include topics such as energy, health care, infrastructure, and safe food and water supplies.

Middle school is a critical juncture during which many students begin to seriously consider career options. Attitudes about self and the world of work that are held during this middle school period form the foundational belief system from which students draw to set career goals for themselves and to choose high school courses and activities. Evidence suggests that an emphasis on STEM activities with middle school students can have a profound impact on students' motivation and interest to pursue careers in STEM related fields later in life [2, 3]. However, a survey from the American Council of Engineering (ACE) [1] indicated that an emphasis on "math and science" can be perceived by middle school students as intimidating and may discourage students from pursuing engineering as their future career. An emphasis on the societal impact that engineers can have may interest a more diverse group of students, especially women, to pursue career in STEM related fields.

The NSF's Innovative Technology Experiences for Students and Teachers (ITEST) program provided the opportunity to implement innovative curricular modules in middle schools to support students' development in STEM and to promote students' self-efficacy and interests in engineering related fields [4]. The preliminary results presented in this paper are based on the baseline data collected prior to the

implementation of two GCE instructional modules for middle school math and science classes.

This paper has three broad foci: 1) to describe the research methods used to examine the impact that inclusion of the GCE content into math and science courses has on student outcomes, 2) to describe the research methods used to examine the impact that using the GCE curricula has on teachers' practices and attitudes, and 3) to report results of the baseline data collection completed with middle school youth.

II. STUDENT MEASURES

A pre/post, comparison group design is being used to examine student level data. We are examining whether students in the GCE curriculum infused math and science courses: 1) report higher levels of STEM interests, 2) report higher math and science self-efficacy and outcomes expectations, 3) report higher beliefs in the egalitarian nature and utility of engineering careers, and 4) endorse different occupational values. Gender, race/ethnicity, and socioeconomic status will be considered as we examine our student data.

Student participants will be asked to complete 4 surveys that measure experiences in school, and opinions and attitudes toward math, science, and engineering. Students will be asked to complete the 1) Middle School Self-Efficacy Scale [3], 2) the Modified Fennema-Sherman Attitude Scale for Math and Science [5], 3) the Occupational Values Scale [6], and 4) the Personal Globe Inventory [7].

The Middle School Self-Efficacy Scale assesses a student's self-efficacy, outcome expectancies, intentions, and goals in the areas of career-decision making and math and science. The Modified Fennema-Sherman Attitude Scale assesses student's attitudes about egalitarianism, self-efficacy, utility of math and science, and perceptions of teacher support. The Occupational Values Scale assesses a student's preferences for occupational values, such as power, money, family, and altruism. The Personal Globe Inventory assesses students' interests in different careers and types of work.

III. SCHOOL STAFF MEASURES

The impact of participation with the GCE curricula on educators and schools will be measured by the school team members' perceptions of: 1) school-wide middle school innovative practices, 2) beliefs about STEM, 3) instructional and counseling practices in STEM, and 4) self-efficacy and

outcomes expectations among school team members for STEM instruction and counseling. School staff data is being collected in a pre/post-intervention, comparison group design.

Teachers will be asked to complete 1) a modified version of the Science Teaching Efficacy Beliefs Instrument [8], 2) the Engineering Education Beliefs and Expectations Instrument [9], and 3) the Teaching Design, Engineering, and Technology survey [10]. School counselors will be asked to complete 1) the Engineering Education Beliefs and Expectations Instrument - Counseling, and 2) the Teaching Design, Engineering, and Technology survey [10]. School administrators will complete 1) the School-Wide Middle School Innovative Practices Survey [11] and 2) the Teaching Design, Engineering, and Technology survey [10]. These measures are being collected before and after training and implementation of the GCE curriculum modules.

Six middle schools (4 urban, 2 rural) in the Midwest are currently implementing our GCE modules in math and/or science classes. Student data has been collected from both student groups (GCE participating and non-participating students) prior to the GCE module implementation. Post GCE curriculum implementation data will be collected in late spring 2012. Similarly, school staff pre-test data was collected in late summer/early fall 2011 and post school staff testing will be done in June 2012. Normative group data collection for the school staff measures is ongoing and will be completed by the end of summer 2012.

IV. PRELIMINARY RESULTS

In spring 2011, initial baseline data were collected and preliminary analyses have since been completed. Two hundred and seventy-six eighth grade middle school students provided baseline data for this project. Students' responses on the Middle School Self-Efficacy Scale were ranked on a Likert-type scale, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) and resulted in average scores of 4.02 ($SD = .46$) for the Career Decision Making Self-Efficacy, 3.90 ($SD = .56$) for the Career Decision Making Outcome Expectance/Intentions and Goals, 3.72 ($SD = .59$) for the Math and Science Self-Efficacy, and 4.37 ($SD = .59$) for the Math and Science Expectancy/Intentions and Goals subscales..

Students' responses on the Modified Fennema-Sherman Attitude Scale were ranked on a Likert-type scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) and resulted in average scores of 3.92 ($SD = .73$) for the Confidence in learning mathematics, 4.10 ($SD = .61$) for the Mathematics usefulness, 3.76 ($SD = .61$) for the Mathematics as a male domain, 3.64 ($SD = .55$) for the Perceptions of teachers with math, 3.74 ($SD = .62$) for Confidence in learning science, 3.59 ($SD = .59$) for the Science usefulness, 3.79 ($SD = .60$) for the Science as a male domain, 3.83 ($SD = .59$) for the Perceptions of teachers with science subscales.

Students' responses on the Occupational Values Scale were ranked on a Likert-type scale with responses ranging from 1 (not at all) to 4 (very much) and resulted in average scores of 3.08 ($SD = .64$) for the Male-typed/Power, 3.38 ($SD = .69$) for the Male-typed/Money, 3.14 ($SD = .71$) for the

Female-typed/Family, and 3.14 ($SD = .74$) for the Female-typed/Altruism subscales.

These analyses indicate that there are no gender differences in students' perceptions of teachers' attitudes and support, in their math/science self-efficacy, or in their math/science outcome expectations. They do, however, suggest that there are gender differences regarding students' perception of seeing math and science as a male domain ($t = 4.53, p < .05$), and students' occupational values of family ($t = 2.68, p < .05$) and altruism ($t = 3.32, p < .05$). These results suggest that girls hold stronger beliefs that math and science are male career domains and hold stronger occupational values that allow for cultivation of family and altruism in their future career compared to their male counterparts.

Post module implementation data will be collected in spring 2012. Two new modules will be implemented during the 2012-2013 academic year.

V. ACKNOWLEDGEMENTS

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Work in Progress – Engineering Case Studies Inspired by Society’s Grand Challenges for Engineering: An Integrated Approach to Middle School STEM Instruction

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Abstract—The National Academy of Engineering “Grand Challenges for Engineering” (GCE) initiative has inspired the introduction of humanitarian applications of engineering into middle school science and math classrooms. Two GCE case study instructional modules have been developed by an interdisciplinary research team and piloted at six participating middle schools during the 2011-12 school year. Each module employs realistic fictional scenarios to engage a broad spectrum of students through role-play as engineers. Students develop engineering skills by tackling specific problems inspired by societal needs. Relevant science and math content, based on state and national middle school standards, are embedded within the modules. Integration of engineering with science and math instruction is aligned with recommendations in the *Framework for National K-12 Science Standards*, recently published by the National Research Council. The pilot modules, “Improving Aging Infrastructure” and “Solar Energy,” were introduced to teachers at participating schools at a professional development workshop during Summer 2011. The success of this approach as a strategy to increase interest in STEM (science, technology, engineering and math) fields among all students, especially women and under-represented groups, is being evaluated through measurement of participating students’ attitudes toward math, science and STEM-related occupations.

Keywords—middle school; STEM; Grand Challenges; engineering education; national K-12 science standards; diversity

I. INTRODUCTION

The “Grand Challenges for Engineering” (GCE) effort at UW-Madison is a pilot project supported by the National Science Foundation (NSF) ITEST program, with the ultimate goal of increasing the representation of women and other

under-represented groups in college-level science, technology, engineering and math (STEM) programs. The innovative practices piloted in this project are two-fold: a) following the recommendations of the *Framework for National K-12 Science Standards* [1], engineering is integrated into core middle school science and math instruction, and b) the societal context of STEM fields is embedded into instructional case study modules through story lines inspired by the National Academy of Engineering (NAE) “*Grand Challenges for Engineering*” initiative [2].

By introducing engineering through the GCE modules in middle school science and math courses, we aim to increase student interest in subsequent high school courses in science, math and engineering design. We also seek to influence the perceptions of not only potential future engineers, but also their peers, teachers and counselors, all of whom influence career choice. In this way, successful implementation will strengthen support for consideration of STEM-related careers at participating schools, through an enhanced appreciation for the value of STEM skills in making a difference in a wide spectrum of societal challenges.

The GCE strategy is motivated in part by National Science Foundation (NSF) sponsored research showing that messaging about engineering, which often emphasizes a passion for math and science and the notion of a “challenge,” is not well aligned with key motivators for high school girls [3]. The data suggests that a focus on features of the engineering profession not widely emphasized, such as “making a difference in the world” and “creativity,” hold stronger appeal.

The research basis of this project lies in Social Cognitive Career Theory (SCCT) [4]. This theory provides the context

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for evaluating the impact of the GCE modules on participating students' sense of math/science self-efficacy and outcomes expectations, their attitudes towards math and science, and their interest in STEM-related occupations. Further, it explores the impact of teacher training in and use of the GCE modules on their teaching practices and their self-efficacy for teaching engineering content.

II. MODULE OVERVIEW

Two instructional modules have been developed to date, *Solar Energy* and *Improving Aging Infrastructure*, based on two of the fourteen "Grand Challenges for Engineering" topics identified by the NAE. Each two- to three-week-long module includes a fictional story line that builds on the GCE themes to illustrate humanitarian applications of engineering. Hands-on activities integrate engineering with underlying middle school science and math instructional standards in a logical way that highlights the connections between the disciplines, as illustrated by examples described below. The centerpieces of both modules are activities designed to build self-efficacy in engineering, science and math [5].

The *Solar Energy* module consists of two units on solar cooking and photovoltaics for lighting. In the solar cooking unit, students construct and test solar cookers built from cardboard boxes and aluminum foil. They next consider design modifications to optimize performance given operating constraints provided by pen pals who have requested their help in designing the cookers. The pen pals live in the fictional country of Aridia, in which cooking fuel is scarce due to a recent influx of refugees from a neighboring country.

Science and math concepts in the solar cooking module relate to properties of light and transfer of energy. Students consider the concentration of solar power as it relates to heating food in designing the reflective panels in the cookers, with activities including a hands-on demonstration of specular reflection. They also use published graphs of solar spectral intensity to estimate the power converted to heat by the cooker, and compare this to their own estimates of energy required to heat the food.

The *Infrastructure* module also consists of two units, which respectively address restoration of aging bridges and retrofitting buildings to withstand natural disasters. In the bridge restoration unit, students role-play as engineers, construct bridge models from blueprints and subsequently inspect the models for damage and repair as needed.

Many of the math and science concepts in this unit relate to the truss design of the model bridge. Mathematical concepts include geometric analysis of triangular substructures, such as the application of the Pythagorean theorem to determine lengths of elements in the model. Students also develop skill in proportional reasoning and unit conversions as they use the blueprints to accurately construct their model to the specified

dimensions. With its focus on load-bearing structures, mechanical forces, static equilibrium and strength of materials dominate the science content of this module.

In the capstone activity, community input from a diverse set of stakeholders is considered along side of technical constraints, highlighting trade-offs between repairing an existing bridge and rebuilding from scratch. This activity culminates with the composition of a recommendation written by student teams in the form of a letter to the fictional city council.

III. IMPLEMENTATION AND EXPECTED OUTCOMES

Six Wisconsin middle schools, with student populations representing a spectrum of ethnicities and income backgrounds, are implementing the first two GCE modules during the 2011-12 school year. A critical element of the curriculum development is the involvement of teachers at the partner schools. Participating teachers evaluated and tested draft curriculum materials at a four-day summer institute held on the UW campus in July 2011. Teacher professional development also included guidance in developing implementation plans, discussion of the upcoming national science standards, and an introduction to the NAE Grand Challenges initiative.

Following classroom implementation of the instructional modules, data collection at the end of the 2011-12 school year will be conducted to assess the impact of the GCE modules on student outcomes as well as teacher experience in implementing the modules. In addition, the feedback will form the basis for revisions to improve the modules in advance of a second round pilot during the 2012-13 school year.

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Work in Progress: A comprehensive approach for mapping student's progress: Assessing student progress in freshman engineering

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Abstract – A new method of assessment is developed that comprehensively maps students' progress in a course. The technique involves the use of two grading rubrics measuring performance in technical and conceptual proficiency, respectively. With these rubrics, one can identify students' progress and learning more effectively and future activities can be adapted accordingly. This paper discusses the development of these rubrics, how to use them, how to interpret their results, and describes an experiment showing their effectiveness in a freshman engineering classroom.

Keywords – assessment, evaluation, learning verbalization, reflection, engineering education, mental representation.

I. INTRODUCTION

As educators, we strive to inspire and motivate students to be at their best. This is an ongoing challenge as each generation has brought different perspectives, and new sets of educational tools. It is our duty to facilitate a learning experience that promotes knowledge transfer, defined as “the ability to extend what has been learned in one context to new contexts” [1]. Such transfer of knowledge in problem solving is known as productive thinking [2]. In contrast, students who use reproductive thinking may be simply finding a solution through rote memorization, and trial and error. Good thinkers practice productive thinking and monitor their progress through metacognition. “Metacognitive approaches to instruction,” such as concept mapping as an assessment technique, “have been shown to increase the degree to which students will transfer knowledge to new situations without the need for explicit prompting.” [1]. Current assessment methods may not capture the desired deeper level (analysis, synthesis) thinking that happens through metacognition. Educators have put great effort in addressing these issues with combinations of related technical and conceptual questions [3]-[6]. However, there is still a need for a continuous, systematic mapping of student progress throughout the entirety of the course (especially for a technical course). In this paper, a method for providing this mapping is proposed.

Traditionally, educators assess student activities based on their correctness of the solutions and methodology. In some cases, problems that are both technical and conceptual are provided such that the educator can know if the student understands the theory and also apply it in a useful way. However, a single grade is given in the end, leaving no separation of technical and conceptual understanding from a grading perspective. It would be useful to provide a more comprehensive recording mechanism that can be applied to any engineering classroom and still achieve a more

TABLE I. TECHNICAL PROFICIENCY RUBRIC

| Technical | Rating | | |
|---|---|---|---|
| | <i>Competent (3)</i> | <i>Developing (2)</i> | <i>Unsatisfactory (1)</i> |
| Appropriate Use of Equations | Clear identification of correct equations | Some equations correct, but makes some mistakes | No idea of what equations to use, writes unrelated things |
| Correct application of the equations to the problem | Clearly puts the right numbers in the right places achieving the right answer | Some numbers put in the correct places, some are not, but may still get the right answer in the end | Majority of numbers are in the wrong places |
| Awareness of the validity of the solution | Clear, correct discussion of the answer | Discussion of the answer is present, but unclear | Lost, or intentionally provides no discussion |

TABLE II. CONCEPTUAL PROFICIENCY RUBRIC

| Conceptual | Rating | | |
|---|---|---|--|
| | <i>Competent (3)</i> | <i>Developing (2)</i> | <i>Unsatisfactory (1)</i> |
| Concept is clearly understood | Use of graphs, equations, process, etc. are sufficient, understandable, and correct | Correct graphs, equations, process, etc. are present but are not used correctly, coherently, etc. | No equations given, or incorrect graphs, equations, process, etc. They are also not used correctly, coherently, etc. |
| Connections between concepts and ideas are made | Demonstrates a valid connection between ideas and concepts | Understands connection with invalid argument, process, etc. | No connection between any concepts is made |
| The student communicates these ideas | Student communicates ideas effectively in sentence form | Communicates ideas but there are inconsistencies or are incorrect | No attempt or communication is incoherent or unrelated |

comprehensive understanding of the class' performance in both technical and conceptual problems.

II. RUBRICS

In order to demonstrate the idea, two rubrics are proposed (Table I and Table II) that are each applied to technical and conceptual problems. The rubrics consist of questions that help assess the student's performance in the problem and, based on their answer and approach, a rating is assigned. The sum of the technical rubric ratings for the technical problem and the sum of the conceptual rubric ratings for the conceptual problem will provide educators a good idea where the student may or may not need help.

These rubrics are most useful in informing instruction. The idea of measuring the technical and conceptual proficiencies

separately is not necessarily different or new. It is the use of these rubrics to accurately map the interconnection of information in a student's mind that give them their novelty. Rubrics commonly used in problem-based learning (PBL) are similar to that which we propose in this work. However, to accurately map a student's progress in an engineering environment, specificity is required. The rubrics proposed are tailored to engineering-type problems assuming a technical and conceptual component exist in the problem. Commonly used PBL rubrics do not separate these components with the intention of mapping cognition.

In addition, if used consistently throughout the student's college career, this rubric could be used in conjunction with the graduate attributes similar to those outlined in the Washington Accord to provide a full student profile showing term-by-term progression, providing a more complete portfolio of the student's work for optimum assessment.

III. EXPERIMENTATION

A. Test Setting

The proposed rubrics were used in an engineering classroom at Iowa State University. A quiz was given to about 130 students, 24 of which were chosen for grading at random. Each quiz consisted of two problems relating to complex numbers. The first question was a technical problem, asking students to determine polar coordinates in the complex plane from a set of rectangular coordinates. The second problem was conceptual, asking students to discuss what the relationship was between a polar coordinate and the complex exponential format, $e^{j\theta}$. An evaluator was then asked to use the rubrics in order to quickly assess the performance of the class from a technical and conceptual perspective. The technical rubric was used to evaluate the technical quiz question, and the conceptual rubric for the conceptual question.

A rating of 3 indicated the student was competent in that aspect of the rubric, a rating of 2 meant the student was developing, and 1 unsatisfactory. So, for the proposed rubrics, a score of 9 was possible for each quiz question, totaling in 18 possible for each quiz. The class technical and conceptual scores were averaged, and then represented as a percentage. In addition, the 9-point technical and 9-point conceptual scores were broken down into three sub-scores which could total in 3-points each. The class sub-score was then averaged, and the scores were represented as a percentage.

B. Results

With this particular problem and classroom, the rubric showed that the overall average score out of 18 points for the class was 87%. This is shown on the left of Figure 1. It was also found that students scored, on average, 94% on the technical question and 81% on the conceptual discussion. Therefore, it can be concluded at the very least that students in this class are generally able to obtain correct numerical results but are having difficulty discussing, recognizing, and justifying them.

Breaking the graded data down even further for the technical question, it was found that students were able, on average, to score a 97% on using equations appropriately, 96% on applying the equations correctly, and 88% on having an awareness of the validity of the solution. For the conceptual question, it was found, on average, that students were able to score a 94% on understanding the concept, 78% on being able to make connections between different concepts and ideas related to the problem, and 72% on being able to communicate these ideas. This is shown in the graph on the right of Figure 1. This information is interesting, but not particularly instrumental in the immediate future. However, it can facilitate finding the next steps to take to address learning issues or shortcomings.

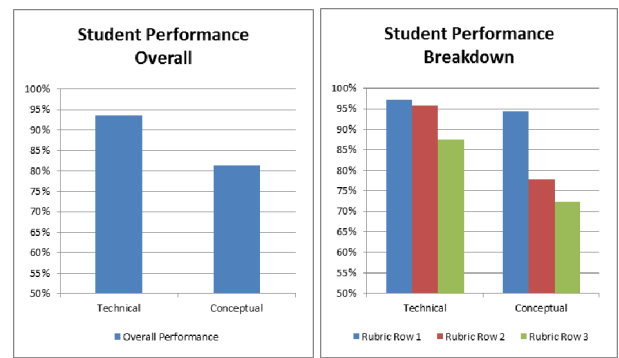


Figure 1: Graded results using rubric

C. Interpretation of Results

Based on the results discussed, it can be concluded that, when given a technical problem, the students in the classroom evaluated are able to recognize problems and solutions in numerical form but have difficulty validating their solution, connecting it to reality. Therefore, it may be useful in future activities to focus on the concepts and ideas and being able to communicate them.

It should be noted that the percent ratings are indeed used for tabulated grading purposes; however, to the ambitious educator these scores are simply indicators of what topics need to be stressed more or less in following assignments or lectures. Such results from these rubrics allow educators of any engineering course to quickly take the next steps to enhance and facilitate student learning. These rubrics together with more frequent small assessment strategies offer a continuum of evaluation and assessment, providing sufficient data that allows educators to adjust the course "live." In addition, the rubrics also provide thorough, detailed data that can be used for the mid- or end-course evaluations.

IV. CONCLUSION

A set of rubrics with new approach to evaluation were developed that enable educators to more effectively map student progress. It was shown the idea provides a valuable set of evaluating questions that accurately assesses how a student understands concepts. Also, the resulting data provides the necessary information for taking the next steps in the course. Preliminary experiments suggest that these rubrics are effective and useful in the engineering classroom.

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Using technology to improve peer review and collaborative conversations to benchmark academic standards

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Abstract— In 2010 the Australian government commissioned the Australian Learning and Teaching Council (ALTC) to undertake a national project to facilitate disciplinary development of threshold learning standards. The aim was to lay the foundation for all higher education providers to demonstrate to the new national higher education regulator, the Tertiary Education Quality and Standards Agency (TEQSA), that graduates achieved or exceeded minimum academic standards. Through a yearlong consultative process, representatives of employers, professional bodies, academics and students, developed learning standards applying to any Australian higher education provider.

Willey and Gardner reported using a software tool, SPARK^{PLUS}, in calibrating academic standards amongst teaching staff in large classes. In this paper, we investigate the effectiveness of this technology to promote calibrated understandings with the national accounting learning standards.

We found that integrating the software with a purposely designed activity provided significant efficiencies in calibrating understandings about learning standards, developed expertise and a better understanding of what is required to meet these standards and how best to demonstrate them. The software and supporting calibration and assessment process can be adopted by other disciplines, including engineering, seeking to provide direct evidence about performance against learning standards.

Keywords- academic standards; benchmarking; peer review; self and peer assessment

I. INTRODUCTION

This paper aims to describe the potential benefits of calibrating understandings about academic standards using collaborative conversations around assessment artefacts and supported by online self and peer assessment technology. The motivation for this research is the international trends for greater provider accountability to funders, accrediting authorities and agencies at state, professional and international

levels as custodians of standards, and employers and graduates as consumers. Without appropriate consensus and calibration around the meaning of minimum standards of graduates' learning, it will be difficult to assure these stakeholders that assessment has been valid and reliable.

II. LITERATURE REVIEW

The academic assessment community has been concerned about practice for some time. Recently forty academic experts proposed six tenets for change in the *Assessment Manifesto* [1]. Tenet 2 urged a move towards the valid assessment of the achievement of intended program learning outcomes because of the problems that arise from the current focus on marks and grades and outcomes at the individual unit of study level [2]. Another set of concerns arises from the local and disciplinary focus on standards [3],[4]: that standards are imprecise and rely on individual professional judgments [5], resulting in variability across regions, subjects and even types of assessment leading to reduced credibility in standards [6],[7],[8],[9],[10],[11],[12],[13],[14],[15]. Tenet 6 of *Assessment Manifesto* [1] advocates the establishment of appropriate forums for the development and sharing of standards across multiple communities.

Assessment is largely dependent upon professional judgement and confidence in such judgement requires the establishment of appropriate forums for the development and sharing of standards within and between disciplinary and professional communities.

Such an approach stands in stark contrast to existing national approaches. The most notable example is in the UK where over 70 disciplinary benchmark statements exist under the auspices of the Quality Assurance Agency (QAA) each containing a list of typical and threshold learning outcomes graduates might achieve. In that approach an external examiner reviews disciplinary intended syllabi, learning

outcomes and assessments at the unit of study level. In theory external examiners review outcomes against QAA benchmark statements and professional body requirements. The QAA found however most examiners assumed that their use was in curriculum planning “and merited little further attention”. Importantly an external examiner is not randomly selected and the scope of their review is limited to an individual provider. Given the latter, it is no surprise that following a major review by Burgess [16], the QAA admitted that despite all of its efforts:

it cannot be assumed students graduating with the same classified degree from different institutions, having studied different subjects, will have achieved similar standards; ... and it cannot be assumed students graduating with the same classified degree from different institutions, having studied the same subject, will have achieved similar standards [17].

Vygotsky [18] and Nonaka [19] found that shared experiences with observation, imitation and practice induce tacit knowledge to be made explicit. Deep shared understandings of assessment standards applied to high-level complex learning requires active engagement of members of the disciplinary community in the assessment of artifacts to identify those standards. Price *et al.* note that cultivating a community where dialogue, trust and participatory relationships can occur should result in more consistent judgements and a restoration of confidence [1].

Emulating trends in primary and secondary education with the PISA project [20], some are calling for standardized tests as an alternative option for tracking and benchmarking higher education learning standards. The *Collegiate Learning Assessment* (CLA), which purports to measure generic graduate outcomes, is gaining traction in the USA’s Voluntary System of Accountability. It is also being used in the OECD’s *Assessment of Higher Education Learning Outcomes* international benchmarking project and will be one performance indicator in Australia’s publically funded university agreements with the Australian government. However, standardized tests have their own perverse problems as evidenced in the Australian primary and secondary school systems; for example, teaching to the test and gaming strategies [21].

III. CONTEXT

Concerns about academic standards of graduates are not new amongst employers. For example in engineering a number of researchers and government-sponsored reports [22],[23],[24],[25] discuss a gap between the skills typically developed in engineering education and a range of skills required for professional practice. Similarly, in accounting, employers have expressed concerns about the standards of accounting graduates, particularly in relation to their employability skills [26],[27].

Recently the Australian government has made changes to the higher education sector to improve national productivity from 2012. An expanded, more inclusive and demand-driven higher education system has been complemented by the establishment of TEQSA, a stronger centralized outcomes-

based regulator. Of the five standards domains, namely Provider, Qualifications, Teaching and Learning, Research and Information, the first two have mandatory or threshold status TEQSA [28]. Provider accountability for academic standards is specifically mentioned in the new system:

The academic standards intended to be achieved by students and the standards actually achieved by students in the course of study are benchmarked against similar accredited courses of study offered by other higher education providers.

In preparation for TEQSA’s role of assuring the quality of academic standards at the discipline level, the ALTC led a project over 2010-2011 where 9 disciplinary groups including engineering established threshold learning standards. As the demonstration discipline for business, management and economics, stakeholders in accounting higher education collaboratively agreed a set of five learning outcomes considered thresholds for Australian graduates of accounting bachelor degrees and another set for coursework master degrees. Some 2,100 people were engaged representing 38 Australian universities, 21 private and other providers, and 20 other key stakeholders including professional and peak bodies. Following endorsement by the Accounting Expert Advisory Group and the Australian Business Deans Council (ABDC), *Learning and Teaching Academic Standards for Accounting* was published by the ALTC in March 2011. In addition the ABDC decided to sponsor a pilot project to obtain external blind peer review evidence of achievement benchmarked against the learning standards. The two major Australian professional accounting bodies subsequently agreed to jointly fund the project and the peak academic association agreed to play a key support role in the external peer review process. Further funding was subsequently obtained from the ALTC to allow the project to expand to all other public and private providers of accounting coursework degrees.

IV. PROJECT

The project compares and evaluates assessment outputs for students in their final year and also the validity of the related assessment inputs (i.e. assessment requirements) and outputs. Each of the accounting departments in ten universities provides two senior academics as external peer reviewers. In addition, professional bodies sourced a range of practising professional accountants.

Underpinning the project methodology is the concept of a ‘cultivated community of practice’ model, put forward by O’Donovan et al. [29] for managing change in assessment in higher education following the 2008 *Assessment Manifesto*. It builds on the communities of practice approach to change [30] and the social constructivism approach to developing students’ understandings about assessment standards [31]. The underlying imperative is that participating professional and academic reviewers need to have collaborative conversations both pre-review (e.g., for training and moderation) and post-review (e.g., for clarifying assessment variances and identifying improvements) to ensure that reviewers are grading to the same standard.

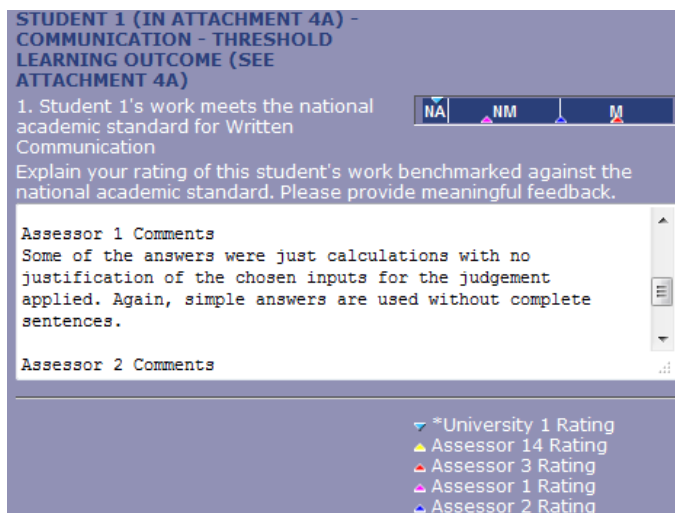


Figure 1: SPARK^{PLUS} results screen showing ratings and explanations of an example student's work.

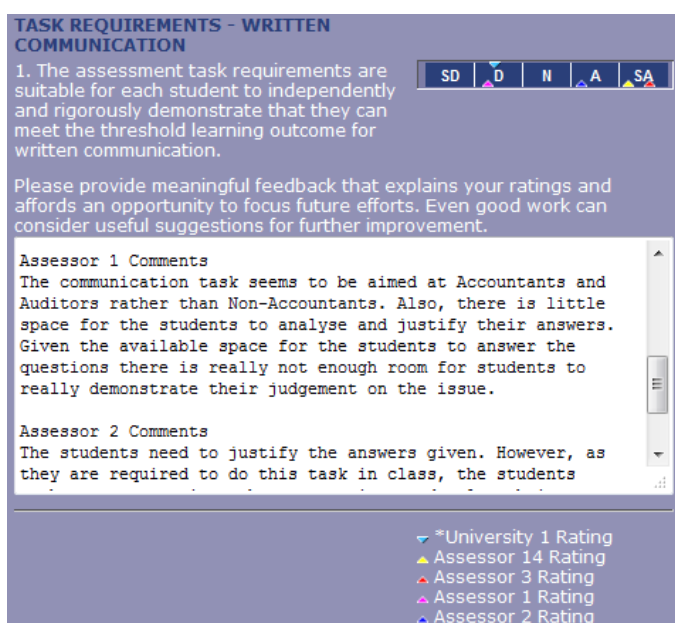


Figure 2: SPARK^{PLUS} results screen showing assessment task validity ratings and explanations.

The calibration process contains two phases. The first phase comprises remote peer assessment where each reviewer independently assesses the sample student work as meeting or not meeting the national standard (see Figure 1), and also assesses whether the task is valid (strongly disagree, disagree, neutral, agree, agree) for students to demonstrate achievement of the standard (see Figure 2). In a process similar to that reported by Willey and Gardner [32-34] reviewers use SPARK^{PLUS} (Self and Peer Assessment Resource Kit), an online tool to submit before the workshop (individual pre-work) both the ratings for the sample work and assessment task (e.g., meeting or not meeting) and importantly the rationale for the rating. Consistent with Dahlgren [35], there are two broad categories (met or not met), but reviewers can actually grade along a continuum within the two categories. The software features can be set to require reviewers to submit a minimum

explanation (e.g. 10 words) to explain their rating – this feature has been utilized as it was found to improve the quality of assessors' feedback. The second phase is a face-to-face workshop where conveners facilitate participants to reach consensus on the standard. The independent peer reviews published on SPARK^{PLUS} are made available to enable reviewers to anonymously compare and interrogate ratings and related reasons. Participants work in small groups discussing each sample sequentially against the reviewing criteria. This allows individuals the opportunity to learn from their peers' justifications before reaching consensus with the whole group of academic and professional reviewers. Near the end of the workshop new samples are introduced and considered in order to confirm that understandings have been calibrated.

This paper focuses on the effectiveness of the technology in improving peer review and collaborative conversations to benchmark academic standards.

V. RESEARCH METHOD

Two survey instruments and convener observations from the workshop were used to collect research data from participants. The first survey was conducted online at the end of phase 1 prior to the calibration workshop (n=20) focusing on the standard or threshold learning outcome (TLO) for written communication where bachelor level graduates are required to "justify and communicate accounting advice and ideas in straightforward collaborative contexts involving both accountants and non-accountants".

The second survey was conducted on paper at the completion of the face-to-face workshop. Twenty senior experienced academic reviewers participated in the activity. Participants were asked a range of questions about their experience of engaging with and interpreting the national learning standards. Eight statements were rated using a continuous scale categorized under five headings (i.e., strongly disagree, disagree, neutral, agree and strongly agree). Participants were also invited to provide free-response comments for a further three questions. However, in this paper we report the research directly associated with the use of technology in the process.

VI. RESULTS / DISCUSSION

The advantage of using an online tool for the pre-work activity (phase 1) is that it required participants to commit their judgement and not be influenced by others. It allowed reviewers to easily readjust their ratings if required at any time during the assessment pre-work period. In addition, the availability of the continuous scale on which sliders could be adjusted and the requirement to provide explanations provided peer reviewers with the opportunity to make fine distinctions. This allowed them to reflect on their initial judgment and assisted them to turn their tacit understanding into explicit descriptions. Consequently, phase 2 workshop discussions were both fruitful, efficient, informed, targeted and covered a range of views. The pre-work activity alone resulted in approximately a third of participants agreeing that it changed their understanding of the two academic standards considered; namely, judgment (30%, Figure 3) and written communication (35%, Figure 4). It is of note that 35% and 45% for judgment

and written communication respectively provided a neutral response in relation to a changed understanding of the two academic standards. This may reflect the challenges associated with the project in working towards a shared understanding of academic standards. However, the vast majority of participants agreed that having to enter their pre-workshop ratings into SPARK^{PLUS} required them to both formalize (90%) and reflect (95%) on their reasons for their judgments (Figures 5 and 6). This finding provides evidence of the value of the technology in improving the quality of academic conversations to benchmark academic standards.

In addition, participants reported that *“the use of spark and subsequent moderation is an excellent learning experience (sic)”* and *“having to use spark made me reflect on my own judgement as well as articulate my reasoning”*.

Furthermore, participants reported that the pre-workshop activity *“provided a valuable opportunity to reflect upon one’s own criteria for assessing students’ work relative to the national thresholds”* and *“forced me to really reflect on what the learning standards mean. It also showed how much professional judgment is needed to assess these key areas and why we as a discipline need to desperately reach a shared understanding of what these standards mean”*.

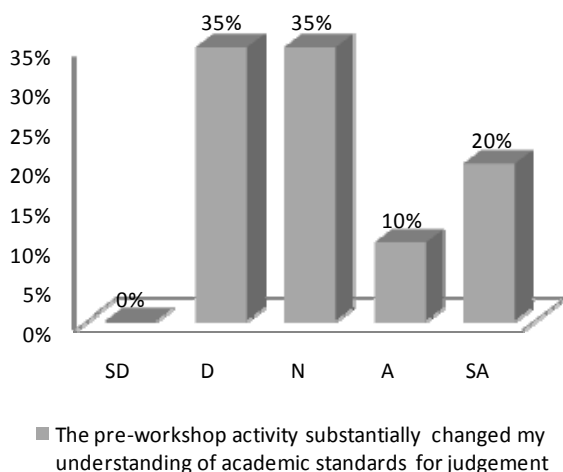


Figure 3: Peer assessors’ ratings of impact of pre-workshop activities on their understanding of the judgment learning threshold.

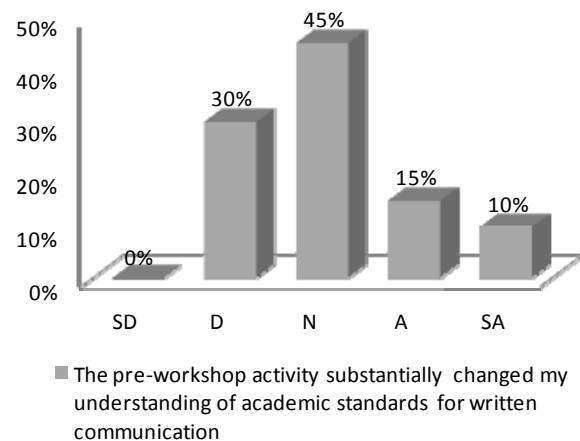


Figure 4: Peer assessors’ ratings of impact of pre-workshop activities on their understanding of the written communication learning threshold.

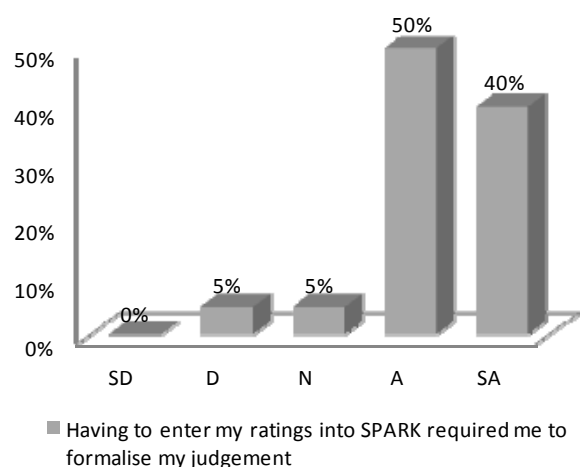


Figure 5: Peer assessors’ perceptions of the impact of SPARK^{PLUS} as a mechanism for formalizing their judgments.

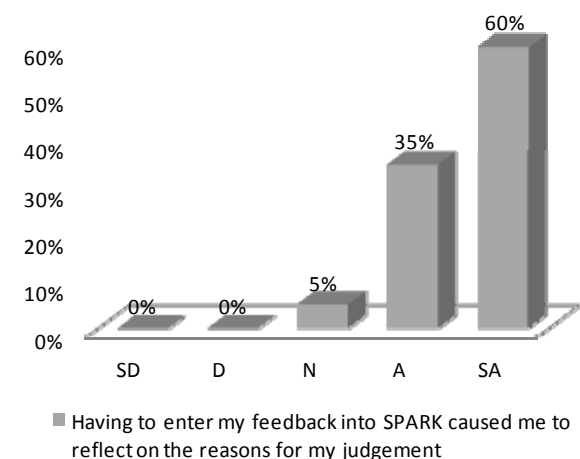


Figure 6: Peer assessors’ perceptions of the impact of SPARK^{PLUS} as a mechanism for forcing reflection about the reasons for their judgments.

A. Impact on activity conveners

Compared to a paper-based approach the conveners found that the automated data collation and ability of the software to present results to participants in an easily accessible form while maintaining their confidentiality provided considerable time efficiencies. Other software features could be leveraged because of this confidentiality: examples of pre-workshop systematic bias by individual reviewers could be easily identified by the software and used as the basis for workshop discussion to distinguish between local and national standards; pre-workshop examples showing considerable inconsistency between ratings and explanations could be easily identified and highlighted for whole group discussion. The software enabled the conveners to identify where there was greater diversity of views of peer reviewers and this information was valuable in planning the workshop activities. The conveners allowed more time for such areas such as assessment design in recognition that this was likely to be required to achieve a shared understanding by reviewers. Furthermore, the software's capacity to enable tasks to be easily cloned, manage groups and add or delete participants reduced the time to organize the initial and subsequent activities.

VII. REFLECTIONS / OBSERVATIONS

Participants indicated that the pre-work activity and workshop had initiated some change to their assessment practice as typified by the following free response comments:

The best aspects of the activity was ... in terms of coming to grips with what was actually in the TLO - much broader than I might have expected. Also there is a difference with what is required to meet assignment outcomes and what is required to meet the TLOs. This means that TLOs need to be given consideration in designing assessment items and in establishing marking criteria.*

The project offers an opportunity for quality enhancement in the setting of assessment tasks via reflecting on the purpose of the task and the design of the task.

[It forced me to] *"reconsider the basis for assessing student work"*.

Throughout the workshop the participants noticed that access to the range of opinions reported by SPARK^{PLUS} enabled areas of agreement and disagreement during group discussions to be quickly identified and understood. This in turn led to well-focused and better informed discussions and promoted consideration of all points of view, discouraging the group from being overtaken by groupthink or a dominant participant.

Conveners identified several improvements for future activities including:

- replacing the 5 category scale for judging assessment task validity with a 2-category scale (acceptable and not acceptable)
- more time was required to enable reviewers to articulate diverse tacit perspectives to adapt pre-existing, institutionally-centric views and calibrate to a national standard

- reviewing new samples was critical to confirming calibrated views
- workshop participation of two professionals was crucial to resolving expectations of standards
- allocating more time to participants identifying improvements in assessment task design would pay considerable dividends in validly and reliably evidencing standards
- While the first workshop was one half-day, subsequent workshops should be a full day and focus only on one standard instead of two and Masters level achievement of the same standard should be resolved before moving to the next learning standard.

The requirement for individuals to provide clearly articulate explanations for their ratings was crucial to the calibration process. It encouraged participants to view and interrogate others views prior to the workshop, allowing reflected perspectives to be voiced during the workshop, first in small groups and subsequently to reach a consensus prior to inter group consensus discussion.

VIII. CONCLUSION

Accounting is the first discipline in Australia seeking to collaboratively develop and implement a national model of expert peer review for benchmarking learning outcomes against nationally-agreed threshold learning standards. It aims to refine a model for assessing learning outcomes based on double-blind external peer review using experienced academics and practitioners as reviewers. Using online self and peer assessment software to complement face-to-face workshops, a process for calibrating reviewers' judgments ensures a process of assessment that is inclusive, efficient, and supports rich, reliable, and valid information. We report how the online self and peer assessment software assisted collaborative conversations and therefore calibrating judgments about standards. The software also facilitated collaborative conversation about assessment design thus promoting quality enhancements in assessment and therefore in curriculum renewal assessment.

SUMMARISE THE RESULTS AND WHAT WE FOUND

The use of SPARK^{PLUS} has been extremely valuable in the process of establishing a shared understanding and application of the accounting learning standards in Australia. The software allowed reviewers to complete the pre-workshop activities remotely and then to view the assessments and comments of others with anonymity. The use of the software provided results of the pre-workshop activity which allowed the conveners to structure the workshop to facilitate an efficient process for calibration of reviewers. The process was effective and efficient in promoting informed conversations between academics from 10 universities that resulted in an increased level of understanding about the two academic standards being assessed. This represents a substantial achievement.

There are several limitations in this paper. First, it involves a limited sample and reports only one instance of the pre-work and workshop activity. Second, it does not provide substantial confirmatory data following the calibration process to

demonstrate that the changed understandings are lasting. Third, while the free-response items asked respondents to describe changes arising from the project, it is an untested assumption that these arose from participating in workshops. However, it would be difficult to imagine how participants would otherwise have heard about them.

Notwithstanding these limitations, the entire process, incorporating sophisticated use of the software pre-workshop facilitated extensive face-to-face dialogue around specific assessment artifacts and greatly limited the potential hazard of groupthink. As other disciplines, including engineering set learning standards at either the national and increasingly international level, the use of SPARK^{PLUS} technology with the supported model process adopted in this project is ideal to sustain these activities.

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Work in Progress: Engaging Faculty for Program Improvement via EvalTools®: a New Software Model

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Abstract— In this paper we present our experiences with a new software-tool model for program assessment and evaluation, and engineering programs improvement in assessing learning effectiveness. In the past, the assessment plan was based on the typical practice of assigning a person in the department for overseeing the whole process. The non-collaborative evaluation that is managed by a single program leader is not effective and problematic. To involve more faculty and in an effort to prepare for the most recent ABET visit, we decided to adopt EvalTools® in fall of 2010. EvalTools® is designed and developed according to ABET standards to provide a mechanism for collecting and analyzing data about the program, students' performance and their learning achievements. In addition, EvalTools® is instrumental in providing a mechanism to simplify the process of inspecting the assessment results as well as identifies strengths and shortcomings of the program before ABET review. More importantly getting faculty members excited about results and involved in the process of program improvement is a major accomplishment. Our experience via first-time implementation of EvalTools® shows very useful results for this model that can be easily disseminated for various programs in various disciplines. In this paper we will show: process of best use of relevant features in aid of streamlining faculty's time in data collection as well as evaluation was achieved; our results and how we succeeded in improving our program quality in an effective, efficient and systematic way; that simple curriculum revisions for multiple programs as a result of using EvalTools® for programs under going ABET is possible; that capturing the process of effective trainings needed for faculty and staff in a simple manner; faculty's experience in a constructive and engaging manner.

Keywords- *Quality Assurance, ABET, Program Evaluation, EvalTools, Faculty Engagement*

I. INTRODUCTION

Engaging faculty in program improvement process is proven to be critical in reaching programs objectives more effectively. It holds the promise for overcoming many of the challenges relevant to the improvement process. Faculty engagement in the process helps keep attention focused on the ultimate purpose. It also results in outcomes that are directly connected to the daily activities of teaching by the faculty members and learning by the students. It is clear that programs improvement is “continuous efforts” that are most effective if

embedded in these daily activities. Majority of faculty members, if not all, would conceivably agree that “*there is always room for improvement*” at various levels. In fact, program improvement is usually attained naturally as faculty exercise simple routine and intuitive measures in their courses overtime. The problem lies in attempting to reach better qualities most effectively and to reach program objectives/goals most efficiently. Structured objective-driven program assessment lies in the heart of these challenges and endeavors. Assessment is, by far, considered by many faculty members as the least interesting of all activities despite the fact that its importance is well acknowledged. Multiple reasons contribute to this sentiment as pointed by the assessment professionals [1]. One main reason is that, assessment essentially is a lengthy process of data collection, organization, sorting, and filtering. The lack of faculty time in most cases constitutes a major hurdle in the instrumentation of a rigorous and detailed assessment method. The lack of expertise in assessment planning and execution is also pointed out by many as another reason. However, the main contribution to problem from the side of many faculty members is the isolation between data collection and the immediate benefit of that on class improvement and student learning. It is clear that engaging in activities of planning, data collection and data analysis is time consuming for the faculty member as well as department assessment leader. It is also argued that the usual assessment process is a “gamble” as it is not clear how to relate or pinpoint the effect of the gathered evidence on a specific learning outcome. In [1] the authors reached a conclusion that the best result in assessment is achieved by implementing a department-level process. They created a model by which responsibility of assessment is assigned to faculty members with encouraging factors.

In this paper we show that simple and clear model based on a simplified software-assisted process can yield better result for program improvement in general. It can also excite faculty members to engage in decision-making at various levels in the process. The software tool, EvalTools® [2], is a comprehensive software tool that allows for many functionalities ranging from course development and management to various assessment and evaluation practices. It symmetrically streamlines the process of data collection process and presents the results readily for assessing teaching effectiveness in meeting course outcomes as well as student outcomes. EvalTools® is designed based on ABET accreditation standards [3] for engineering programs which makes it easy to deal with for that purpose. Aside from ABET

injunction, we saw great improvement in our faculty perceptions towards program assessment when we applied EvalTools®. The software alleviated the burden of planning and provided a clear process that can be geared towards program specific structure and needs.

The paper is organized as follows: at first we present a brief background about our program and our department. Then we provide a general description of EvalTools® outlining its main features that we used in preparation for our accreditation visit in 2011 for the Mechanical Engineering program. We then explain our assessment plan and how EvalTools® was instrumental in capturing our students learning attainment addressed by ABET. It is imperative to mention that the faculty engagement was also quite instrumental not only in executing the assessment plan but also in improving the program. The tool made it easy, in a relatively short term, to see the benefits of the old assessment data which kept faculty excited and awaiting the new set of data.

II. BACKGROUND OF FSU PROGRAMS

Frostburg State University (FSU) has been providing higher education opportunity to Western Maryland since 1898. In spring 1994, FSU and University of Maryland at College Park (UMCP) began planning collaborative programs in Electrical Engineering (EE) and Mechanical Engineering (ME) on the FSU campus. The programs are provided in the department of Physics and Engineering at FSU. The goal of the project was to establish a national model by offering engineering education in a rural area, with access to the resources of a large metropolitan university over distance. The first students were admitted to the program in fall 1997, and the first group of students graduated from EE and ME programs in spring 2001.

The department of Physics and Engineering also offers a BS degree awarding program in General Engineering from FSU with four concentrations: Electrical Engineering, Material Engineering, Engineering Management and Industrial Chemistry. This program started in fall 2008 as a replacement for the collaborative EE major. While the collaborative EE program experienced enrolment decline following the national trends, the collaborative ME program was steadily on the rise. Our focus in this paper is on the experience acquired during the ABET accreditation efforts for the collaborative ME program. This collaboration model developed by FSU and UMCP is a unique one that showed great success in meeting its objectives. Advantages and limitations of the developed collaborative engineering programs based on the structure of the curriculum, available facilities, assessment results, and alumni feedback in their initial phase were reported at the American Society for Engineering Education Zone I Conference [4-5].

Faculty Involvement:

In the past one faculty member was in charge of the activities of implementing the assessment. A plan for assessment was created to meet ABET accreditation criterion. The plan was based on the typical practice of assigning a person (faculty member or staff) in the department for

overseeing the whole process. Although the plan was greatly simplified to take advantage of data related to students' performance (exams, assignments, etc) and graduates attainment of program objectives, the plan did not succeed in identifying and executing particular action-items related to the findings of the assessment process. Perhaps because these typical methods are, often unclear, cumbersome, un-scalable, seasonal (whenever ABET review date is approaching), highly contingent (if ABET department coordinator disappears, the plan stops), or most importantly, perceived as non-beneficent. We researched the aforementioned problem and reached the following two conclusions: 1) faculty members committed to quality education would individually or collectively adopt and apply any method if it shows clear direct impact on students' performance in their class. Two, those faculty members will embrace such a method if it was simple, non-time consuming and sufficient training is provided.

The software tool described below satisfies these aforementioned conditions.

III. EVALTOOLS® SOFTWARE

EvalTools® – an online program assessment toolset – that replaces the functionality of Blackboard® for daily classroom lesson and assignment activities; additionally, it tracks key assignments which are automatically ported into the appropriate Faculty Course Assessment Report (FCAR) [6] document for evaluation purposes. EvalTools® integrates best assessment practices into its features. In particular, EvalTools® uses a performance vector that classifies student learning performance into four categories: Excellent (E), Adequate (A), Minimal (M), and Unsatisfactory (U), which form the EAMU performance vector [6-7]. The results are flagged with different colors according to heuristic rules which indicate academic status. The performance vectors are collected from a matrix of selected courses for particular student outcomes; the resulting performance vector table illustrates the areas of strength, weakness, and concern. The computation and tabulation of EAMU performance vectors are embedded in EvalTools®. Once a key assignment is graded, the scores are submitted to EvalTools®. EvalTools® then produces the necessary EAMU vectors for each key assignment and their mapping to either the course outcome or the student outcome in the relevant FCAR. EvalTools® also provides the necessary objective evidence folders electronically at the end of the semester. As a result, the faculty workload is lessened, allowing faculty members to focus on teaching and their usual daily activities.

The following are highlights of essential features of EvalTools® pertaining to outcomes assessment:

- Lessons – a depository for lessons and lectures
- Assignments – tracking of assignments in meeting course objectives
- Grade book – maintaining course grades
- FCAR – Faculty Course Assessment Report
- Course syllabus – systematically documenting learning activities
- Rubric – easy creation of rubric for consistent gauging of meeting outcomes

- Objective evidence folder – a centralized depository for all artifacts collected in class
- Course exit survey – tracking end-of-semester course survey in meeting course outcomes
- Senior-exit survey, alumni survey, employer survey – customizable surveys to suit this university's needs
- Curriculum outcomes matrix – facilitating easy review of program strengths and weaknesses
- Trend-analysis course matrix – giving longitudinal perspective on course performance
- Action items matrix – systematically documenting action items for closure and improvement
- Student outcomes evaluation – tracking and reporting the review and results on PVT
- Executive summary on Student outcomes – tracking and reporting the review and results on evaluation

IV. FACULTY ENGAGEMENT IN PRPGRAM EVALUATION

Our faculty engagement started early in the process of developing a plan for program assessment and continuous improvement. In the spring semester of 2010 the Physics and Engineering department chair met individually with the department faculty members whom are involved the mechanical engineering program. These are faculty members teaching or supervising students' projects, research, and/or other activities. The department chair discussed ABET's program review process in general and many specific items related to the individual faculty. These individual meetings helped prepare the faculty members to take part in the process as issues and concerns related to time budgets were discussed at this stage. The following was the outcome of these individual faculty meetings:

- Create individualized consultation for program assessment/evaluation and assessment evidence gathering.
- Prepare faculty members to become part in the program evaluation and continuous improvement process by mapping the program outcomes and objectives to the instructor courses.
- Incite the faculty member to use new software tool (EvalTools®) by highlighting the software features relevant to the faculty member's course delivery, course assessment and improvements.
- Emphasize course learning outcomes related to program learning outcomes required by ABET in courses.
- Construct the *Curriculum-Student Outcome Matrix* in a way that supports program efficient assessment.
- Discuss with faculty their time limitations and the challenges that may occur as a result of the process and review alternative solutions like student help and staff assistant.
- Improve course syllabi in general and the syllabi for the courses included in the Student-outcome course assessment matrix in particular.

Developing Curriculum-Student Outcome Matrix

Constructing Curriculum-Student Outcome matrix was accomplished by involving faculty members in multiple one-

to-one meetings with chair in spring of 2010 as well as meetings in, a newly established committee for program assessment and improvement (PAC). The chair of the department of Physics and Engineering who is, also, leading the program review initiative worked with faculty members in the department in identifying key courses in the ME curriculum to set one aspect of the program assessment as the heart of the program continuous improvement. Bloom's Taxonomy [8] for learning pattern was used where learning pattern suggests that a learner goes through the cycle of *knowledge, comprehension, application, analysis, evaluation and synthesis*. Even though this cycle of learning pattern takes place in many courses at various levels, our curriculum focuses mainly on a specific pattern of learning which is presented in Table 1. Similarly, one can also use Biggs constructive alignment principles [9] for this stage of evaluation instead of Bloom's taxonomy.

Table 1: Bloom taxonomy applied to evaluation

| Level of Courses | Focus of Learning |
|------------------|--------------------------|
| first year | Knowledge/ Comprehension |
| second-year | Knowledge/ Comprehension |
| third-year | Application and Analysis |
| final-year | Evaluation and Synthesis |

The Curriculum-Student Outcome matrix lists the courses which are used in assessing our student outcomes. Table 2 bellow represents this matrix. Once this matrix is established, the designated courses are considered key or "core" courses in the assessment process. A faculty who teaches a core course becomes an owner in the program assessment and improvement process.

Table 2: Curriculum-Student Outcome Matrix (generated by EvalTools® representing a-k coverage)

| Spring 2010 - Fall 2010 | | Student Learning Outcomes | | | | | | | | | |
|-------------------------|--|---|--|-------------------------------|--|--|------------------------------------|--|---|----------------------------------|---|
| Course ID | Ability to apply mathematics, science, and engineering knowledge to solve problems | Ability to design and conduct experiment, and to analyze and interpret data | Ability to design a system, component or process to meet desired needs | Ability to function on a team | Ability to identify, analyze, and solve problems | Understanding of professional and ethical responsibility | Ability to communicate effectively | Ability to understand the impact of engineering on the environment | Recognition of the need for, and an ability to engage in life-long learning | Knowledge of contemporary issues | Ability to use the techniques, skills, and engineering tools necessary for the solution of engineering problems |
| Total Courses: 13 | 7 | 4 | 3 | 4 | 5 | 1 | 5 | 3 | 2 | 3 | 4 |
| Spring 2010 | | | | | | | | | | | |
| ENES100001 | x | | | | | | | | | | |
| ENME232001 | x | | | | | | | x | | | |
| ENME271001 | | | | | | | | | | x | |
| ENME332001 | x | | | | x | | | | | | x |
| ENME362001 | | x | x | | | | | | | | |
| ENME472001 | | x | x | x | | x | x | x | x | x | x |
| ENME480001 | | | | | | | x | | x | | |
| Fall 2010 | | | | | | | | | | | |
| ENES220001 | | | | | x | | | | | | |
| ENES221001 | x | | | | x | | | | | | |
| ENME231001 | x | x | | | x | | x | | | | |
| ENME250001 | x | x | | | x | | | | | | |
| ENME271001 | | | x | | | | | | | x | x |
| PHYS311001 | x | | | | | | | x | | x | |

As can be seen from the matrix above, the courses selected for the assessment of the program provides complete coverage for ABET Student Outcomes. Late on we will be able to see that the required student outcomes map into our program educational objectives and hence the educational objectives (PEO) are linked to several courses in the curriculum. Our assessment for the PEO was attained by obtaining data about our graduates. We were able to learn about our curriculum from this data. It can be easily demonstrated that adjustments in our curriculum, course offering, pedagogy, course content (and generally any activity at this level) would have an effect

on the program attainment of Student Outcomes and general PEO.

A course owner is required to map the Student Outcomes in the matrix to the specific course learning outcomes. These course outcomes are typically identified by the instructor and reviewed by the PAC and department chair. A course owner develops the assessment tools for these course learning outcomes. The assessment tools are referred to as *Key Assignments*. We required that the course owner maps the course learning outcomes to the Student Outcomes. It is of the essence to mention here that the selection of courses in the matrix is based on multiple factors:

- Focus of learning according to the Bloom's taxonomy
- Level of course and depth of material covered and skills developed
- Coverage of the program Students Outcomes
- Relevancy of the course outcomes to the overall PEO
- Level of interest in the process as identified by the faculty
- Simplicity of the assessment instrument developed to measure the outcome attainment

Strategies for Faculty Engagement

Designing course assessment instruments for courses in the matrix based on simplicity was clearly outlined to faculty members who are participating in the accreditation process and the program improvement process in general. It is essential to be able to bring concerned faculty members on board, and to stress on the simplicity and efficiency of the process. Our strategy to reach this goal was based on two **main** factors: First, highlighting and stressing on the direct and immediate benefit of this (program improvement) process on the faculty's course performance. The second factor is stressing on the simplicity of using the software tool and the added value of utilizing the tool for improving their course performance and the program in general. The software tool, as was described earlier, alleviates the burden of organizing, saving, presenting assessment data in a form easy to study and contemplate. Its features allow for other class management activities that are also quite useful. When this fact was made clear to our involved faculty member they felt more encouraged. One faculty member (also member of PAC) commented "...I was able to easily discover how my course and others impact future engineers. I was also able to adjust my teaching to have better impact". Another PAC member commented "I am happy to join this project. I was skeptic at first that I would not have time... Through this software (EvalTool®) we can easily identify where in the curriculum students have problems and help select the action-items". Hence, involving faculty members as owners of the process and the careful strategizing prepares faculty members to embrace and interact with the process as part of their own teaching goals rather than dealing with it as part of a mandated project.

Building Course Assessment Instruments

Building the assessment tools for courses in the Curriculum-Student Outcome matrix is in the core of this

project. For each course the "course owner" (or instructor) developed appropriate assessment tool for the various course learning outcomes. We focus on including only those course outcomes which are related to our general Student Outcomes. As can be seen in the matrix above, courses may map to one or more Student Outcome. EvalTools® presents also the mapping between the Program Educational Objectives and the Student Outcomes.

The appropriate assessment instruments developed by the course owner vary based on the learning outcome. Currently we use the following instruments referred to as *Key Assignments*: homework problems to address concepts and principles, exam problems, project assignments with specific outcomes, design projects, lab experiments, project presentations, surveys of team collaboration, rubrics for various observations addressing soft skills, targeted assignments and other graded work.

In EvalTools®, the course portfolios include, course syllabi, Key Assignments, grade book to store results, etc. EvalTools® automatically calculates the attainment of the Student Outcomes based on a rigorous and adjustable formula that takes into account the data collected from all various courses which are related to the specific Student Outcome. For example, in Table 1 if we take the Student Outcome C: "*The ability to design system, or process to meet a designed need*", we find three courses that map into this outcome: ENME 371, ENME 472 and ENME 488. Key assignments are developed in these courses to address this ability at junior and senior level. PAC will be able to review the result and identify problems in the respective outcomes. Then PAC is able to delve into the courses where these outcomes map. Section 5 gives details of EvalTools® output.

PAC review includes data from the previous evaluation cycle as old action items are reviewed. Based on the review results, new action items are developed at the level of Students Outcomes attainment. This allows for closing of the loop on the program Students Outcomes. In addition, on the level of course learning outcomes, EvalTools® allows for closing a smaller loop by allowing the instructor identify action-items related to the course. These course specific action-items are reviewed by the instructor at the end of the semester to develop new ones. The third loop is due to the general PEO review which takes place every two to four years.

Training Faculty for Effective Use

To achieve effective and efficient use of this process of program continuous improvement and the use of EvalTools® we provided a number of training sessions. Two of these sessions were provided by EvalTools® as part of their support. The sessions involved designated course owners and PAC members. Each one of the two main sessions was provided as one full-day workshop held in the department. EvalTools® training was very instrumental in emphasizing the importance on the procedure adopted. The workshop covered essential topics for program assessment and continues improvement. It also helped identify our departmental priorities related to this process. It brought faculty members involved in the process to a better understanding of the process in general and EvalTools® as a software package. After the training sessions,

our faculty members were ready to apply the process immediately.

V. RESULTS FOR PROGRAM ASSESSMENT AND REVIEW

We will now discuss the results of the application of our new assessment and improvement plan in conjunction with EvalTools® for the cycle of 2010-2011. The data collection started in the spring of 2010. Assessment data from spring 2010 were compared to data collected in spring 2011 by individual faculty members to close the small cycle on a portion of the programs **key courses**. Data from fall 2010 were compared to fall 2011 data. Hence, the small cycle for improving these key courses which insure targeted Student Outcomes is completely closed by the end of fall 2011. It is essential to observe that it required two full years’ data to close the smaller loop. However, one full year data is sufficient to identify ABET’s program outcomes attainment and identify improvement actions. The closing of the loop takes another year to reflect on the actions provided for improvement. Also the two year period provides complete data on the workability of process itself. We will discuss bellow our review data from two spring semesters and one fall semester. From this data we can prove that the process works and that improvement items were identified and reflected upon by our faculty. Obviously, the improvement in the program is attained only if the correct action is applied. EvalTools® provides the way of identifying, applying and reflecting on action items.

Student Outcome Assessment and Review

Figure 1 shows the process utilized for Students Outcomes assessment. We will provide the results of the assessment as presented by EvalTools® for one ABET outcome bellow.

Performance Vector Table (EAMU Table)

To measure the performance of students in the designated key assignments we adopted the EAMU performance vector approach come with EvalTools®. The results from a graded Key Assignment are converted into the EAMU vector which simply carries the number of students in the Excellent, Adequate, Minimal and unsatisfactory categories in that particular Key Assignment. One or more Key Assignments will be used to identify the students’ performance in a course-outcome. Consequently, that course-outcome is used to indicate the students’ performance in a Student Outcome which is mapped to that course. The EAMU vectors are flagged with different colors according to heuristic rules which indicate academic status. The efficiency of this rules-based approach during program evaluation relies on well-justified Key Assignments that address the course-outcomes and form the performance vectors. Table 3 shows the explanation of the codes for the EAMU vector. Bellow, in Figure 2, we see a page generated by EvalTools® showing the result of evaluating one Student Outcome. EvalTools® captured the PAC member discussion and actions.

The review shows data for one year when completing the cycle this page will be utilized by course instructors to implement the actions on specific courses.

Course Outcome Assessment and Review

The course assessment and review takes place by the individual faculty to ensure the course quality. EvalTools® captures the outcomes related to the specific course, allowing the instructor to see the performance and performance criterions. By seeing this color-coded section the instructor is

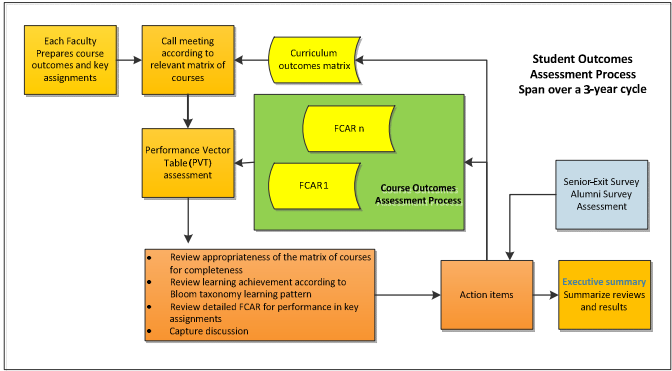


Figure 1: Student Outcomes assessment process

Table 3: Criteria category

| Category | Criteria Description |
|-------------|---|
| Red flag | Any performance vector with an average below 3.3 and a level of unsatisfactory performance that exceeds 10% in the U column |
| Yellow flag | Any performance vector with an average below 3.3 or a level of unsatisfactory performance (U) that exceeds 10%, but not both |
| Green flag | Any performance vector with an average that is at least greater than the 4.6 and no indication of unsatisfactory performance (U) |
| No flag | Any performance vector that does not fall into one of the above categories |

able to identify leaning outcomes that need improvement in the course. EvalTools® reports provides a way to reflect on the action-items identified by the instructor the next time the course is reviewed. We currently review these courses by PAC to ensure the quality of the evaluation process. [6-7] reported examples on course assessment matrix generated by EvalTools®.

VI. LESSONS LEARNED AND CONCLUSIONS

Engaging faculty members in program improvement via use of software is considered an innovative practice which was quite successful because of the following reasons: 1) Engineering faculty members, are generally well acquainted with the use of online software tools, like Blackboard, for classroom and general educational activities. Such tools provide access from remote locations and can be utilized in flexible times. 2) The direct relationship between program improvement (as required by ABET) and specific course improvement (as strived for, naturally, by instructors) was clearly highlighted by EvalTools. This enticed faculty members to embracing the process from the beginning. 3) Creating a sense of ownership of courses for involved instructors helped enhance faculty engagement. Performance improvement became a clear goal and the new process provided a clever way to gauge individual course improvement and general program improvement.

Spring2010: Ability to apply knowledge of mathematics, science, and engineering

Fall2010: Ability to apply knowledge of mathematics, science, and engineering

Metric: FCAR reports from the following courses will summarize the necessary evidence in meeting this specific outcome.

| Term | Course | Name | E | A | M | U | Average |
|------------|------------|---------------------------------|-----|-----|-----|-----|---------|
| Spring2010 | ENES102001 | Statics | 6 | 2.5 | 0.8 | 3.8 | 3.03 |
| Spring2010 | ENME232001 | Thermodynamics | 0 | 8 | 7 | 5 | 1.92 |
| Spring2010 | ENME332001 | Transfer Processes | 5 | 2 | 0 | 1 | 3.96 |
| Fall2010 | ENES221001 | Dynamics | 5.5 | 4.5 | 0 | 1 | 3.86 |
| Fall2010 | ENME331001 | Fluid Mechanics | 12 | 4.5 | 3 | 1.5 | 3.81 |
| Fall2010 | ENME350001 | Electronics and Instrumentation | 9.5 | 3.5 | 7 | 7 | 2.62 |

Classification: Below Expectations (1.5 barely meeting)

Discussion:

- Students' math abilities need improvement at lower levels.
- Improvement is seen at upper levels.
- Many students were Excellent and Adequate and some are Minimal.
- Result is alarming but can be rated 1.5 with immediate strong actions to be taken in all of the courses.
- ENES102 Statics: Weakness in application of cross product moment of force.
- ENME232 Thermo: Application of calculus to fluids, physics, chemistry. They can't finish the math operations to the end. Instructor needs to set up the title of the key assignment and the description and justifications for the key assignments.
- ENME350 Electronics & Instrumentation: Solving differential equations was not satisfactory or was minimal for many students because they don't have adequate the background or the training for that. The solution is in the form of gaining more diff. eq problems to work on.
- PYHS311 Thermo: Same as above
- List of courses is okay for this outcome. We need to challenge the students with their math abilities, make them do the work.

Action:

- Give more math problems in the above listed courses.
- Seek resources to hire math graders to help in grading the extra problems needed to strengthen the math abilities.

Reviewers:

- Eltayeb, Teker, Soysal, Budzien, Wang, Moore, Mak.

Review Date: 2011-04-08

Figure 2: EvalTools® review Student Outcome page

4) Highlighting the simplicity of software use and simplifying the whole process, removing unneeded efforts was instrumental in the success of the process. 5) Providing essential training for involved faculty members helped reduce learning time. 6) Finally, it is worthwhile mentioning that faculty collaboration and teamwork spirit was a valuable asset in the process. The key, always, was to develop and maintain this spirit.

In conclusion, our experience with EvalTools® as a software tool to help improve faculty interaction with program improvement is summarized as follows: First, we were successful in meeting ABET accreditation criterion relevant to program assessment and continuous improvement applying this process to our program. The program reviewers commented "...EvalTools is a 'great tool' to apply because it provided a thorough and solid assessment mechanism for improving the program...". Second, we were successful in developing an assessment and evaluation process that is quite sustainable. Third, with the use of EvalTools, we were able to focus more on data evaluation than on data collection and compilation. Faculty members are less burdened on evaluation data and more focus on their teaching and hence, yield a better result in the use of faculty time and effort in program improvement.

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Work in Progress: Building Information Literacy Assessment

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Abstract— In today's electronic age, information literacy skills are more important than ever. It has been challenging for most engineering faculty to find a place to infuse and integrate information literacy into already demanding curricula. However, engineering faculty need to address the topic of information literacy in order to support achievement of ABET student outcomes related to communication, contemporary issues, and lifelong learning. This paper presents the steps taken to assess and evaluate information literacy skills through the development of specific performance indicators related to ABET student outcomes g, i, and j. Using existing assignments, assessment data were captured and preliminary results are presented.

Keywords—Assessment, Information Literacy, Outcome, ABET

I. INTRODUCTION

According to the Final Report of the American Library Association Presidential Committee on Information Literacy [1], Information Literacy (IL) is defined as “an individual's ability to know when there is a need for information, to be able to identify, locate, synthesize, evaluate, and effectively use that information for the issue or problem at hand.” IL knowledge and skill have been identified as critical components to gathering and using information. With the tremendous amount of information available at the click of a mouse, knowing how to find, organize, and evaluate this information is the challenge [2-3]. Despite the amount of information that is available, students are still not information literate and are struggling to retrieve and evaluate information that is required for problem solving and decision making in the workplace and society [4]. Engineering students must be encouraged to develop these skills to be successful. It has been challenging for most engineering faculty to find a place to infuse and integrate IL into already demanding curricula [5]. Research has shown that IL is most successful when it is associated with an existing assignment within a course [2, 6]. The authors believe that the best way to ensure that teaching faculty provide students with opportunities to develop IL skills and the most effective way to assess and improve the curriculum in support of IL development is to incorporate IL into existing assessment processes. For engineering programs this means incorporating IL into assessment of student outcomes known as ABET a-k [7].

II. PROGRAM OUTCOMES AND INFORMATION LITERACY

The curricular ABET outcomes for the ME department are generic to the four engineering majors at the U.S. Coast

Guard Academy (USCGA) and correspond to ABET-student outcomes a-k. During the development of the three student outcomes under consideration herein, the ME faculty noted that the USCGA Civil Engineering (CE) program evaluation provided a model from which ME could launch its own assessment [8]. The ME faculty observed that IL was not specifically addressed in the current curriculum, which sparked the ME faculty to reevaluate the current program outcomes and make several modifications. The process developed by the CE faculty was used to identify IL-related student outcomes, link them to current courses and develop assessment tools. This process is shown in Figure 1.



FIGURE 1. PROCESS TO IDENTIFY IL LINK TO COURSES

It was identified that IL was captured in the following ABET-student outcomes: g (the ability to communicate effectively, i (ability to engage in life-long learning), and j (knowledge of contemporary issues). Once this was established, performance indicators were developed to capture IL skills, knowledge, and ability. The performance indicators related to student outcomes were then mapped to current courses in the ME curriculum as shown in Table 1.

TABLE I.
PERFORMANCE INDICATORS RELATED TO IL ASSESSMENT MAP

| ABET-Student Outcome | Related Performance Indicator | Courses that Contribute |
|--|--|--|
| g: an ability to communicate effectively | Research information from a variety of sources, use information to make engineering decisions/ judgment and produce a technically sound report | Mechanics of Materials, Mechanisms, Engineering Experimentation, Mechanical Engineering Design, Design Project Management |
| i: a recognition of the need for, and an ability to engage in life-long learning | Use a variety of tools such as professional journals, books, codes, and standards as sources of industry information | Engineering Experimentation, Mechanisms, Machine Design, Mechanical Engineering Design, Design Project Management |
| j: a knowledge of contemporary issues | Investigate, gather and analyze information related to contemporary issues | Intro to Mechanical Engineering Design, Mechanisms, Thermal Systems Design, Mechanical Engineering Design, Design Project Management |

The performance indicators developed in Table 1 were further examined and an evaluation process and plan was constructed. This included identifying which classes would be the primary source of assessment data, the assessment tools to be used, the collection cycle, the assessment coordinator, and the evaluation of results.

III. ASSESSMENT TOOLS

A variety of tools can be used to assess student performance, to include research papers, technical papers, journals, capstone project reports, laboratory reports and oral presentations. Graded performance criteria were developed to ensure IL components were consistently assessed and evaluated. The IL components of the graded performance criteria (PC) evaluated students' ability to: (1) write a well organized paper, (2) develop a clear and concise theme, (3) identify the type and importance of information related to theme, (4) use of good technical writing skills and (5) incorporate a variety of high quality references. The student performance results were divided into three performance categories: (1) exceed, (2) meet, and (3) below expectations.

IV. RESULTS

Examples of student performance in two courses, *Mechanisms* and *Machine Design*, are presented in this section. In *Mechanisms*, a junior level spring semester course, students were required to write a paper on contemporary issues including engineering failure cases.

In *Machine Design*, a senior level fall semester course, students were required to write a technical research paper that would contribute to their capstone senior design project. The objective of the paper was to research a specific component, problem, or technology related to that topic. Although each senior capstone design project consisted of four to five students, each individual student was required to submit a separate research paper. As part of the assignment, IL guidelines were provided and discussed.

The students assessed in the *Mechanisms* course and *Machine Design* course were not the same group of students, nor was the assessment completed in chronological order. The results of the student performance assessment, based on the IL-related components of the writing assignment, are shown in Figures 2 and 3.

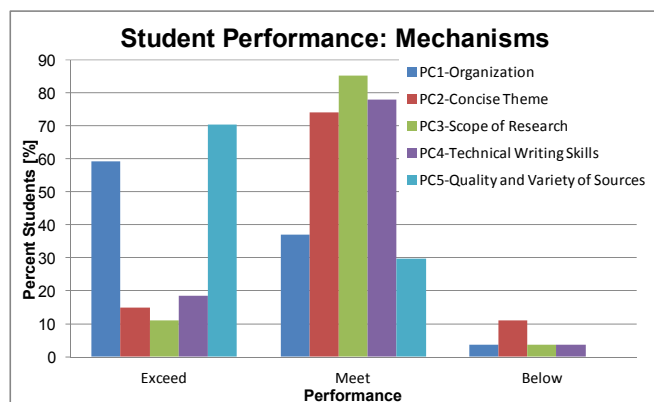


FIGURE 2. IL COMPONENT IN MECHANISMS PAPER.

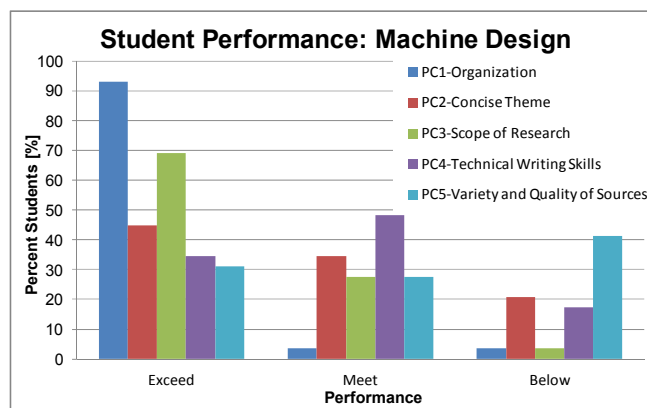


FIGURE 3. IL COMPONENT OF MACHINE DESIGN PAPER

In both figures, “exceed” corresponds to a score of 90-100%, “meet” corresponds to a score of 70-89%, and “below” corresponds to a score less than 70%. Figure 3 shows us that overall student performance met or exceeded expectations. One might expect a higher level of performance in *Machine Design*, but over 40% of the senior level students fell below minimum (70%) in PC5 (variety and quality of sources), while 100% of the students in the junior level class met or exceeded in the same category.

These results indicate that more work is required in the area of assessing and evaluating IL. One area of improvement is to provide students with the grading rubric along with the assignment to ensure that expectations of the instructors are known. Assessment and evaluation of IL skills should be expanded to additional classes within or outside the ME program of study and should continue to be assessed annually or bi-annually. The progression of student performance should also be evaluated to include assessment at the sophomore, junior, and senior level. Results of assessment need to be documented and changes will be incorporated into the holistic assessment process used by the ME program. Indirect assessments from the operational Coast Guard should be used to gauge the IL skills of ME graduates. Finally, Engineering and English faculty should collaborate to strengthen assessment standards and practices and improve student technical writing skills.

V. CONCLUSION

It is essential that educators help undergraduate engineering students develop and improve their information literacy (IL) skills in the context of the current and emerging information infrastructure. As a result of applying the continuous-improvement program assessment cycle, the Mechanical Engineering faculty at USCGA has developed performance indicators and assessment tools under existing ABET outcomes to investigate the current state of engineering student IL skills. This was achieved by utilizing existing grading rubrics for classroom assignments that students are already doing. Preliminary results indicate that embedding IL into the existing assessment model will inspire greater development and improvement of student IL skills in a sustainable and effective manner.

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Managing Student Outcomes in a Totally Asynchronous Learning Environment: Lessons Learned

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Abstract – A graduate course, APMA 6430 *Probability and Statistics for Engineers and Scientists*, has been offered by the University of Virginia's School of Engineering and Applied Science since 1985 in both traditional and synchronous distance learning modes. The decision to move to a totally asynchronous delivery mode was made in 2009 and fully implemented in Spring, 2010, based in part on the desire to support student achievement given the many – but different – challenges faced by both on-grounds and off-grounds students. The shift in delivery method brought its own set of challenges along with its inherent flexibility in student engagement with the course. In this paper, we review the lessons learned and how we met various administrative, support, and instructional challenges from the first three offerings of this course in a totally asynchronous on-line mode.

Index Terms – Asynchronous learning, on-line learning, graduate engineering education, statistics education.

INTRODUCTION

The question is not whether asynchronous learning will be a major instructional delivery method, but when it will be the method of choice, and under what circumstances. Distance and on-line learning have a long history in Virginia and at many other schools (Illinois, Florida, Georgia Tech, and Southern California). The Sloan Consortium has focused on on-line and asynchronous learning for several years. These efforts have existed within established educational institutions

Now several new educational initiatives are challenging traditional educational institutions and their practices. Massive open on-line courses are now offered by edX and UDACITY. These offer free on-line courses to anyone who decides to enroll. They provide instruction, assess student progress and award certificates, but not course credit or degrees. Massachusetts Institute of Technology's OpenCourseWare program has been available for several years; it also allows anyone who wishes to sit in on an MIT class. The Khan Academy has over 2700 lessons mostly on basic math available for free. [1] – [3] David Brooks warned of a “campus tsunami” based on his interpretation of comments by Stanford president David Hennessy. [4] These experiments are exciting and informative, but they have not yet established a business model that challenges that of the

traditional model of the mortar-and-brick colleges and universities.

The support infrastructure for asynchronous learning allows for the capture and retention of lectures, discussions, and labs from leaders in academe and industry. The implications of having this archival material are many, and we have yet to work through them to a coherent vision of education in the Internet age. For example, the upfront investment in time and equipment in recording lecture modules may be recouped in succeeding semesters, allowing professors more time for teaching another course, conducting research, working in an administrative role, or providing community outreach. Guest lecturers can be easily accommodated. Or, it could be decided that a faculty member leaving, for whatever reason, does not have to be (fully) replaced since his/her class(es) can be covered using the archived material. However, these benefits may be more apparent than real given the need to material up to date, factoring in advances in the area or changes in texts and other supporting material.

The delivery method for APMA 6430, *Probability and Statistics for Engineers and Scientists*, a graduate course offered by the School of Engineering and Applied Science, University of Virginia (SEAS UVa), switched from mostly real time to totally asynchronous in the spring of 2010. What happens to student attitudes, learning, and achievement when a course's delivery method changes? We explore the impact that offering this course in asynchronous mode has on student perceptions and attitudes, learning outcomes and on course management in this paper.

BACKGROUND

APMA 6430¹ has been delivered in several modes since 1985: in a traditional classroom setting to resident students; as distance learning with resident students on-site and non-residential students participating at local viewing sites, first through satellite transmissions and then via Internet streaming; and now as distance learning through pre-recorded lesson units downloadable from the course site. Asynchronous learning opportunities were available when the course was taught through a distance learning program, the Commonwealth Graduate Engineering Program (CGEP)

¹ Formerly APMA 643; a university-wide change in the course numbering system was necessitated by a switch to a new student information system in Fall, 2009.

[5], via videotapes and archived streams; however, these asynchronous learning opportunities could occur only after a given class had been delivered. In addition, students who wanted to make up a missed class or review material in the videotape era could also encounter logistical challenges in obtaining, viewing, and/or returning a tape. The move to internet streaming removed many of those challenges but again, asynchronous learning opportunities could occur only after the fact. Creating a pre-recorded version of the course meant that learning could occur at the student's convenience, following his/her schedule, not an institutional timetable.

The decision to go to a totally asynchronous delivery mode was made in 2009, based in part on the desire to support student achievement given the many – but different – challenges faced by both on-grounds and off-grounds students. Challenges faced by on-grounds, or residential, students are reported in [6] and [7]. Students are typically in their first or second year of graduate study, and therefore are dealing with various challenges that may include balancing classroom and research loads, taking qualifying exams, and adjusting to a new environment. In the case of 13% of students in 2010, 21% in 2011, and 34% in 2012, this challenge also included adjusting to a new country. We've noted in [6] and [7] that international students would review materials in informal study groups held right after a lecture or by reviewing course modules recorded during previous CGEP offerings in order to overcome cultural and linguistic barriers to comprehension. Off-grounds students must balance class attendance and work with full-time employment, which may include travel, and family obligations. These students have, in the past, reported difficulty in accessing viewing sites in Northern Virginia and Tidewater/Hampton Roads due to traffic volume and class times that conflicted with work. For example, the first UVa time slot for a CGEP class time is 3:30 pm ET, and the first Virginia Tech time slot is 4 pm ET [5]: the mid-end of a typical workday and beginning of the afternoon rush hour in both regions.

Richards has been the primary instructor of APMA 643/6430 since 1985; his historical perspective has been invaluable in the analyses presented here and in [6] and [7]. Additionally, all SEAS graduate students, whether master's or doctoral, regardless of department, must complete at least one course in (applied) mathematics as part of their graduation requirements. This requirement is one explanation for the enrollment figures presented later in this paper and for some of the unique challenges encountered in delivering and administering this course no matter the mode chosen.

ASYNCHRONOUS CLASS STRUCTURE AND DEVELOPMENT

Delivering a course in the asynchronous mode allows us to realize the best pedagogical practices that we frequently ignore in traditional lecture based classes: present the material in manageable chunks, make sure the student learns the material before moving on, perform formative assessments on a regular basis and provide immediate

feedback, personalize the learning experience, pace the presentation to the individual learner, address common misconceptions and misunderstandings, and provide help and assistance as needed.

In the asynchronous version, the lecture material was previously delivered twice a week in 75 minute class periods. Now the material has been segmented into a series of 20 - 30 minute modules, which better suits student attention spans. The modules are clustered into units. Each unit focuses on a coherent set of topics such as data analysis and display, basic probability and random variables, estimation, hypothesis testing, analysis of variance, correlation and regression, quality control, and categorical data analysis. Supplementary modules review prerequisite knowledge, such as set theory and basic probability concepts; the use of the course's software application, Minitab; course logistics; and test reviews.

The modules were initially recorded over six months in mid-to-late 2009 using Camtasia [8]. Existing course notes were elaborated and adapted to the new delivery mode. A number of course delivery systems were explored and evaluated and we experimented with several formats and approaches. Each had advantages and drawbacks. Faced with a deadline (the start of classes), we had to just select a system and start recording. We decided that seeing the instructor was not necessary, and that voice over slides was sufficient. Initially we tried editing the videos to improve their quality and eliminate verbal distractions. After the fifth class, we tried just recording and eliminated all editing. The students did not seem to notice.

Links to the modules, which reside at screencast.com, are available on the course's UVa Collab site [9]. Collab is UVa's course management system, based on open-source code from Sakai (current version 2.8.1). The ability to download the modules was enabled after the first offering in response to student requests to be able to view them when internet access was not available or allowed. Modules are periodically re-recorded to update the content based on student feedback; advances in pedagogy, asynchronous or otherwise; and current examples related to the covered topic(s). The welcome and course logistics module is re-recorded for each semester. A list of modules is provided in Table V, presented at the end of this paper.

MANAGING STUDENT OUTCOMES

The initial plan was to grant students access to a unit for a given amount of time, with the students deciding when and where to review the material. Each unit has embedded assignments to facilitate active learning. Graded homework is also assigned. Answer keys are provided for both the embedded assignments and graded homework: concurrently with the embedded assignments and consecutive with the graded homework. Tests and quizzes are assigned at defined times throughout the semester to insure steady progress by the students. Learning is self-directed but ideally done at a pace that allows a student to cover the materials throughout the provided time. The goal is to provide a personalized path

through the material relevant to the students' interests and needs.

However, we found that some students in the initial offering had delayed longer than they should have in viewing modules and completing assignments when they requested an extension for the first test. Providing a suggested viewing schedule was not sufficient to keep some students on track; additional graded homework turned out to be the most helpful means to ensure steady and consistent progress.

Based on student feedback concerning having only a few modules available at a time, we now post all modules before the class' official start. A map of the readings and modules to cover each week (again, please see Table V) is available to help students pace themselves, but individual students are free to move ahead as they wish. This change has given the students a greater sense of control over their learning: a good thing.

Communication, monitoring student use of course materials, and keeping students to the schedule by numerous and carefully spaced graded assignments and exams are vital to managing student outcomes. Managing the email traffic is also extremely important, especially in the immediate period before and then during the administration of graded assignments and exams. The class email listserv is an efficient method of communicating to all students. We assume that if we get similar questions from several students that it is likely that others will have it as well, so the answer goes out to the listserv. Students are also notified by email when class materials are (re)posted, which also serves as a means of reminding them about class responsibilities and requirements. However, we have learned to respond to each student individually even when his/her question have been answered in a mass e-mail. That personal attention has increased the perceived level of connection and engagement between the instructor and student.

ASSESSMENTS

At the end of every test, students are asked to complete a short survey and provide comments on the progress of the course. A survey on class logistics is given midway through the semester, and three end-of-course surveys are available, but not required, for students to complete. We always use our own survey tailored to the needs and format class. The other two surveys, administered by SEAS and CGEP, are standard surveys. These surveys gather some useful information, but our main data comes from the class survey. The other advantage of having our own survey is that we obtain responses from almost all of the students.

Table I present shows on- and off-grounds enrollments for the three semesters in which APMA 6430 was delivered in total asynchronous mode, and Table II presents the gender breakdown of those enrollments. It is interesting to note the 50% increase of on-grounds enrollment relative to the more stable percentage of off-grounds students between Spring 2010 and Spring 2012, presumably due to students disseminating the benefits of taking at least one required

course asynchronously given the "busyness" of their previously discussed schedules. The increase in the percent of females enrolled (55%) is comparable to the percent increase of males enrolled (50%), so a gender balance of sorts has been preserved. Additional time and research will be needed to determine the worth of this finding.

TABLE I
APMA 6430 ENROLLMENT – SPRING 2010 - 2012

| Spring | On Grounds | Off Grounds | Total |
|--------|------------|-------------|-------|
| 2010 | 19 | 26 | 45 |
| 2011 | 31 | 25 | 56 |
| 2012 | 47 | 21 | 68 |

TABLE II
APMA 6430 ENROLLMENT BY GENDER – SPRING 2010 - 2012

| Spring | Females | Males |
|--------|---------|-------|
| 2010 | 9 | 36 |
| 2011 | 14 | 42 |
| 2012 | 14 | 54 |

The comments reported here are from the CGEP survey for all three offerings of APMA 6430 from 2010 - 2012. The CGEP survey, since it asks the same questions from year to year, is the best source of comments that can be compared over time. The presented comments are selected but representative.

2010: Selected Comments

The convenience of online modules makes it possible for me to learn on my own time. This is extremely valuable since I'm on the road 80 percent of the time for work and this venue enables me to pursue an advance degree while working.

Completely recommending UVA progress with this pilot project and offer more courses through the methodology that was deployed for this course.

Great format adopted by Prof Larry. He actually worked hard and I think this format should be extended to other classes.

I felt that the online environment offered a relaxed and flexible environment for learning the course material. Initially, it was a bit tricky to set a pace for the material, but once the course was underway, this was less of an issue.

Inadequate turnaround time for graded materials

I liked most everything about the class, but I was generally a bit confused about the pace through different parts of the class. There were some very slow periods when no lectures or homework were due. Then the gates would open up and lectures and homework would be assigned.

2011: Selected Comments

I enjoyed having all the lectures at once and then a practically at your own pace course with specific deadlines.

I thought the idea of breaking the material into modules was very helpful and made the course more manageable. Also, being able to access the course lectures on my own schedule was beneficial.

My previous experiences showed serious deficiencies in both material preparation, as well as online access to materials, whereas this course (MAE 6430) was well prepared, and all materials were easily accessed from all the locations I used.

There was a set your own pace element to this class which was nice for a working/traveling professional. Also you could download the lectures to put on tablets so you can view them offline during plane rides and hotel rooms.

The only thing missing as opposed to in-class courses is that there was no peer-to-peer interaction or group projects. I tend to prefer these since, as a student, you tend to learn more when you participate in these types of projects. As I found out on the 3rd homework and 2nd test, I was unaware of several of the flaws in my understanding until seeing the results of my missed problems on a graded assignment.

2012: Selected Comments

This course was meticulously structured and very simple to follow from one module to the next.

30 minute asynchronous classes are much much MUCH easier to focus on and comprehend than 90 minute lectures.

The asynchronous delivery of this class was much preferred over live delivery of other classes

Comparing my previous on-ground course work, I haven't seen any downside of taking a course online. I even got the chance to pause and play any section of the lecture at any time.

The challenge is to stay engaged and the on-line format can be difficult if a student doesn't make a conscious effort to do this.

Most pleasant: Ability to take lectures whenever. (Ability to digest information in small chunks comes in a close second). Unpleasant: None.

Most pleasant aspect of this course is the flexibility in time management, which enables the student to spread learning out over day-to-day, or take large chunks of the class in a single setting. It was particularly helpful that all the classes were pre-loaded onto the COLLAB site, allowing maximum flexibility.

The CGEP surveys also contained several questions about the instructor's performance and student reactions to this course. The most relevant are summarized in Table III, following.

TABLE III
APMA 6430 STUDENT EVALUATIONS (SELECTED QUESTIONS), 2010 – 2012

| | 2010 | 2011 | 2012 |
|---|------|------|------|
| 11. Apparent knowledge of the subject matter | | | |
| Poor | -- | -- | -- |
| Fair | 1 | 2 | -- |
| Good | 2 | 12 | 7 |
| Excellent | 15 | 27 | 33 |
| 12. Success in communicating or explaining subject matter | | | |
| Poor | -- | -- | -- |
| Fair | 4 | 4 | 1 |
| Good | 5 | 20 | 19 |
| Excellent | 9 | 17 | 20 |
| 13. Degree to which subject matter was made stimulating or relevant | | | |
| Poor | 1 | 2 | -- |
| Fair | 5 | 7 | 5 |
| Good | 5 | 22 | 15 |
| Excellent | 7 | 10 | 20 |
| 15. Concern and respect for individuals as students | | | |
| Poor | 1 | 1 | -- |
| Fair | 2 | 3 | -- |
| Good | 5 | 16 | 10 |
| Excellent | 10 | 21 | 30 |
| 16. Administration of class and organization of materials | | | |
| Poor | 3 | 2 | -- |
| Fair | 3 | 7 | 3 |
| Good | 8 | 22 | 19 |
| Excellent | 4 | 10 | 18 |
| 17. Encouragement and management of class interaction | | | |
| Poor | 2 | 5 | 1 |
| Fair | 3 | 8 | 4 |
| Good | 11 | 23 | 19 |
| Excellent | 2 | 5 | 15 |
| 18. Responsiveness to inquiries outside of class | | | |
| Poor | 5 | -- | -- |
| Fair | 3 | 7 | 2 |
| Good | 4 | 19 | 17 |
| Excellent | 6 | 15 | 20 |
| 19. Overall rating of this instructor | | | |
| Poor | -- | -- | -- |
| Fair | 5 | 4 | -- |
| Good | 4 | 22 | 13 |
| Excellent | 9 | 15 | 27 |

The important conclusions to draw from the data in Table III are that both the course and instructor show improvement over the three iterations of the course to date. The content has remained unchanged, but we have learned to manage the environment, logistics, and relations with the students.

The change in responses to one question from the last two CGEP surveys is especially relevant: Based on the quality of your on-line experience this semester, would you recommend courses in this format to fellow engineering school students in the future? The responses are reported in Table IV, below.

TABLE IV
APMA 6430: WOULD YOU RECOMMEND THIS COURSE?

| | 2011 | 2012 |
|--------------|------|------|
| Definitely | 8 | 14 |
| Probably | 15 | 9 |
| Maybe | 4 | 1 |
| Probably not | 1 | 1 |
| Never! | 0 | 0 |

We clearly made real progress in the latest iterations of the course. There were fewer problems each year. In 2010, we attempted to grade the homework on-line with a tablet p.c.; we quickly fell behind and received complaints about the slow return of assignments. In the last two years, all homework is graded by hand; this traditional, “old-school” method is much quicker and more accurate. This change has been valuable as we have been able to add much more graded homework at the request of the students, and to provide feedback in a more timely manner.

MAIN BENEFITS AND CHALLENGES

Using total asynchronous delivery for a course can confer many benefits. For example, we receive emails from students viewing a particular lesson while waiting for a flight or between meetings. The ability of students to view class material at times that fit into their schedule and demands is a strong selling point. Total asynchronous delivery can also benefit non-native English speaking students; a certain topic can be replayed until understanding is achieved. Another potential benefit is that students can take the course outside of traditional offering times, such as over the summer. The logistics of such offerings are still being worked out.

Total asynchronous delivery can also be frustrating for both students and instructors. An on-grounds student can attend office hours and receive immediate feedback or pick up graded assignments and exam as soon as they’re ready; feedback for off-grounds students is typically delayed and delivered through impersonal methods such as email.

The shift to total asynchronous learning brought its own set of challenges along with the flexibility. Making connections among class members in the virtual community was a particular challenge. Keeping students on pace is

another. More detailed schedules and additional graded homework helped students plan their studies better.

STUDENTS’ REACTIONS TO THE CLASS AND ITS FORMAT

The level of acceptance of the on-line, on-demand lectures was surprising. On-grounds students, some of whom initially had misgivings about the change in format, are as happy with this format as off-grounds students. Referring to Table I, the increase in enrollment is driven by on-grounds students because the flexible schedule helps them meet other commitments. All students report high levels of satisfaction with the quality of the material, mode of dissemination, flexibility, and convenience. Student performance is comparable to that in previous semesters. Therefore, the switch to a totally asynchronous delivery method has not compromised student learning and accomplishment.

Providing a course in asynchronous mode does not remove the need for instructional support. In fact, instructional support is critical to positive student outcomes. Interaction tends to be more electronically-based than in person, with emails the predominant method. It is critical that the instructor is free to respond to student questions, develop assessments, and manage class progress. A teaching assistant / grader is essential to grade the homework and exams, and support is needed to coordinate the reception and shipping of materials to off-grounds students. The assistance of an education technology specialist was invaluable in the design and initial phase of module production. Therefore, personnel staffing needs are not diminished or removed because the classroom is now virtual; in fact, more personnel hours are likely necessary if course enrollment increases as per our experience.

CONCLUSIONS

This course is a work in progress. For the next offering, we will revise and update all the recordings and alter the pacing of the materials. By student demand we will condense the material at the beginning of the course, expand the coverage in the middle part and include greater coverage of the advanced material

For example, we participated in an e-text experiment with McGraw Hill this year. The textbook was available in electronic form and it could be annotated and highlighted by both students and the instructor. We are continuing the experiment this year and plan to make greater use of the features of the electronic book.

We would also like to develop asynchronous courses on multivariate statistics and quality control as funding permits. These topics were requested by students and industry contacts.

Finally, we would be remiss if we neglected to mention the degree to which the issue of online learning played in recent events at UVa; see, for example, [12]. It is critical that this debate be conducted from a solid base of evidence.

ACKNOWLEDGMENT

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TABLE V
APMA 6430 MODULES AND READINGS – SPRING 2012

| Topic | Module(s) | Chapter(s) |
|---|-----------|------------|
| Course Overview and Logistics | 1 | Scan text |
| Data Summarization and Visualization | 2 - 5 | Preface, 6 |
| Probability Basics | 6 - 9 | 1 - 2 |
| Discrete Distributions | 10 - 12 | 3 |
| Discrete Distributions | 13 - 14 | 3 |
| Continuous Distributions | 15 - 16 | 4 |
| Joint Distributions | 9 | 5 |
| Test 1 | 17 | -- |
| Estimation | 18 - 20 | 7 |
| Hypothesis Testing | 21 - 25 | 8 |
| Hypothesis Testing | 26 - 27 | 9 |
| Hypothesis Testing | 28 - 31 | 10 |
| Test 2 | 32 | -- |
| Correlation; Linear & Multiple Regression | 43 - 46 | 11 - 12 |
| Quality Control | 53 - 56 | 16 |
| Review and Look Forward | 103 | -- |
| Final Exam | -- | -- |

Helping engineering students develop skills in content-based problem solving workshops outside classrooms

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Abstract— This paper describes practices of the Supplementary Instruction (SI) Problem-Solving Workshop in helping entering engineering students develop the concept of problem solving and obtain the necessary knowledge and skills required to succeed in their courses.

Keywords—problem solving; content-based; peer-led; outside classrooms

I. INTRODUCTION

In an increasingly globalized and technology-driven world, engineers need excellent problem solving abilities more than ever. But reasons exist to doubt that many of today's engineering students are obtaining such abilities. Because students who enter an engineering school in a big research university such as the University of Wisconsin-Madison (UW-Madison) have passed through a very selective process requiring proficient knowledge and skills in mathematics and science, they are usually considered "high achievers." However, many studies find that some entering engineering students lack confidence when encountering new academic challenges [1]. These students often possess ineffective habits and skills, which hinder their learning. Researchers have identified deficiencies in problem solving skills as one significant learning obstacle college students face, leading to calls for instructional innovations to increase college students' practical problem solving ability [2]. The recently released DBER (discipline-based education research) report summarizes key findings on problem solving and includes an excellent literature review in the area [3]. The research examines how students use conceptual understanding to solve problems and investigates how spatial thinking and the use of representation facilitate or impede students' problem solving. Even though there is a large volume of research focusing on students' problem solving with well-defined problems, only a few studies took a deeper look at why beginning students get stuck in solving such problems [4]. There are some

observations of students' inability in problem recognition, yet in depth discussions concerning students' struggles when attempting to start the process of problem solving are still lacking.

Our current study uses results from student surveys to identify student learning needs and to discuss Supplemental Instruction (i.e. SI: Problem-Solving Workshop), specifically SI's outside-the-classroom strategy to facilitate learning problem solving skills within the course content. The survey results reveal that many students lack an intuitive concept of problem solving and that the SI program effectively helps them develop the concept. This study will argue that it is important for beginning engineering students to obtain an intuitive concept of problem solving and that engineering curricula thus need to provide well-structured activities to facilitate students' acquisition of the concept. To help students develop the concept, it is important for instruction to emphasize the role of domain-specific and metacognitive knowledge [5]. Failure to develop curricula that help students attain such a concept in their early learning stage will delay students' learning in problem solving, and will prevent students from reaching their full potential as engineers.

II. BACKGROUND OF THE STUDY

A. General information

The Supplementary Instruction Program (SI) in the College of Engineering at UW-Madison has a strong focus on the development of problem solving skills within the course content and shares some common practices established for SI at various institutions for different disciplines [6]. SI programs are designed to target traditionally challenging, so-called "at risk" courses. Currently, SI at UW-Madison is listed as a course in the timetable, InterEGR150-SI Problem-Solving Workshop, for zero credits. The college's Undergraduate Learning Center manages the program. SI supports a statics course, two calculus-based intro-level physics courses, and two dynamics courses; it is open to all students enrolled in these

courses. The SI session for each course consists of a small study group of 20 students that offers a peer-instructional, cooperative problem solving environment. The group meets for an hour session twice a week under the direction of the SI facilitator, an undergraduate engineering student who has completed and excelled in the course. Students spend the majority of a session's time working on problems within a smaller group of three or four students. SI facilitators provide worksheets with problems that highlight the important concepts. Most worksheet problems are well structured with course content constraints. SI facilitators assist with problem solving, lead group discussions, and also give a mini lecture at the beginning of each session [7].

B. Setting and methodology

(i) Post-midterm surveys to identify learning challenges

Periodically during the semester, SI encourages students to think retrospectively about their learning progress. Starting in fall of 2007, the SI workshop has routinely asked students to review their learning experiences after every midterm exam. Physics and statics courses have three midterms. One dynamics course has two midterms while the other has one. SI uses surveys to understand students' learning difficulties and to find better ways to help students. The survey questions regarding learning challenges are listed in Table (I). Responses were on a scale of 1-5 where "1" was defined as "a little bit difficult", "2" as "somewhat difficult", "3" as "difficult", "4" as "very difficult", and "5" as "the most difficult". Empty entries were considered as "not applicable". The analysis consisted of frequencies for each question and ratings of "4" and "5" were characterized as "very and most difficult" in this study. From fall 2007 to fall 2010, between 400 to 500 students responded to survey questions after the first midterm examination, 250-300 responded after the second exam, and about 90 after the third. In spring 2011, modifications for some of the survey questions were made. See Table II.

TABLE I. POST-EXAM SURVEY QUESTIONS (FALL 2007-FALL 2010)

| Label | Questions |
|-------|--|
| Q1 | Cannot figure out what concepts are relevant. |
| Q2 | Don't understand what the question is about (wording). |
| Q3 | Get stuck with computation. |
| Q4 | Difficult to identify equation. |
| Q5 | Don't know how to get started. |

(ii) End of semester surveys to assess learning progress

Surveys conducted at the end of each semester include three questions designed to assess SI students' learning gains in conceptual understanding of the course material and problem solving. A scale of 1-3 was applied to measure the degree of helpfulness of SI in these areas. "1" is defined as "least helpful" and "3" as "most helpful". Students were also asked to provide explanations about if and how SI workshops help them improve their problem solving skills.

(iii) SI facilitators' professional development and workshop teaching

All SI facilitators receive ongoing professional development and are required to attend class lectures as well as weekly training meetings for session planning. In the weekly meetings, peer instructors describe the main concepts covered in lectures, identify students' learning challenges, and present session plans and worksheet problems. SI facilitators typically receive constructive criticism from their peers and from the program director, who leads these meetings. Weekly training meetings have led to the production of a series of online teaching modules. In this study, we utilize a representative module to illustrate teaching in the SI workshop. The module captures crucial elements of SI facilitators' professional development as well.

TABLE II. REVISED POST-EXAM SURVEY QUESTIONS (SPRING 2011)

| Label* | Questions |
|--------|---|
| Q1 | Couldn't figure out what concepts are relevant. |
| Q2 | Didn't understand what the question was asking (wording of the problems). |
| Q3* | Didn't know how to interpret the diagram. |
| Q4 | Got stuck with computation (not proficient in math skills). |
| Q5 | Didn't know which equation(s) should be applied. |
| Q6* | Didn't know how to get started to solve the problem even though I knew which equations should be applied. |

Q* referrers to modified questions

III. RESULTS

A. Post-midterm surveys

Fig. 1 shows students' responses to the 5 questions about their learning difficulties (questions shown in Table I). The questions are intended to help students uncover areas that challenge them the most. Figure 1 displays the three main learning obstacles identified by students: (i) "Don't know how to get started", (ii) "Difficult to identify equation", and (iii) "Cannot figure out what concepts are relevant". Most students reported "Don't know how to get started" as a major challenge in all three midterms. The percentages of students who used "very difficult" and "most difficult" in responding to this question are shown in Fig. 1(e): 51% of the 425 for the first exam, 38% of the 217 for the second, and 40% of the 90 for the third. Figure 1(d) shows "difficult to identify equation" as another hurdle: 35% out of 476 for the first, 29% of the 294 for the second, and 51% of the 82 for the third one. Fig. 1(a) illustrates students' struggles with concepts: 32% of the 401 for the first exam, 39% of the 265 for the second, and 25% of the 72 for the third. In the end of the semester, students significantly improved their conceptual understanding of the course content and confidence in starting the problem solving process. However, no measurable gains in their ability to identify equations in the process have been observed.

Fig. 2 displays the spring 2011 survey results of three of the six questions listed in Table II. The rating for the survey used a

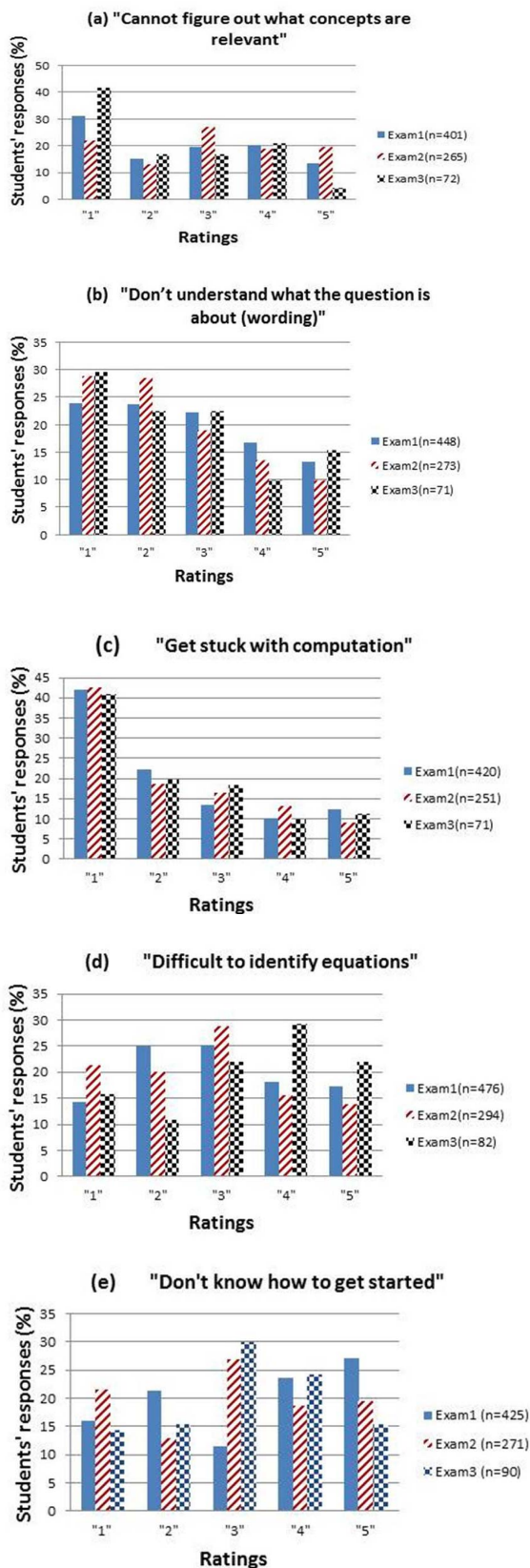


Figure 1. Survey results (Fall 2007-Fall 2010)

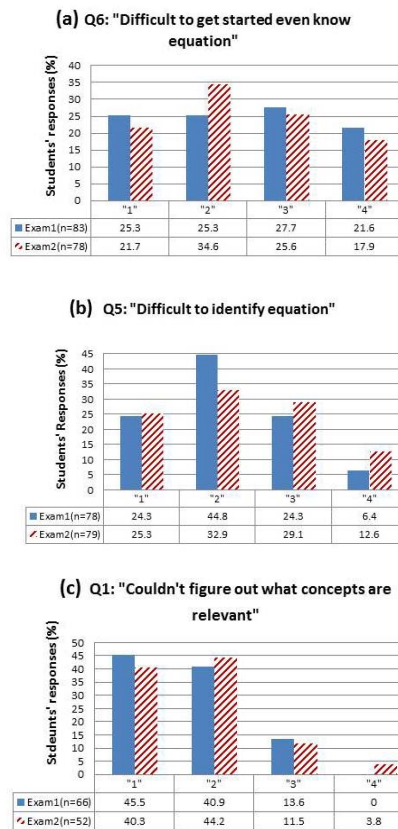


Figure 2. Selected survey results for Spring 2011

scale of 1-4 where "1" is defined as "a little bit difficult", and "4" is "the most difficult".

To gain greater specificity in the survey questions, some statements were revised in spring 2011. For example, because many students consider problem solving merely a process of "matching equation with the problem," we speculated it was likely that a number of students who indicated they did not know "how to get started" really struggled to "identify which equation to use" [8]. We also wanted to know whether some students answered that they "did not know how to get started" because of their inability to interpret a diagram. In the revised survey conducted in spring 2011, "Didn't know how to get started even though I knew which equations should be applied" got half of the 83 responses with ratings of both "very difficult" and "most difficult" for the first exam, and 31% of the 78 for the second exam, and the ability to interpret a diagram was not the cause. These results are consistent with what is shown in Fig. 1(e). Students continued to indicate that "identify equation" is "very" and "most" difficult.

B. End-of-semester surveys

Table (III) shows students' ratings of three questions about their learning gains in conceptual understanding and problem solving skills after attending SI workshops. Average ratings, used

in this table, are converted to a percentage for the purpose of display. That is, a score of “1” is equivalent to “33%”, and “3” is “100%”. All three questions drew ratings of 87% or higher. Students’ answers to the free response question regarding their views of why and how SI is helpful in fostering true learning are generally encouraging. While almost all reported positive learning gains, some indicated that SI had helped them master problem solving in an organized and systematic way as we hoped. These results will be discussed in the concluding section.

TABLE III. IMPROVED LEARNING IN SI WORKSHOPS (SURVEY RESULTS, 2001- 2010)

| Survey questions | n | Percentage |
|---|------|------------|
| Instructions from the facilitator are helpful. | 667 | 93% |
| Facilitated discussions in SI help me learn how to solve problems | 667 | 92% |
| Discussions in SI help learn course material | 1074 | 87% |

IV. INTERPRETING RESULTS

A. Students lack an intuitive concept of problem solving

More and more instructors are aware that students rely on memorization when faced with learning challenges, but only a few instructors are aware of why it is happening in students’ learning [8]. In the survey results, students particularly expressed concern regarding their learning difficulties in three areas. The survey results shown in Figures 1 and 2 indicate that students need help in (i) learning basic skills of problem solving, i.e. skills to start a process, (ii) gaining conceptual understanding of the subject matter, and (iii) understanding how and why equations they study in class can be applied to solve problems. It is not surprising that students who struggle to grasp conceptual understanding in physics and engineering physics courses have difficulties identifying the appropriate equation to apply. However, it is alarming that more than half of the 425 students indicated that “don’t know how to get started” was the main problem during their first exam. Some may argue these three items are connected and influence one another. So, if our teaching focuses on learning concepts, students should be able to overcome hurdles and learn how to apply equations to solve problems. Nonetheless, students continued to report challenges with “problem solving” even though they indicate that they know the equation (see Figure 2). In fact, research in physics education provides evidence that vindicate students’ concerns. Researchers have found significant improvement in conceptual understanding in studio style classrooms, but no observable gain in problem solving skills. It suggests that if we want students to be proficient, we must teach concepts and problem solving skills together [9]. Why do students struggle with basic “problem solving” skills? Our observations suggest two explanations: (i) misconceptions of “problem solving”; (ii) students’ prior learning experiences in “problem solving”. Quite often, the terms “solving a problem” and “problem solving” are used interchangeably, leading to misconceptions about learning. Essentially, solving a problem refers to the conclusion stage of a larger process of “problem solving” that includes the procedures of defining and

framing a problem [10]. Problem solving requires higher levels of cognitive thinking and skills. Unfortunately, many students consider problem solving as nothing more than finding a solution. When they fail to reach a conclusion using for example, “matching equation and problem” approaches, they are left no choice [8]. The students’ sentiment that they “don’t know how to get started” indicates that a very important component in problem solving is missing: an intuitive component. In other words, students who actually possess a good deal of knowledge often seem clueless when encountering a new and unfamiliar problem because they have not had enough exposure to situations in which they are encouraged to use logic and analytical methods to find answers or explanations. Students need to uncover their spontaneous analytical ability while developing the concept of problem solving. The first step in teaching problem solving is to help students understand that problem solving requires more than finding a solution.

B. Integrate instruction- and problem-based approach

How do we teach problem solving? SI, a peer-led workshop to teach problem solving, is an effective strategy to help engage students in a life-long learning process. First, SI helps take away stigmas some struggling students may possess. Many students are less intimidated seeking assistance from a peer to whom they relate easily than from an instructor in a big lecture hall. Second, problems which integrate course content in the workshop add incentives, keeping students motivated and interested in learning. Problem solving requires students to integrate factual, conceptual and procedural knowledge within the content, and helps students gain necessary skills to succeed in the course. Third, using well-structured problems allows SI workshops to direct students’ attention to the concept of problem solving. SI helps students become familiar with the procedures of defining and framing problems. Students have to build a strong belief in “problem solving” and understand that solutions draw on logic and analyses to solidify the concept.

SI workshops align teaching and learning goals by using a teaching method that combines instruction- and problem-based approaches. Guided by an understanding of students’ learning difficulties, each SI session reinforces important concepts to help students harness various topics taught in the class. Illustrations of how to break down a problem step by step show students ways to define and frame a problem. SI instructors work very hard to balance the need for instruction and hands-on practice to facilitate true learning. SI workshops introduce a problem solving framework, shown in Figure 3, which helps novices break the barrier of “don’t know how to get started” [2, 11,]. Applying the framework properly can keep students on track by showing them how to analyze problems instead of rushing to reach a numerical solution. To many beginners, the framework is a useful reference when they come across different aspects of problem solving: the meaning, the nature, and the solution of a problem. Instructional strategies applied in SI are based on a systematic approach of cognitive apprenticeship developed by Collins, Brown, and Newman [12]. This model has been effectively applied to teaching complex tasks in physics and other

disciplines [13]. Even though some of the problems used in the workshop ask for one solution, there are multiple ways of defining, rephrasing and representing these problems. Exercises like these allow students to establish and test various strategies for problem solving. Teaching and learning that focus on developing an intuitive concept at an early stage of engineering education will have a lasting impact on students' skills. For one, it will help students avoid, or at least minimize, adoption of the default "trial-and-error" approach when confronting real-world situations. Sometimes the "trial-and-error" approach is necessary. Yet, as engineering educators

C. A concrete example in SI workshop teaching

The SI program's online teaching module, "the framework of problem solving", highlights important strategies of SI instruction [15]. Like other aspects of engineering learning, developing problem solving skills requires students to comprehend knowledge in a constructive and organized way. Students need to integrate conceptual and procedural knowledge, and constantly assess and reflect on their learning progress. This module provides one concrete example of how SI students are taught to apply the framework.

Although facilitators typically introduce the problem solving framework in the SI workshop at the beginning of the semester, the online module is a representative illustration made available to students to reinforce their exposure to this important topic [15]. The "three-legged race" problem used in the module (Fig. 3) highlights logic and an organizational matrix, which can be generalized and applied to more sophisticated situations. The way the material is organized and delivered, as displayed in the module, provides the students with a framework that the facilitator will refer to throughout the semester using examples based on course content. By encouraging students to approach problems using the problem solving framework, SI helps them make connections to applications outside the classroom.

SI facilitators created other online-teaching modules for subject matter students typically found difficult to learn. These "difficult" topics are also important for subsequent engineering courses for example, mechanical properties of material as well as other courses [15].

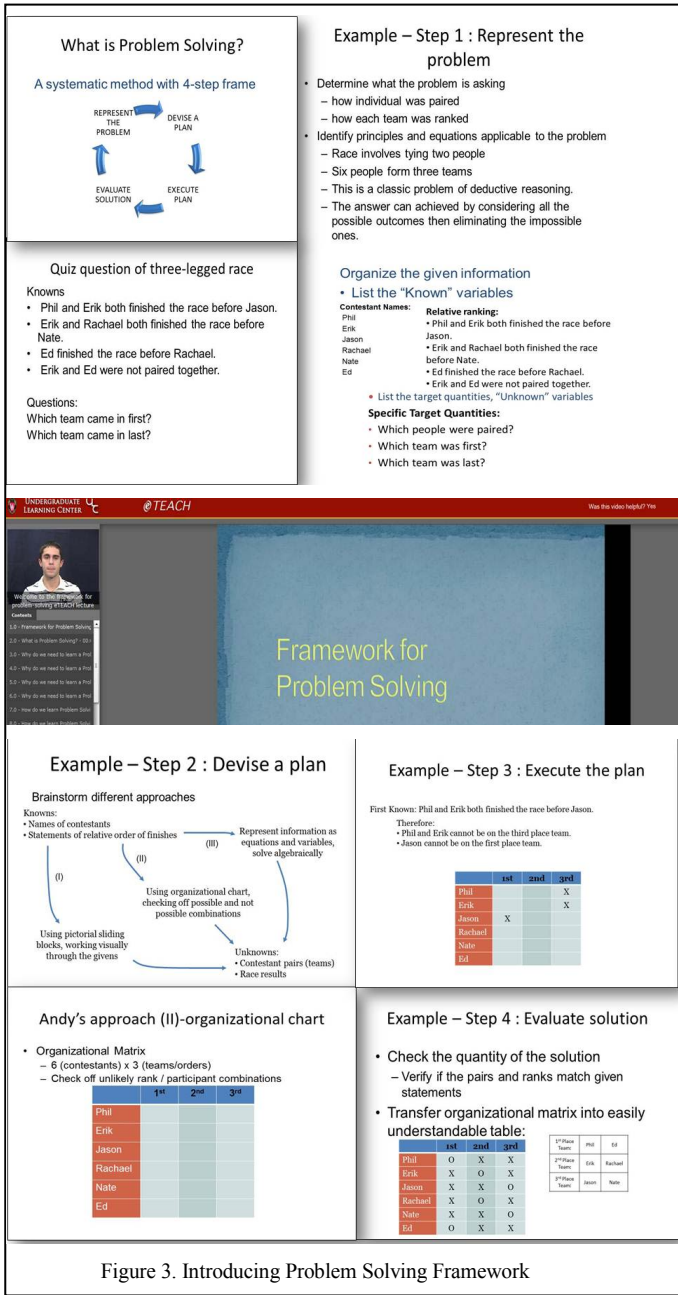


Figure 3. Introducing Problem Solving Framework

observe, it is not productive if used frequently [14].

V. CONCLUSIONS AND FUTURE PLAN

Due to space limitations, we present here just a few SI students' comments that are representative of those collected in the end-of-semester surveys. These comments provide insights into why SI is helpful and highlight core education values that SI has embraced since it started more than 10 years ago.

- During SI sessions, I learn how to, in an organized and logical way, approach the highly complicated problems in this class.
- In SI, my facilitator does an excellent job explaining how to set up a problem from the beginning in order to reach the correct solution within a short amount of time.
- SI helped me thoroughly learn concepts instead of just going through the motions of doing the homework.
- SI made me much more confident in my ability to do the problems and more confident in what I knew going into exams.

The positive learning outcome is also confirmed by the shrinking number of students who struggled with challenges of "did not know how to get started" in problem solving by the third exam, from 50% to 38%-40% as shown in Fig.1(e), and from 50% to 31% in Fig.2(a). Students' comments also highlight several contributing factors to the success of SI workshops, including students' engagement, a supportive

learning community, aligned teaching and learning goals, effective pedagogies and teaching techniques, and critical roles that facilitators play [7].

With an improved understanding of what underlies students' learning challenges in problem solving, the SI workshop applies content-based problems to align teaching and learning goals for entering engineering students. Without a strong foundation of intuition about problem solving, teaching and learning will be difficult and unproductive. The intuitive concept of problem solving developed in students' early learning is effective not only in engaging students in learning, but also in facilitating skill transfer. The effectiveness of instructional approaches applied in the SI workshop is due in part to the concept of metacognition while focusing on mastering content knowledge [5, 16]. The SI workshop contextualizes instruction to help students develop problem solving concepts and skills.

The current study also indicates several areas in which SI can improve. When asked in our surveys if they feel comfortable learning concepts on their own, only 65% of the 445 participants responded positively. In addition, as displayed in Fig.1(d), students continue to report difficulty finding and applying relevant equations even when they are equipped with the framework for problem solving. Research indicates that students' struggle in this area is caused by their misconceptions about the nature of the solution process [3]. SI plans to help students to improve skills in problem representations and gain deep understandings in concepts and principles, including more activities to help students confront their habits of "selecting and sequencing equations" during the process. These skills are important for a creative learner, and will help students make transitions from encountering content-based problems to real-world problems. Students need to learn how to solve open-ended and ill-structured problems [17, 18]. Problems that simulate and represent real-world situations are critical to help advance their knowledge and skills, and help them become innovative problem solvers. Engineering curricula need to provide learning activities that are tailored to meet students' learning challenges at every stage of their learning.

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Work In Progress: How student use Lecture Notes in an Operating Systems Course

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Abstract—In our Operating Systems course we make available in advance the lecture slides and lab sessions material. The slides are built paying attention to present the key ideas and with embedded links to sites in the Web where the topic is covered in greater detail. We also provide the corresponding excerpts of selected textbooks. Following the download activity and paying attention on what our students are doing during the lectures, we are able to collect some data on notes usage. By carefully selecting some questions in the test we can distinguish which student used the material available in links and excerpts. In this paper we present some patterns of use of the lecture notes. est

Student Notes; Hypertext; Student Attendance; Operating Systems

I. INTRODUCTION

In a classical work [1] a description of the potential benefits of note taking and reviewing is presented. Note taking and reviewing are labeled in the literature as *encoding* and *external storage* respectively. *Encoding* is described as generating a personalized written record of the lecture or the class activity. *Storage* is keeping this written record during the gap between presentation and evaluation and use the record for review or study guide.

There are several studies on the benefits of both functions [2] [3] with the storage function having an apparent greater impact. However these researches are related to the humanities. In Science, Technology, Engineering, and Mathematics (STEM) the storage function appears more standardized and is supplemented by other course materials, mainly books and Internet available information.

The potential productivity of reviewing notes is limited by the encoding function of the note taker. If key ideas are missed or misinterpreted, students start at a disadvantage when reviewing the material. In addition, students are notoriously incomplete note-takers, generally recording less than 50% of the critical ideas [2] [3]. These facts are addressed by providing students with instructor's notes.

Providing that notes are to be made available to students, there is a question concerning the detail of the material. Some teachers use skeletal notes in the form of slides, supporting a further development of the subject. This detailed development can be made in the lecture. If the

student does not attend to the lecture, she/he is supposed to search more information in order to force a personal encoding of the provided key ideas. This approach can lead to a surface learning-strategy where students tend to rote-learn by heart repeating only the provided key phrases with no further elaboration. The opposite approach is to provide detailed notes which are close to textbook detail.

II. INSTRUCTOR'S NOTES FOR STUDENTS

We decided to make available to students the slides we use to develop our lectures in the basic theory track. There are skeletal notes with the key ideas hoping to complement the coding function of note taking. As for helping with the storage function two levels of details are added to this first skeleton: embedded links in the slides to selected web pages and excerpts of the course recommended books. As a final information source, course main and consulting books are available at the institution's library.

The slides notes follow the same pattern we do when we explain the subject in class. The hypertext links are real world examples or more detailed explanations of these key concepts. Slides are projected during the lectures and selected hyperlinks were explored and augmented with searches leading to videos, animations, and other material. When real world examples are wanted, product logos are inserted in the slides and links to product descriptions are used. After some time the linked pages migrate and finally we decided to link Wikipedia pages as an intermediate step.

III. HOW STUDENTS USE THE MATERIAL

Mean enrollment in the course is around 80 students. There are very few drop-outs. Attendance to lectures is not mandatory and when students get the idea that the whole subject is covered by the material with no "hidden surprises" they begin to skip classes. In end of course surveys, other courses pressure and homework are blamed for this desertion. Usually we move after midterm to a lesser Lab with a capacity for 30 stations. We call this use of notes as substitutional use because students believe that a careful study of the material can substitute classroom attendance. By the end of the term, attendance was reduced to a 30% of the enrolled students.

This study was supported with the grants I333 and I226 from the University of Buenos Aires, Argentina

Figure 1 shows attendance rates in the two 2011 terms. The very low rates at weeks 9 in the first and week 10 in the second term reflect other subject's homework deadlines. In average we have half of the enrollment attending lectures. We consider high attendance students to those who attended at least to six out of twelve classes.

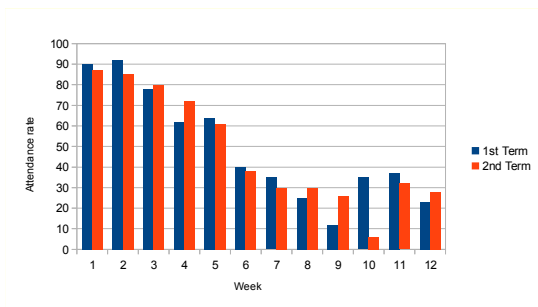


Figure 1. Week attendance rate

Other students use the material as a supplement or a guide for their study, according to their learning style. In spite of our use of annotation tools, and specifically addressing these kind of tools in our lectures, very few students made use of electronic annotations, most of them after our presentations. Not even do they use text editors on the provided computers.

We do not tape the lectures or the lab sessions. Students are very concerned about their privacy and recording the session is seen as intimidating. However we observed that many students brought printed copies of the slides. It seems that a printed copy defeats the whole purpose of the hypertext.

Some of the students annotate the slides explaining in their own words the meaning of the key ideas. Other highlight when we followed some links and in some cases the URL are copied. All of these activities can be made automatic using tools like the ones we use in our presentations. We expected students to annotate their pdf version of the slides and to use some cloud storage system like Dropbox to made them available later at home but this behavior was seldom observed.

IV. GRADES

In the following sections we use a three pass grades scale. These are not the final grades the students got because the final grades are obtained using a mix of the test, the team work performance and scripting midterm examination.

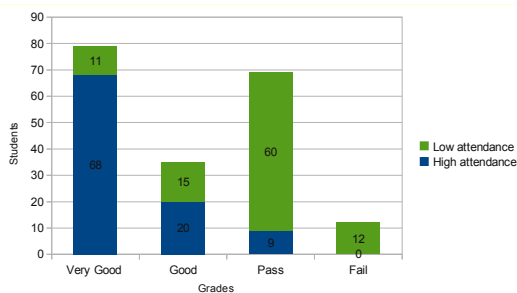


Figure 2. Attendance and grades in 2011

Very few students fail the test. Actually the number has been steadily increasing in the last years. Operating systems

is a subject at junior level and students are well trained to know when they are to ready to pass the test.

In Figure 2 we plot the attendance and the earned grades. The figure shows clearly that the substitutional use of the provided material is not a good strategy if a student wants to earn a good grade. In our country motivations for a good grade are more intrinsic to the student than institutional. There is no honor program or GPA.

In surveys completed online after they approve the subjects, students acknowledge the importance of class attendance. They find a greater engagement with the subject in the face to face interaction. However working only with the material pays for students who actually are not able to assist to the lectures and have a real interest in the subject.

In order to know if the links embedded in the slides have some effects, some questions ask for material addressed in the first order links. Figure 3 relates the reading with the grades.

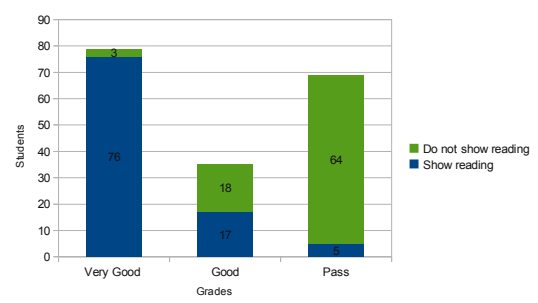


Figure 3. Reading the material of the embedded links and/or books

Answers that show the use of links also show the use of textbooks. It is clear from the style the answer is written and the precision the used technical jargon. Interesting enough, we found no mention of the commercial products we refer to in slides using logos and links

V. CONCLUDING REMARKS

There is little doubt that the coverage of the material is useful for the students at least in two ways; students are able to pass the course without attending to the lectures and students who really are engaged get the supplemental material they want.

Students do not show advanced technology uses in our lectures. This is opposed to the idea of the 'digital natives', a generation of tech-savvy young people immersed in digital technologies for which current education systems cannot cater. Further research is needed but some confirmation of this trend is beginning to show up in the literature [4] [5]. Students seem to look to their lecturers for clues as to how to use technology tools for learning.

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Assessment of Self-regulated Attitudes and Behaviors of Introductory Programming Students

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Abstract - Great emphasis has been given to the cognitive and methodological aspects of learning and teaching programming. Nevertheless, research shows a significant correlation between student self-regulation and academic achievement in higher education. The Attitudes and Study Behaviors Inventory (IACHE) is a multidimensional inventory that integrates in its design behavioral, affective-motivational and cognitive aspects of learning. This paper presents the results obtained from the application of the IACHE inventory to 190 introductory programming students from Brazil and Portugal. Data suggests that Brazilian and Portuguese students have very similar attitudes and behaviors regarding learning strategy, self-efficacy perception and study activities' organization, which seems to suggest that the same type of students choose undergraduate computing programs in both countries.

Keywords – *Self-regulation; Behavior; Motivation; Cognition; Achievement; Programming, IACHE.*

I. INTRODUCTION

Teaching basic programming in higher education is one of the greatest challenges of computing. Many students entering computing degree programs have their first contact with programming in their first semester, and are faced with the need to develop a logical/algorithmic reasoning, to learn about a new technology and acquire knowledge about a new language's syntax and semantics, in addition to dealing with their transition from high school to university. Given this scenario, it is not a complete surprise that these courses have been globally responsible for large failure and dropout rates in undergraduate computing programs [1].

Although great emphasis has been given to the cognitive and methodological aspects of learning and teaching programming, research shows a significant correlation between students' self-regulation and academic achievement in higher education. According to Zimmerman [2], self-regulation

implies personal knowledge and motivation to make deliberate use of skills to act. In school, self-regulated learning involves the regulation of three main aspects of academic learning: *behavior*, which involves the active control of the many resources that students have available to them, such as their time and study environment; *motivation*, responsible for controlling and changing motivational beliefs such as self-efficacy and goal orientation, so that students can adapt personal resources to their school settings' demands; and *cognition*, which involves the control of several cognitive strategies implied in the learning process, such as the use of deep processing strategies [3]. In the following, we will focus on how each one of these regulatory dimensions of academic learning is related to students' academic achievement.

(i) *Behavior*. Starting in elementary school and throughout schooling, students face several tasks, contexts and learning methodologies that help them develop their study behavior, helping them find a learning approach that best fits their personality, beliefs and values. They set goals to be achieved, select resources, and implement strategies to tackle specific learning tasks [2]. In this context, study skills and academic learning approaches include, for example, time management, use of information resources, taking notes in class, communicating with teachers, or even, preparing for and taking examinations. In their meta-analysis, Hattie, Biggs and Purdie [4] conclude that if we aim to improve academic achievement and increase academic success in higher education, institutions must foster interventions directed at students' learning strategies.

(ii) *Motivation*. Understanding motivation to learn requires a deep analysis of the socio-cognitive components associated to personality (identification with the institution, chosen program, vocational project and career, accessibility to teaching, analysis of school success) and the quality of relationships in life environments (social identification and learning approaches) [5]. The motivational dimension has a great impact on the individual's cognitive development and is a determinant factor

for success in the learning process [6]. It is motivation that fosters in the student the disposition to want to progress and reach the goals that were set, maintaining an adequate level of volition to overcome the demands that are being dealt with [2].

(iii) *Cognition*. The interaction between motivation and cognition positively impacts students' academic performance [7]. Furthermore, students who have a more adequate approach to learning and who are more motivated, elaborate more positive cognitions regarding themselves in the long term, increasing their chances of academic success [2]. In other words, such students build self-efficacy beliefs, which are influenced by their motivation and affect their judgment about personal ability to perform a task in a specific domain. In learning situations, self-efficacy influences the use of efficient cognitive strategies while solving problems, the amount of effort expended, the type of coping strategies adopted, the level of persistence in the face of failure, and the performance outcomes [8].

Based on these research findings, the "Attitudes and Study Behaviors Inventory" – *IACHE* (in Portuguese, *Inventário de Atitudes e Comportamentos Habituais de Estudo*) [9; 10], a self-report questionnaire, was developed by a Portuguese research group to assess behavioral, motivational and cognitive factors related to students' study habits and learning approaches in higher education.

Considering the difficulties, failure and dropout rates experienced by introductory programming students, and having in mind the impact of self-regulated attitudes and behaviors in academic achievement, we have used *IACHE* to assess Brazilian and Portuguese university students. Despite the clear differences between both countries, the programming learning-teaching scenario has some aspects in common, namely high failure and dropout rates, hence the interest in analyzing what students from Brazil and Portugal share in common and what sets them apart, in order to identify possible clues to successfully intervene on these issues.

II. BRAZIL AND PORTUGAL, TWO REALITIES

Content delivered in introductory programming courses is very similar in Brazil and Portugal, despite the realities inside the classroom in both countries being very distinct. In the last few years, the Federal University of Goiás, in Brazil, and the University of Coimbra, in Portugal, changed the way introductory programming courses had been historically taught in their institutions. The reasons that have led to such changes varied, as well as the new chosen approaches, as presented in the following.

A. Federal University of Goiás (Brazil)

In 2008, Problem-Based Learning (PBL) with tablet PC support was introduced in the Computer Programming 1 course of the Bachelor in Computer Science's program of the Computer Science Institute of the Federal University of Goiás (UFG), in Brazil, to minimize the recurring problems of students' low achievement, high dropout rates and lack of motivation [11].

The forty students that enter the program are divided in two groups of twenty, so that each student can have his/her own tablet PC. The laboratory used to teach the course is composed of four trapezoid-shaped tables with up to six students each. Each student is provided with a tablet PC with the necessary environments installed. Besides the professors, one for each class, there is a teaching assistant for each class, usually an undergraduate student, to help during class and in specified hours after class, with a weekly workload of 12 hours.

In the classroom, the PBL method [12] is used to introduce the concepts in the course syllabus as a series of open-ended problems, using a method adapted from Nuutila, Torma and Malmi [13], according to which groups of four to five students work collaboratively to reach a solution to the proposed problems. The description of a problem is given to each group; students are given approximately 40 minutes to discuss among themselves possible ways to solve the problem, relating it with the knowledge they already possess and identifying topics for which they need more information or with which they are not yet familiar. After this "brainstorming stage", students filter their ideas and the group identifies learning objectives that represent knowledge they must have to solve the problem and that must be researched/studied. Outside the classroom, students work individually each of the learning objectives, and are not allowed to divide their task. Having obtained the necessary knowledge to solve the problem, students gather again to propose a joint solution, obtained from suggestions and individual solutions from each one of the members of the group. The resulting algorithm is then implemented. This process can take a week or more, depending on the complexity of the problem. Eventually the teacher can give a lecture addressing issues that were misunderstood by the students or to complement the learning objectives proposed by the groups.

The course is divided in two parts: the first using only the SICAS environment [14] for flowchart diagramming, and the second using the DevC++ environment. The SICAS environment allows students to draw flowcharts that are then automatically translated to C or Java. The system offers a drag and drop environment with constraints that guide the students in the algorithmic definition of the problem, contributing to the learning process. All basic programming concepts are discussed in the first phase, and again in the second phase. The first part extends for about a month and a half, while the second part lasts 3 ½ months. In each stage, several distinct problems are proposed. Examples of these problems include defining a calculator or implementing games such as Battleship and Pac Man.

This course is offered in the first semester of the program, with a total of 64 hours in the classroom (32 encounters of 2 hours, twice a week). Attendance is mandatory. Students that are absent in more than 25% of the classes fail the course. To be approved, the students must achieve a minimum of 5 points, in a 0-10 scale; these points are distributed by the activities of the course, and the teacher has autonomy to define the distribution. In the last few years, the distribution that is being used is: 20% for individual participation in class and exercises, 20% for group solution of problems, 30% for the mid-term exam, and 30% for the end-term exam.

B. University of Coimbra (Portugal)

In Europe, one of the most important recent events in the educational sphere has been the evolution and adaptation of universities to the Bologna Process, which led to the creation of a European Higher Education Area (EHEA) with unified strategies and development goals [15]. Within this new reality, the University of Coimbra (UC) has adapted its programs to conform to Bologna Declaration since 2005 [16]. In some cases, this means classes with a greater number of students and the standardization of some courses so they can be attended by students from several programs, which accounts for an expressive heterogeneity of student profiles in some of them. This is the case for the introductory programming disciplines. Students from the Bachelor's Degree in "Engineering and Information Technology" – LEI, in the Faculty of Science and Technology of the University of Coimbra (FCTUC), attend classes where the number of enrolled students is usually very high: between 200 to 300 candidates, who come from several programs such as "Industrial Engineering and Management" and "Communication and Multimedia".

In the new curriculum, introductory programming was divided in two courses: "Introduction to Programming and Problem-Solving" and "Principles of Procedural Programming" – PPP. The first was proposed as a transition programming course designed to present the first programming concepts to the students in a problem solving context using Python. This course is followed by "Principles of Procedural Programming" – PPP, the second programming course of the LEI program, aiming to support the basic problem solving knowledge acquired in the first semester which is taught using ANSI-C. There is no pre-requisite, which explains the high number of students enrolled in these courses.

Although the PPP course accepts students from several programs, the whole course was designed to fit the LEI students' profile. The program includes basic programming knowledge for understanding the ANSI-C programming language (1999 standard), memory management, pointers and algorithms for fundamental data structures. The course is based on content presentation lectures and more applied classes, where students can practice what they have learnt from lectures, with evaluation points done using small practical programming challenges done in pairs. Classes in the UC are usually organized into:

- (i) Lectures (2 hours). All students enrolled in PPP have class with a coordinating professor responsible for the subject;
- (ii) Practical sessions (2 hours). The class is divided in smaller groups in order to do hands-on lab exercises under the supervision of a teacher, who may or may not be the lecturer, depending on the total number of enrolled students and the capacity of the laboratories. These groups have usually 20 to 30 students, with a total of 10 to 14 groups for each course, and involve 3 to 4 teachers, in addition to the coordinating professor;
- (iii) Practice-Lab Sessions (2 hours). These are not classes *per se*, but support sessions in which the students have study guides, reinforcements and clarification of doubts, with the aid of a tutor, usually a graduate student.

With the exception of practice-lab sessions, which are not mandatory, all classes require advance registration and attendance, except from working students. Besides classes, the activities developed during the course included: 10 exercise lists to be implemented in the practical sessions (with the designation of some exercises to be presented orally), a theoretical evaluation, a mini-project and a final exam taken at the end of the course. All activities are scored, and students must achieve a minimum of 10 points in a 0-20 scale, in order to be approved in that subject. To qualify for the final exam, each student must obtain a minimum frequency and grade that is equivalent to 35% of the points attributed to the activities. For those that do not succeed in the final exam, there is a second chance with a "special season exam". However, even amongst those who have the right to take the final exam, there are approximately 40% that choose not to take the exam because almost all exams occur in the same period and the students choose to study for those that they believe they have a better chance of success in. Furthermore, many students who failed "Introduction to Programming and Problem-Solving" enroll for PPP, as there is no pre-requisite and enrolment is done once a year. However, most of these students dropout in the first month, or right after the first exam is taken.

III. GOALS OF OUR STUDY

With our study, we aimed to use IACHE to assess Brazilian and Portuguese university students. We believe that the analysis of data obtained from IACHE can provide some important information about the attitudes and behavior of students, individually and in groups, and shed some light on cognitive and motivational aspects of programming students' profile.

Our main research goals were to:

- (i) Apply IACHE to introductory programming students in Brazil and Portugal and estimate the psychometric proprieties of this instrument;
- (ii) Identify possible differences between the profile of introductory programming students in Brazil and Portugal;

IV. METHOD

A. Participants

A total of 190 students – 72 from UFG (in Brazil) and 118 from UC (in Portugal) – participated in our study. To have a more homogeneous profile of our sample, we chose only UC students enrolled in PPP that come from the LEI program, as this program has a similar objective and structure as the Computer Science program of UFG. Furthermore, we chose to evaluate students from the PPP course that occurs in the second semester, as the course uses an imperative language, similar to the one used by the UFG students.

In UFG, testing was done in 2009-2, 2010-1 and 2010-2, always at the end of the course. In the Brazilian sample, 23 students were assessed in 2009-2, 31 in 2010-1 and 18 in 2010-2. On the whole, 63 were male and 3 were female (6 did not identify their sex). The sample ranged in age from 16 to 26 years ($M = 18.5$; $SD = 1.68$). IACHE was administered to

students who had just completed or were completing the first semester of introductory programming.

In UC, testing was done in the beginning of the second semester of the 2008/2009 school year. From a total of 320 enrolled students in the PPP course, 244 were from the LEI program of which 118 answered the inventory. Of these, 109 were male and 9 were female. The sample ranged in age from 18 to 31 years ($M = 20.0$; $SD = 2.73$).

B. Procedures

IACHE was applied collectively, in a classroom environment. Students were informed about the study purposes and assured about the confidentiality of their results. Participation was voluntary and there was no financial compensation.

C. Instrument

The instrument used in our study, IACHE – “Attitudes and Study Behaviors Inventory” –, was administered to assess behavioral, motivational and cognitive aspects of students’ study habits and learning approaches. This multidimensional inventory integrates in its design three main factors: *behavior* (concerning actions, daily routines, time management and study materials), *motivation* (concerning commitment, interest, involvement and progress in the study) and *cognition* (concerning personal perceptions, strategies or approaches to learning). Regarding the learning approach, IACHE allows to contrast between a superficial and a comprehensive approach to learning: the first focuses on the memorization of information; the latter emphasizes a more significant learning and understanding of learned contents. According to these factors, IACHE is divided in five sub-scales:

- **Comprehensive Learning** - using reflection and analysis in depth of content, which means more effort and time spent by the student in learning, who is focused on understanding (10 items, $\alpha = .86$);
- **Surface Learning** - tendency to spend a minimal effort to learn. Learning is superficial, based on memorization and reproduction of contents (8 items, $\alpha = .81$);
- **Intrinsic Motivation/Involvement** - the availability for study activities, primarily related to requirements of intrinsic motivation (8 items, $\alpha = .83$);
- **Study Activities Organization** - examines the evidence of structured activities and study. Focus on how students organize and manage their study (time, materials, etc.) (10 items, $\alpha = .83$);
- **Self-efficacy Perception** - personal perceptions about capacity to succeed in the academic tasks, self-concept, expectations, etc. (8 items, $\alpha = .80$).

IACHE is composed of 44 items, distributed in the five dimensions previously described. Items are presented in a six-point Likert scale, according to the degree of agreement (1 = “never” and 6 = “always”). In the parenthesis associated to each dimension description above, the distribution of these items can be found, along with the value of Cronbach's alpha,

used as a measure of the internal consistency or reliability of a psychometric test score for a sample of examinees, associated to each dimension. Values above .80 indicate good reliability. According to preliminary studies (see [10]), the factorial analysis and internal consistency of the items of IACHE have shown satisfactory results (Cronbach's alpha coefficient ranging between .80 and .86).

V. RESULTS

Before comparing the results obtained in the sample from Brazil and Portugal using IACHE, it was necessary to test the validity of the scale. This was undertaken through a factor analysis of the internal structure, in order to see if the items grouped alike in the two countries. Even though theoretical background, as well as preliminary studies of IACHE, assumed the existence of five dimensions, the factor analysis of our data captured three dimensions that can be interpreted with a minimum of coherence. Each one of the factors attained the 5% minimum variance criteria (Kaiser criteria), explaining together a total of 45.7% of the variance. Thus, there were identified three dimensions explaining what is common to both countries, which was used to test the hypothesis of the existence of differences between Brazilian and Portuguese students.

The items that did not meet a minimum of 0.5 factor loading criteria were eliminated. A closer analysis of the items associated to the three identified factors revealed that they correspond to the items originally associated to the *Study Activities Organization*, *Comprehensive Learning* and *Self-efficacy Perception* sub-scales proposed by the theory underlying IACHE. Hence, although the original factor analysis did not replicate the theory, some level of validity may be given to these three factors.

Following, a score per subject was calculated for each one of the three dimensions. This was done using a regression factor analysis. An original Z score was obtained and transformed to a T score, to avoid working with negative values. No correlation between the three dimensions was found according to the Varimax rotation factor that was implemented. A UNIANOVA was calculated for each dimension, separating the groups (Brazil and Portugal), with sex and age as covariates. Significant variance was found for the *Study Activities Organization* dimension ($F(1,188) = 4.64$, $p < .05$).

To better understand the variance encountered in *Study Activities Organization*, an analysis of the items associated to this dimension was undertaken using an Independent t-Test. Significant variance was found in item 17 ($t(93.35) = 5.49$, $p < .001$). This item asked if the student went regularly to the library to read or browse for books and documents. Brazilian students ($M = 3.0$; $SD = 1.66$) presented a higher mean than Portuguese students ($M = 1.9$; $SD = 0.84$), suggesting that Brazilian students go more often to the library to read or browse for books and documents, even though their mean was positioned in an intermediate level of the scale ranging from 1 to 6, corresponding 6 to maximum agreement. For the remaining items, no significant variance was found, with means ranging from 2.6 to 3.7 for both Brazilian and Portuguese samples, indicating that students rate themselves in an intermediate level of the scale.

VI. OTHER CONSIDERATIONS

In addition to the analysis of the IACHE results, we have undertaken an analysis of the academic grades obtained by both samples. Table I compares Brazilian and Portuguese realities, presenting the total number of enrolled students in the cohorts where IACHE was administered, the number of dropouts, as well as the number of students who failed even though attending classes (were not dropouts), and finally, those who succeeded. A mean grade was calculated for those who succeeded. A general mean grade was not available because in UC failure grades are not recorded. As the grade range in UC varies from 0 to 20, we have divided the mean grade of approved students ($M = 14.12$) by two, so that it can be compared to the Brazilian sample. Furthermore, we calculated the total percentage of approved and retained students considering only those who did not abandon the course.

TABLE I

CHARACTERIZATION OF PROGRAMMING COURSE STUDENTS IN THE BRAZILIAN AND PORTUGUESE SAMPLES

| | Course-Program-University | |
|-----------------------------------|---------------------------|-----------------|
| | PC1-INF-UFG | PPP-LEI-UC |
| Enrolled students | $n = 110$ | $n = 244$ |
| Dropout | $n = 15$ (14%) | $n = 126$ (52%) |
| Failed | $n = 20$ (18%) | $n = 37$ (15%) |
| Approved | $n = 75$ (68%) | $n = 81$ (33%) |
| Mean Grade of approved students | 6.54 | 7.06 |
| Not considering dropout students: | | |
| Percentage of approved | 79% | 69% |
| Percentage of retained | 21% | 31% |

According to the information presented in Table I, the teaching methodology appears to have a relevant impact on the dropout rate. However, it does not seem to have the same impact on the students' grade nor in the percentage of retained students (only 10 % difference). This may suggest that the methodology, by itself, is not decisive to reduce the percentage of failure. This may lead us to question the validity of the investment made by INF-UFG, where the number of students in each cohort was drastically reduced, given the expectation that a more personalized methodology would foster higher success rates.

This information, along with the results of our study, lead us to wonder if the high failure rates found in Introductory Programming courses may be mainly due to internal factors associated to the cognitive and motivational processes of the students. In fact, authors have suggested that the difficulties experienced by novice students who are learning to program are related to the lack of fitter mental models [17, 18, 19, 20, 21, 22]. For several reasons, including the difficulty of first year students, several researchers propose the development of Computational Thinking skills, i.e., thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent [23], as early as elementary school [24, 25]. However, these are hypothesis that would need to be tested in future studies.

VII. CONCLUSIONS

In the traditional method of teaching programming, students hardly feel excited because they have to concentrate on coding and compiling problems generated by the rigidity of professional programming languages, in addition to solving the algorithmic problem. In the aim of tackling such challenges, different approaches have been defined, mostly through the use of new classroom methodologies and the use of different programming languages and tools.

At UFG (in Brazil), the Computer Science program adopted, in 2008, the PBL method for teaching their CS1 course, along with the use of tablets PC and flowcharts. The results obtained were quite satisfactory. Although there had been no significant increase in average scores, compared to classes in previous years, there was a significant decrease in the number of failures and dropouts rates. However, there is still a 25% failure rate in this course.

The adaptation to the Bologna process undertaken in UC (in Portugal) aimed to make students more independent and proactive in building their own knowledge, returning teachers to their role of guides of the students' learning journey. Even though the idea is interesting, its implementation still has some issues to overcome, given the large classes and the heterogeneity of students' profile, and also the expressive dropout and failure rates.

To improve the CS1 outcomes, new solutions must be thought of, taking into account the students' profile, their attitudes towards learning and their method and strategies to acquire knowledge. In this sense, a first step is to better understand the students and their profile. To do so, we have applied the IACHE questionnaire to Brazilian and Portuguese university students, aiming to identify their attitudes and behavior towards study and academic learning. Data obtained from our application allowed us to observe that there are no major differences between Brazilian and Portuguese students concerning their attitudes and behaviors, despite the fact that they belong to two very idiosyncratic realities, where two very distinctive teaching approaches are being implemented.

An analysis of the academic outcomes of Brazilian and Portuguese students seems to indicate that the teaching methodology has an impact on the dropout rate, but not so much in the grades or in the number of retained students. This raises the hypothesis that the problems faced by students may be related to internal factors associated to their cognitive processes. Further investigation is needed to test such possibility, as well as to better comprehend and intervene on difficulties experienced in introductory programming courses, as well as to verify if a specific student profile can be expected when we consider students who chose Computer Science programs.

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Work in Progress: Analysis of the Relationship between Teaching Contents and Motivation in Programming Education

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Abstract— In this research the motivational levels of the students in a social welfare department while learning computer programming were analyzed relative to the contents that were taught in each lesson. The introductory programming course was game-based, and Java language was used with Eclipse as the Integrated Development Environment (IDE). The lessons were designed in such a way that as the students finished more and more assignments they were nearing completion of the Tetris game. The motivation levels were measured using a questionnaire based on the ARCS motivation model, which has four factors: Attention, Relevance, Confidence, and Satisfaction. As a result, it was found that the motivation of the students changes according to the lesson content.

Keywords—introductory programming; motivation; analysis; ARCS model

I. INTRODUCTION

It is often said that being fluent in information technology is important not only for computing majors but also for non-computing majors [1], and many universities offer programming modules in their CS/IT courses [2]. However, teaching programming is not an easy task especially when teaching to non-computing majors because their motivation to learn programming is not as strong as computing majors. Therefore many researchers have been concerned with the motivation of students studying programming. T. Jenkins assessed the motivation of students at the beginning of a computing course [3]. He defined four types of motivation: extrinsic, intrinsic, social, and achievement. He obtained a somewhat disappointing result that there was little evidence that any significant number of students were motivated by an intrinsic interest in the subject itself.

In this research, the ARCS motivation model introduced by J. M. Keller [4] was used as the background theory. This model assumes that motivation has four factors: *Attention*, *Relevance*, *Confidence*, and *Satisfaction*. In the context of the ARCS model, using games in programming courses can be considered

as a mean to raise *Attention*. M. Feldgen and O. Clúa introduced what students regard as their ‘real world’: games and Web-programming, to motivate their freshman students to learn programming [5]. They used University statistics such as rate of attendance in class or rate of drop out from the institution to prove the effectiveness of their approach. Some researchers also used robots [6], narrative media [7], artwork [8], and media computation [9] for the same reason. Using graphical programming languages such as Scratch can be considered as a mean to raise *Confidence* and *Satisfaction*. S. Uludag et al. used the Scratch programming language in order to achieve constructionist learning and contextualized computing education in their CS0/IT0 course for majors and non-majors [10].

In this research, an introductory programming course was offered to the students in the department of social welfare, and the motivation of the students was regularly assessed using the questionnaire based on the ARCS model. The programming course was game-based because games played on mobile phones are very popular in Japan and the authors thought that games would attract the students’ attention. The game chosen to be used in the course was Tetris. Though there are several programming languages/environments that are said to be suitable for novices such as Scratch, Java language was used with Eclipse as the IDE in the course so that the students could prepare for the programming environments at the work places.

II. THE PROGRAMMING COURSE

The programming course was offered to the sophomore students in the Social Welfare Department, Niigata Seiryō University from April to early August 2010. There were 51 students enrolled in the course, and 48 students remained at end of the course. None of the students had previous programming experience. The students were supposed to complete the programming of the Tetris game at end of the course of 15 lessons. Since the students were not expected to do this by themselves, most of the Classes were prepared by

the instructors, and the students were supposed to work only on the program in Tetris Class which controlled the behavior of the game. The assignments given to the students in the late stage of the course were designed in such a way that as the students were nearing completion of the Tetris game as they finished more assignments. After finishing the assignment given in Lesson 14, the students could play Tetris. The last assignment given in Lesson 15 was to display the score of the game. The syllabus for the course is shown in TABLE I.

III. PRELIMINARY EXPERIMENTAL RESULTS

The motivation of the students in the programming courses was analyzed using the authors' original questionnaire based on the ARCS model. Each of the 12 question item in the questionnaire was presented using a five-point Likert scale where answer 5 always corresponded to "agree" and answer 1 to "disagree".

Among the 48 students who finished the course, 24 students attended all the 15 lessons and filled out the questionnaire 15 times. The data of those students were used for the analysis. The change of the average scores for all the 12 question items from Lesson 1 to Lesson 15 is shown in Fig. 1. As can be seen in the graph, the motivation score at Lesson 14 was highest. Toward the end of the course, the Tetris game is near completion, and it could be played by the students after they finished the assignment in Lesson 14, and that is considered to be the reason of the high score. The motivation scores dropped drastically from Lesson 14 to Lesson 15. The authors presume this is mainly because the assignment given to the students brought their motivation down. The students worked on the final assignment in the class and none of them could finish the assignment by end of the lesson. Most students needed one more week to finish the assignment. In other lessons, if the assignments looked too difficult to the students, the instructor gave some hints to the students.

In any introductory programming course, new concepts are being introduced and the degree of difficulty should increase as lessons progress. But, if the increase in difficulty and the learning of the students are balanced, the motivation would not drop. Therefore, when new concepts are introduced in a lesson, care should be taken not to increase the difficulty too rapidly.

TABLE I. SYLLABUS FOR THE PROGRAMMING COURSE

| Lessons | Title | Contents |
|---------|--------------------|--|
| 1 | Eclipse (1) | Installation of Eclipse |
| 2 | Eclipse (2) | How to use Eclipse |
| 3 | Java basic (1) | main() method, Import statement |
| 4 | Java basic (2) | variables, data types |
| 5 | Loops (1) | for statement |
| 6 | Loops (2) | while statement, Random() method |
| 7 | Event handling | Event, Listener, Mouse event |
| 8 | Conditional branch | if statement, if-else statement, nesting |
| 9 | Arrays | Array initialization, 2D arrays |
| 10 | Animation | Thread, moving ball, moving balls |
| 11 | Classes | Fundamental programming structures |
| 12 | Inheritance (1) | Circle Class |
| 13 | Inheritance (2) | Ellipse Class, Inheritance and Override |
| 14 | Tetris (1) | Making Tetris playable |
| 15 | Tetris (2) | Displaying scores |

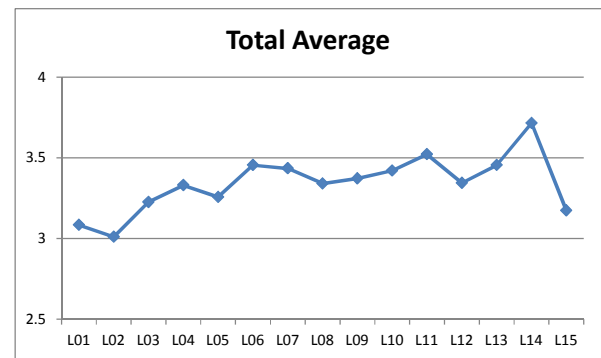


Figure 1. The Change of Total Average

Also, when giving assignments to the students, they should not be too challenging.

IV. CONCLUSION

In this research, the motivational levels of the non-computing major students while learning introductory programming were monitored and analyzed.

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Work in Progress: What Calculus Do Students Learn After Calculus?

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Abstract— Clinical interviews were held with students in senior level electrical engineering and methods of teaching secondary mathematics classes. These students had all completed a 4-semester calculus sequence including differential equations. Engineering students had then taken advanced classes applying mathematical ideas in real-world contexts while mathematics education students had taken a similar amount of coursework in advanced mathematics courses. Students were interviewed to determine how their conceptual understanding of function and accumulation (integration) had grown or regressed during work after calculus. Back-transfer, where later learning improves conceptual understanding of earlier material, was observed.

Keywords—component; back transfer; APOS; function; accumulation; understanding

I. INTRODUCTION

There have been numerous studies looking at the concept of transfer, where material learned in one course is available (or not) for application in later courses (for a variety of examples of such studies, see chapter 3 of [1]). The idea of transfer underlies much of the structure of the modern engineering curriculum, where students begin in calculus and physics and then apply that knowledge in later work. Much less studied is back-transfer, where seeing material in a later course deepens understandings of concepts that could have been developed in an earlier course [2]. A proper understanding of how engineers' conceptual understanding develops throughout their training requires an understanding of how both transfer and back-transfer work. The research questions addressed in this study are:

- Does back transfer occur?
- If so, does the application of math in different contexts lead to different levels of back transfer?

This study focuses on the concepts of function and accumulation (integration) as developed in calculus. However, a better understanding of back transfer in mathematics should provide a guide to the study of transfer and back-transfer in other aspects of the engineering curriculum.

II. METHODOLOGY

A. Subjects

This study builds on earlier research about the level of conceptual understanding exhibited by students at the end of a 4-semester math sequence, Calculus 1, 2, 3, and Differential Equations [3]. The participants consisted of 20 senior-level engineering majors and nine senior-level mathematics education majors. Each group was selected from their classes in the Spring semester of 2011. The engineering majors were recruited from ECE 512: Linear Systems in the College of Engineering. The mathematics education majors were recruited from MATH 570: History of Mathematics in the Mathematics Department. These groups were selected because students in both groups had completed the same 4-course sequence, typically during their first two years of college, and had both taken additional courses which used that material afterward. However, the engineering students had seen the calculus ideas applied in more real-world settings than the education majors, few of whom took any additional science courses and instead primarily looked at more abstract applications in advanced math courses. By comparing the conceptual understanding displayed by the seniors to that displayed by sophomores, back transfer could be assessed. By comparing engineering and education majors, the role of different contexts of application could also be assessed.

B. Interviews

Each student participated in a (roughly) 60 minute clinical interview. Interviews were conversation-style following a protocol with predetermined questions along with spontaneous, related follow-up questions determined by the course of the interview to get at understanding. Questions were taken mostly from the level of Calculus I and II with two questions coming from Differential Equations. The questions were chosen based on whether each would demonstrate a student's understanding of various calculus concepts including function, differentiation, and integration. For example, the interview questions included:

Graph $x(t) = \cos t$, $y(t) = \sin t$, $0 \leq t \leq 2\pi$

Graph $x(t) = \cos 2t$, $y(t) = \sin 2t$, $0 \leq t \leq \pi$

Are these the same functions?

The researchers were not specifically interested in the “correctness” of the student responses. However these questions lead easily to a discussion of ideas about what it means to be a function, from which the students’ understanding of the concept could be assessed.

C. Analysis

Interviews were transcribed and analyzed using both qualitative and quantitative techniques.

1) First pass (qualitative)

After each interview, students were rated on their level of conceptual understanding of function and accumulation. These ratings were based on a modified Action-Process-Object-Schema (APOS) scale that was refined to admit intermediate levels between each of the normal Action, Process, Object and Schema levels (see [4] for details about the APOS scale). A student was rated by the researchers by analyzing how they answered the series of questions in the interview and deciding to what level a student could think about a particular topic. A student would be rated at a particular level if the researchers felt that the student could think about a topic and operate within a problem at that level. The rating was not an indication to which level a student would naturally operate when answering a question but rather an indication of the highest level a student could reasonably operate when answering a question.

The overall rating for each student was assigned based on a composite of the student’s individual ratings on each question. Once all students had been rated, the percent of engineering majors and the percent of mathematics education majors at each level were compared to results after Differential Equations to see if seniors demonstrated deeper understanding (showing back transfer) or lesser understanding (demonstrating forgetting of basic concepts).

2) Second pass (quantitative)

As a check to prevent the preconceptions of the researchers from blinding them to ideas expressed by the students, we also used a quantitative data-mining approach to analyzing the interview data. The transcriptions were used to create a matrix where each entry was the total number of times each student said each word. So the sixth entry in the eighth row would be the number of times the eighth student said the sixth most commonly used word from the interviews. A non-negative matrix factorization was then used on the resulting “word bags” to identify different vocabularies used by different students. The researchers were somewhat surprised when the vocabularies did not indicate differences between different majors, but did identify groups based on words linked to confidence or willingness to participate in answering questions when they weren’t sure of the answer such as “don’t” and “know”, “understand”, etc.

3) Third pass (qualitative)

Once the quantitative analysis suggested student confidence in dealing with questions where they were unsure of the answer was important, the interviews were divided into segments of information (sentences or phrases as appropriate) and coded for topic, level of understanding, current representation, confidence, and willingness to participate.

These codes were then used by the researchers to rate each interview with an average level of confidence and willingness from 1 to 3 using half steps so that they would be more comparable to the rating of the student’s level of understanding on the modified APOS scale.

III. PRELIMINARY RESULTS

Senior students had, on average, progressed along the APOS scale farther than students at the end of the calculus sequence. However, not all students exhibited growth. Indeed, some students never advanced past the initial Action level during their entire college career. So in answer to research question 1, back transfer can occur, but is not guaranteed.

While engineers overall displayed higher levels of conceptual understanding than education majors, we are unable to conclude that exposure to more concrete applications was better at supporting back transfer than the more abstract applications of advanced mathematics classes. Variations within the majors were larger than variations between the majors, which suggests that the nature of the student rather than the application is the most important variable in supporting back transfer. Of course, self-selection of students into majors complicates this analysis.

Finally, the coding for confidence demonstrated that engineering majors were in general more willing to try problems when they didn’t know how to work them. Again, self-selection is an issue here. But it appears that in comparing practical vs. abstract extensions of mathematical ideas, the difference lies less in terms of supporting back transfer and more in terms of developing confidence to persist in problem solving in the face of uncertainty.

IV. FUTURE WORK

Additional research will need to be done to identify what conditions support development of conceptual understanding in general, and back transfer in particular. It seems clear from the preliminary results that these conditions depend not just on the type of application but also on the student. This involves not just their academic abilities, but also their attitudes, especially toward working with problems where the solution technique is not immediately obvious. The connections between transfer, back transfer, self-efficacy, and conceptual understanding are not currently well understood.

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Work in Progress: Video Tutorials that Enhance Laboratory Learning

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Abstract—Laboratories are a means by which students take a hands-on approach and practice concepts learned in class lectures under real or close-to-real world settings. This provides a kinesthetic method of learning which rounds out the auditory methods typical of a lecture course. Unfortunately, many students spend most of the lab time troubleshooting their experiment instead of deepening their understanding of the concepts taught in class. This causes frustration and anxiety amongst students. In our opinion, this is due to a lack of knowledge of equipment used in the lab as well as training on different equipment in previous classes. We have developed a video tutorial series for our Biomedical Measurements class that teaches basic circuit building, equipment set-up, and equipment use – students may watch these videos before the lab and at any moment during the lab. Thus far, post-semester surveys have indicated that all respondents, whether bio-electrical, pre-medical, or bio-mechanical concentration in biomedical engineering, find the video tutorials helpful in the lab. The incorporation of technology in the lab session ensures that the lab time is spent deepening conceptual knowledge instead of troubleshooting circuits.

Keywords: *laboratory, videos, tutorials, YouTube, circuits*

SITUATION AND MOTIVATION

Laboratory components (whether large or small) are required in all engineering curriculums. In our experience teaching a Biomedical Measurements Class and Lab, we noticed that troubleshooting usually took up most of the laboratory time, taking the emphasis away from deepening the knowledge of the concepts taught in the lecture. Sadly, out of a 2 hour lab session, students would spend over three-quarters of it fixing basic mistakes and the last 30 minutes rushing to get data because the lab was going to close. The only “understanding” that they would leave the lab with was: “Circuits is hard”, and/or “I hate circuits”. Such impressions were particularly stated from biomedical engineering students who were not bio-electrical concentration.

Psychologically, most of the students entering our lab for the first time expressed how extremely anxious and nervous they were because they were afraid that they would not be able to finish in time. They were going in “blind” without understanding exactly what they were doing; additionally, they were not confident in their skill level to complete the tasks. As educators, we know that the more nervous and/or anxious a student is, the worse they will perform and the longer it takes for them to perform a task [1].

Observing the students semester after semester led to the realization that the students (especially those that were not bio-electrical concentration) had a gap in their knowledge base. Although many of the students had taken a circuits-building lab and class before, they didn’t use the same equipment in their prior circuits classes and/or had taken the class at least 2 years earlier and were no longer proficient in their ability to build and troubleshoot circuits. We envisioned that tutorial material designed specifically to describe equipment use, techniques of building circuits, and the laboratory setting would be an efficient tool to assist students and increase their probability of success in the lab. The objectives of the tutorial tools would be to: i) promote efficient use of lab time, ii) reduce anxiety in the lab, and iii) help students focus on the important part of the lab; namely, reinforcing important concepts being taught in the lecture course.

OUR CONCEPT AND APPROACH

Visualization is the concept that communicates abstract and concrete ideas using images, and stemming from the adage “a picture is worth a thousand words”, we believe that a video is better than a static picture at conveying ideas [2,3]. It is our opinion that incorporating video tutorials as part of the pre-lab work (in addition to reading/reviewing the assigned handouts) will enhance the ability of students to deepen their knowledge and understanding of the lecture concepts instead of troubleshooting a circuit for the most part of a lab. It is widely known that visual learners represent approximately 65% of people while auditory learners represent 30% and kinesthetic learners represent 5%. Video tutorials take full advantage of the 95% of learning styles (both visual and auditory) present in the classroom [4].

Additionally, we wanted to take advantage of the fact that 49% of college age students own smartphones [5], and that 54% of smartphone users watch videos on their smartphones [6]. The use of tablets and other devices makes it even easier for students to access videos or video websites such as YouTube. In fact, most phones and tablets have a YouTube “app” where they can directly stream videos from this extremely popular site. YouTube has emerged as a new technology to assist in the facilitation of deep learning in fields such as nursing [7] and chemistry [8]. Our approach therefore was to create a library of tutorial videos for our Biomedical Measurements laboratory that involved basic circuit building, equipment set-up, and equipment use and upload these videos as a channel on YouTube – students would have the ability to watch these videos before the lab and at any moment during the lab.

In the beginning of the semester, we recruited students who were taking the Biomedical Measurements Class to create the tutorial videos. Students volunteered to create the videos. Our expertise in being a teaching assistant for 5 semesters for this laboratory course allowed us to set-up requirements based on the needs and mistakes we saw in the laboratory semester after semester. The students were required to learn about the equipment (set-up, use, etc), capture and edit the video, and present a 10 minute long final product that was interesting and informative to assist future students. Here is where a huge benefit of today's "technological revolution" took place – many students did the recordings on their iPhones and were very quickly able to edit their videos using pre-installed software on their Mac and/or PC computers. The students were encouraged to enhance their videos with music, titles, and captions in order to maximize the attention-grabbing power of their tutorial. Following completion of the videos, a majority of which were less than 10 minutes, the students turned them in for approval prior to receiving credit. The videos were evaluated by the TA's for video and content quality and accuracy of content. Comments were given to the students and once the final version was submitted they received the extra credit.

SURVEY SAYS...

After completion of the first set of 7 videos (Breadboards 1 and 2, The Power Supply and DMM, The Oscilloscope, Powerlab, The Thermistor, and The Function Generator), students who took the Biomedical Measurements Class were asked to watch the tutorial videos and answer a survey. The post-semester surveys indicated that all respondents, whether bio-electrical, pre-medical, or bio-mechanical concentration in biomedical engineering, found the video tutorials helpful in the lab. Survey results indicated that 52% of respondents believe that watching the videos makes understanding the concepts easier. Also, 36% and 29% said that building the circuit would have been faster and easier, respectively. Finally, 76% said that watching the video before the lab would have made it easier to use the lab equipment.

BETTER OR NOT?

While our survey results indicated very positive feedback, we performed a very small study (5 students in total) to determine if there was a positive effect of watching the videos before building a basic circuit. In our preliminary study there was no statistical difference in terms of time spent in an introductory laboratory experiment among students who had watched the videos beforehand versus those that only heard the pre-lab lecture. We strongly believe that this was due to the small number of students that volunteered for the study. What was obviously different however, was the level of nervousness prior to completing the circuits. Compared to students that had taken the class before and never watched the videos, our test takers were much more at ease once they were told they would get to watch a video before starting to construct their circuit that would explain all of the required steps.

SUMMARY AND FUTURE PLANS

Biomedical Measurements and Bio-instrumentation are two important and mandatory training courses for most Biomedical Engineering programs/curricula. In our department we have a unique situation which results from three different concentrations (Pre-medical, Bio-Mechanical, and Bio-Electrical) of Biomedical Engineering. Students that are pre-medical and bio-mechanical concentrations do not have a lot of previous training on circuits. As this is the majority of the students in the department, our present situation provided for students not being able to maximize their lab time to strengthen and further their understanding of the concepts taught in class.

Tutorial videos may be applied to most engineering courses to enhance the quantity and quality of learning. This method may also be beneficial in training and preparing students to work in other lab-based settings such as research labs – they will have an understanding of the concepts before they go to work. The wonderful aspect of tutorial videos is that they need not be created/compiled by the professor – students created our tutorial videos with specific requirements and were given extra credit for their work.

Our future work will include increasing the number of tutorial videos to cover all of the lab topics. We also want to perform a more robust study on the benefits of watching the tutorial videos before arriving to class. Not only the physical aspect of building the circuit but also on the level of anxiety and nervousness that the students experience in the lab.

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Categorizing How Students Use Collaborative Technologies in a Globally Distributed Project

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Abstract—Possibilities for collaboration in globally distributed projects have radically changed with the introduction of new Collaborative Technologies (CTs) in the Web 2.0 era. The use of such technologies in the context of students collaborating in a globally distributed project is little explored in research. A better understanding would provide opportunities for improving the collaboration, and more importantly is that a better understanding would improve the possibility of scaffolding, and student learning in general. In this paper we present results from a study of students' use of CTs in a globally distributed project with a focus on the challenges encountered in trying to collaborate using this technology. The study is focused on a few aspects of how a combination of CTs could be utilized and issues associated with their set up and adaption for use. We discuss potential reasons for the observed patterns of technology use and how they influenced the collaboration environment around a globally distributed student project.

Keywords—component; survey; reflections; Open-Ended Group Projects; global collaboration; collaborative technologies

I. INTRODUCTION

Use of Collaborative Technologies (CTs) in globally distributed projects is the theme of this paper and we look at it from an instance of student collaboration. The educational setting is a semester long collaboration between Computer Science students at Rose-Hulman Institute of Technology in USA and IT engineering students at Uppsala University in Sweden. The learning environment is based on the Open-Ended Group Project (OEGP) concept [1, 2] in which the students gather and expand knowledge about a complex real-world issue in the health care area on behalf of an external client. Close and genuine collaboration is essential for the success of this project and use of CTs is a necessary component in achieving this due to the geographical distance between the two cohorts. One of the students depicts the importance of CT in this colorful quotation:

"I don't think this project would exist without the communication tools available to us"

Use of CTs has become an everyday activity and is today more or less taken for granted in the workplace and in education. It has certainly made communication both easier and richer since we first started our student collaboration in 2005. The students' collaboration has nevertheless not been without problems and difficulties, and an attempt to improve

communication by giving the Swedish students access to a high tech laboratory classroom was made during the 2011 instance. This attempt has been studied and some observations from this study are reported in this paper and in companion paper [3] looking into how the students reflected on CT.

A result of our study is an increased understanding of the challenges students encounter in trying to collaborate with the use of CTs. This is done with the broader aim to improve scaffolding and learning with regards to collaboration and communication in globally distributed projects. Data in the study was gathered using two surveys and two written reflection assignments during one semester in a course with computer science and IT students from two countries six time zones apart. The study also included direct observations of the collaboration made by the teaching faculty and staff at a collaboration room at one of the Universities. Results show that students use numerous technologies in their collaboration, and that their perception of the usefulness of the different technologies depended on factors such as the possibility of using the technology on a smart phone, their previous experience with using the technology, and the possibility of combining asynchronous and synchronous communication. Surprising results revealed that email was much less frequently used than expected and had to a large extent been replaced by asynchronous use of chat through Skype. Moreover, many students considered the collaborative project platform useless despite its advanced technology, which included possibilities for different forums, milestones and shared folders. It appears that the demands of technology use mediation imposed by collaborative technologies were not appreciated by students with prior experience of more personalized technology use.

We will first present the local setting in some detail in order to provide the reader with an understanding of the context of the study. This is followed by giving a general theoretical framework for the study and presenting the data collection methods used. Some results of the study are then presented and discussed.

II. BACKGROUND

A. The Student Collaboration

The local context for this study is a globally collaboration between students at the Swedish university taking the IT in Society course and students at the American university taking

the Computing in a Global Society course, where the two cohorts are almost 7.000km and six time zones apart. This setting and different aspects of it have been described elsewhere [4 - 8], but a short summary is given here to provide the reader with a quick update.

The educational setting is aimed at developing professional competencies that are essential in relation to working in a global collaboration setting. This setting is based on the Open-Ended Group Project (OEGP) concept, where complexity and many options for how to approach a problem are central issues. OEGP is a suitable concept for preparing our students for working on a global arena. An important aspect of the educational setting is that the project is placed in a real environment with a real client, which adds to the complexity and also is shown to increase motivation for the students [9]. An issue with real clients is that they also have other obligations and can be hard to get reasonable access to, which we have addressed by only using one reliable client and putting all students into one project. This solution has, as seen from an OEGP perspective, the added benefit that it adds to complexity. Another issue with a real client might be that some students feel ethically constrained to help certain clients, e.g. for political, religious, or competition reasons. We have for that reason chosen to work with in the public health sector, i.e. the Uppsala County Council and the associated academic hospital.

Also of relevance to this paper is that the students have more or less total freedom in choosing CTs. Examples of constraints set up by the staff are that some form of collaboration platform should be used and that there should be weekly synchronous meetings that preferably should include video. The choice of CTs and how to use them is up to the students and varies over the years, e.g. this year the team leaders required the members to keep track of the time they spent on the project. The CTs used this year are presented below.

The students participating in the course this year were all men of age between 20 and 37; the American cohort was between 20 and 22, and the Swedish cohort had all but one member in the range of 21 to 24. The majority of students had their major in computer science or IT, but some students had other majors such as mechanical engineering. This year there were ten Swedish students and eight American students taking the course. Most students had studied for three or four years at the university.

B. Uppsala Learning Lab and the Laboratory Classroom

Uppsala Learning Lab (ULL) was created in 2000 as a part of an effort to raise the level of IT use in education, research and especially international collaboration. It is now an administrative unit at the Swedish university with the task of spreading knowledge on how IT can be used in teaching and in research projects. ULL experts actively collaborates with faculty in order to develop their use of IT and an essential part of this effort is to maintain, to develop, and to evaluate the use of a high tech classroom, called the laboratory classroom. The laboratory classroom is open and free of charge to all teachers at the Swedish university for education and seminars. The classroom seats up to 80 persons and has four interactive whiteboards and four large screens that can be used for video

conferencing facilities, and the opportunity to lend laptops to students. The room can be subdivided into smaller sections and all furniture is on wheels and can thus easily be adapted to different needs. ULL's staff provide technical support for users, but above all help faculty to test and evaluate the possibilities offered by CTs in a classroom setting from a pedagogical perspective.

When using the laboratory classroom in the project course, the students were in charge of the contact with faculty at ULL, and they made arrangements regarding furniture, the use of different rooms and technology.

III. RELATED RESEARCH

A. The Digital Generation

The students have grown up in a world of CTs, and they have other ways of thinking, interacting, working and socializing that revolve to a much higher degree on CTs. This is seen as fundamental difference as expressed by Prensky [10] on what he denoted the Digital natives and the Digital immigrants and by Tapscott [11] on what he called the Net generation. Similar ideas are expressed by Veen and Vrakking [12] in what they describe as the Zapping generation. Selg [13] did a study of students and faculty in Sweden where he classified use behavior into Web 1.0 and Web 2.0 categories, where the latter is roughly the same as Digital natives, the Net generation, and the Zapping generation. He concluded that Web 2.0 behavior is predominant in the age group 25 years and younger to a much higher rate than for older age groups. Notwithstanding this observation, he points out that there are substantial differences within the different age groups that indicate that it rather is a question of culture than generation. That is, having the competencies to use CTs in a Web 2.0 manner can be seen as being in a culture, e.g. a Digital native, and is not a definition of a whole generation. It might thus not be appropriate to describe our students as digital natives just because they are young, but Selg observes that CS and IT students to a high degree belong in the Web 2.0 culture. The behaviors and views of this culture are thus relevant for our study.

B. Communication and Globally Distributed Projects

Technology plays a crucial role in supporting communication in globally distributed projects, and an increasing range of collaborative technologies are available for use, ranging from the ubiquitous email through wikis, blogs, text chat systems, version control systems, video-conferencing systems from desk-top applications such as Skype to dedicated rooms and services, cloud based file sharing services such as Dropbox, and virtual learning environments (often incorporating a range of features). Personalized social networking services such as Facebook, Youtube, Twitter are also complementing the more group focused collaborative technologies. However, this plethora of choice does not necessarily contribute to effective communication in a global team context. Many challenges remain to be surmounted, as noted by Olson and Olson [14] and elaborated in [15], where "common ground" needed to be established with respect to "collaboration readiness" and "technology readiness" in order to engage in "tightly coupled" work activities.

Central to the functioning of geographically distributed collaboration is the creation of “common ground”, i.e. establishing “mutual knowledge”, which is addressed in a paper by Cramton [16]. Mutual knowledge can be established through 1) Direct knowledge created in first hand experiences with individuals, 2) Interactional dynamics, where it is created through any kind of interaction (although it should be remembered that uniquely held information, as opposed to commonly held information, is much less likely to surface in interactions [17], and 3) Category membership, where assumptions on another’s knowledge is based on social categorization [18], (e.g. a cabdriver is assumed to know how to get to the airport). Establishing such mutual knowledge in a distributed collaboration in which only the last two are available, is not an easy task. There are difficulties in conveying nuances when compared to face-to-face meetings [19] and these are exacerbated by the fact that CT communication is slower [20]. Cramton identifies a number of problems that contribute to difficulties in establishing this mutual knowledge: failure to communicate and retain contextual information, unevenly distributed information, communicating and understanding the salience of information, differences in speed of access to information, and difficulty interpreting the meaning of silence. She also points out that the difficulties are accentuated by the fact that the collaborators often are unaware of these problems.

IV. METHOD

In this study, data was generated during four months through observations, two surveys and two written reflection assignments. Faculty made observations throughout the course on the use of technology when participating in meetings, and in the university’s laboratory classroom. Faculty consisted of three people who were the main teachers responsible for the courses, and during meetings in the university’s laboratory classroom studies were made by people responsible for the high tech collaboration room. The first survey was sent to all eighteen students in the middle of the project. Thirteen students answered the survey. It consisted of 21 questions regarding CTs in the project course. Most questions were multiple choice, but there were also open-ended questions. The first reflection was a compulsory written exercise answered by all students in the course. The task was to reflect on the positive and negative aspects of the different communication technologies used in the project. The last reflection was also a written compulsory reflection sent to all students in the course, and it contained general questions regarding the work and learning in the project as well as some specific questions regarding their use of CTs.

Data was thematically analyzed [21] and reviewed, organized and read through to identify themes. At this stage a mind map was used, and data was then reviewed again to iteratively refine the themes and to categorize the findings in a data analysis software program. Finally the different themes were exported from the software tool in order to get an overview. This overview constitutes the basis for the written text presented in this article in the following section. When writing the quotations from the different data sources, language errors have been corrected in order to make them easier to read.

V. THE STUDENT’S DESCRIPTION OF COLLABORATIVE TECHNOLOGIES USED

The following is a description of how the students reported CTs in their project, categorized by the different technologies that were identified. In some cases, short descriptions of the technologies are provided, based on information from www.wikipedia.com.

Adobe Connect is software used to create information and general presentations, online training materials, web conferencing, learning modules, and user desktop sharing. It was used in the very beginning of the project and most students described that they used it once or twice during the project. The students’ ranking of the value of Adobe Connect was 2.46 on a scale from 1 to 5, and due to technical problems it was soon replaced by Skype during meetings: “We started out trying to use Adobe Connect for communication, but after a while we moved over to mainly using Skype”. It seems that the features in Adobe Connect were not appreciated by the students, and problems with sound and video made them abandon it. Moreover, the students found that it was easier to communicate with a technology that they were already using, such as Skype, and that the possibility to use Skype with their cell phones made a difference.

Email was frequently used in the project, and most students used it on a daily basis. However, compared to previous instances of the course, the use was less frequent, and much communication was directed through Skype instead. It was ranked as very useful in the survey (4.08 out of 5), and gave rise to comments such as “E-mail is the best way to spread information because everybody check their mail everyday” and “best way to get hold of people”. Some students stated that other means of communication such as Skype had been preferred and that email had also been an option when other ways of communicating failed. It is also interesting to note that many students did not answer emails, even though they frequently read them. This might be due to the students being “flooded with irrelevant information and therefore [didn’t] pay attention to broadcasted emails”.

Github is a web-based hosting service for software development projects that uses a revision control system while *LaTeX* is a document markup language and document preparation system. They were both used when writing up the final report, and many students described them as easy to use and without any problems. However, a few students not experienced in using Github and LaTeX stated that they were “tedious to learn” and at the same time as writing the report. Others stated that LaTeX can be “tricky” to use, but that the design of the report became very nice and professional. The technical matters when making LaTeX and Github work together on all computers were time consuming and frustrating. It is noticeable that the expectations on the usability of LaTeX was quite different the other forms of CTs mentioned, and that “this is to be expected if someone has not used it before”. Several of the students perceived Github and LaTeX as more similar to programming languages, and explain this difference in usability requirements as a consequence of this.

Google Docs is a web-based office suite and data storage service. It allows users to create and edit documents online

while collaborating in real-time with other users. It was used in the project to collaboratively write reports and for making presentations. Many of the students have used Google Docs extensively: "Google Docs is a well used tool in my small team. We have used it for drafts of what we gather now doing research. We also did write conclusions of what we found in a shared document. It is really good and you can get a direct look at each others work as they progress".

Microsoft Word was mentioned by very few students, but was presented as a "very simple tool" that fulfilled the basic needs during the course.

Phone. Some students reported that calling people when asking for interview times was one good way of getting a contact, which could then be followed up by emailing the person regarding questions etc. Most students did not use phone calls in the collaboration as their use was too expensive compared to Skype, for example. However, despite the description that phones were not very much used, faculty observed that most students used their smart phones for communication on a regular basis. This discrepancy might be due to the fact that many students had traditional models of phone usage in mind when answering questions about their use. One student reflection reveals this usage of phones in the project: "I often used my phone to check my mail and login on Skype to see messages and calls. I even had a Skype conference call from my phone once. ". Moreover, the example of phone use illustrates quite well that there are several grey zones to consider when talking about CTs, e.g. has the phone evolved into essentially being in the same category as a computer. We could perhaps choose to talk about voice calls instead of phone use, but what would then be the difference with using Skype for a voice call?

Skype is a service that allows users to communicate with peers by voice, video, and instant messaging over the Internet. The students described that they used Skype daily or several times a day in the project and its usefulness was rated very good with an average of 4.31 (out of 5) in the mid-term survey about collaboration. Skype was used in the project for chat conversations between two or several students as well as voice and video call. The reflections about Skype described a simple and useful tool that was easy to use, and with which the students think that they have had very few problems. For example, in this quote: "No problem, works great for team meetings". However, many students point to the fact that they would have appreciated the group video functionality in the project and that this would have improved communication.

There were several "permanent discussion groups in Skype", i.e. group chats where group members add a constant flow of comments from different areas, both personal and professional. These "permanent discussion groups" occurred within the whole project group with faculty as members, in subgroups, and within the writing team and the presentation team. Many of the conversations in these groups were informal, such as a virtual coffee room, and students posted items from YouTube or links to both unrelated and related websites. One feature of Skype mentioned several times in the reflections on communication was the delivery of messages

even when the recipient is off-line. This was perceived to have a positive impact on communication.

Some of the students reported that one advantage with Skype is that they used it in their day to day work. Moreover, it was seen as an advantage that you could chat in Skype at any time without risking disturbance to anyone: "We are able to communicate any time, any place and free of charge".

An example of a reflection regarding the use of CTs in the project, and how it affected the discussion was the following: "One interesting drawback of using Skype is that it is harder to discuss freely. A good [Skype] meeting is usually one where someone takes charge and decides who should speak when, but this means that opinions and thoughts that would've been shared if the meeting was on location in the project room might get missed. Having frequent Skype meetings means that you are less likely to meet the people you're working with in person so in that sense the technology actually separates us when the spatial distance is small (but connects us when the distance is big, as it is with the Americans)"

Another interesting reflection about using this technology for meetings is that many students did things other than participating in the meetings during the time allocated. This was perceived by many as very disrespectful, and some students reported that they explicitly asked people to stop typing during meetings, or to turn off their microphones when not talking.

SMS is a form of text messaging communication on phones and mobile phones. Very few students used SMS in the international collaboration on either side of the Atlantic. A small group of students in Sweden used it quite regularly, however. This is quite surprising since generally many students regularly use SMS quite extensively. It is interesting to note, in this context, that the "Group SMS" feature was used extensively for communication when the first year IT engineering students did a small collaboration project studying their seniors working in the IT in Society course.

TeamLabs is an open-source platform for project management and business collaboration. TeamLabs was chosen by the students themselves as a collaborative platform, and one student described the choice in this way: "They have a quite flashy introduction video, and I think that that is what caught everyone's interest". The vast majority of the students had never used a project management tool before, and they reported that it initially took some considerable time to understand what they were supposed to use it for. The reflections also reveal that the use of TeamLabs as a collaborative tool varied: "The members of the project have adopted the use of TeamLabs to different degrees, which result in a lack of communication"

Most students used TeamLabs about once a week, and they rated it as functional (an average of 3.31 out of 5). All students reported the time they had put in the project on TeamLabs, and they also kept track of the different milestones that the students had decided to have in a calendar with TeamLabs. Some students miss functionality in TeamLabs, such as the possibility to do Gantt diagrams. However, others described

that TeamLabs also contained features never used in the project such as chats and forums.

The team leaders and the project leaders reported that they have used TeamLabs to keep track of time in their group, and to get information about and set new milestones in the project. From the reflections it seems that team leaders and project managers appreciated TeamLabs to a very large extent, which is also verified by reflections from team members: "I see it more of a tool for the team leaders and project leaders to help manage their team and track progress of the project"

Some also described TeamLabs as difficult to use and stated "it isn't exactly clear where you need to go in order to do certain things. There are too many different tabs that you can navigate". This was also illustrated in the quote: "getting to some features is just flat up confusing".

It is also noteworthy that many students described their use of TeamLabs as a way of showing others what they have done, and not for finding information written by their peers. "I used it mainly to add documents for the full group to see", "Very few members read all documents that are uploaded to teamlabs". The reflections regarding TeamLabs reveal that many of the students thought their use of TeamLabs was not particularly valuable, as there was "too much information in TeamLabs and it is difficult to find information you need quickly". Others noted that, after having uploaded the material found or written to TeamLabs, it was forgotten, and not used in the project: "I'm under the impression that information uploaded into teamlabs is distanced from the project members, and then forgotten". Another student reflected on the same problem, and stated that a simpler file sharing tool such as Dropbox would have changed the use of the documents. "Dropbox could have been used instead of TeamLabs to maintain a document archive. My personal belief is that this would have rendered a higher relationship on all documents created within the project /.../ This way all documents would have been available closer to the actual usage situation"

It is noticeable that many of the students thought that TeamLabs could have been replaced by the use of Dropbox as a common document library. This reveals that most functionality provided by TeamLabs were not appreciated, and that the document storage was the most useful functionality. "I see the point of having the whole project located on a single site, but personally I'd rather just used a shared dropbox".

ULL, the university's laboratory classroom, is described earlier in this paper. Most students really appreciated ULL, and when valuing the usefulness of the classroom in the collaboration the average was 3.82 on a scale from 1 to 5. Faculty also noted that the general feeling from using ULL had a positive impact in terms of increasing motivation and commitment to the course. The first reactions when entering the classroom was one of amazement at the high-level of technical equipment. Use of the classroom significantly enhanced student motivation as well as other affective reactions to the course, and there was considerable appreciation for the opportunity to use the state-of-the art facilities. However, from a purely technical perspective the classroom's impact on their use of CTs was limited. ULL's staff assisted in setting up some of the Adobe Connect and Skype meetings,

providing cameras and speakerphones. On one occasion, students used an interactive whiteboard when presenting their work to other students in the hall. However, the technologies most frequently used in the project were not connected to ULL, and one student describes their use of the classroom in the following way: "We haven't really used it as much as we should". However, the students' comments regarding the classroom are very positive as for example: "Great for collaboration" and "With the technology available in the learning lab it has been great for project meetings and as well as for the presentations".

VI. DISCUSSION AND CONCLUSIONS

One conclusion from the study is that students use numerous examples of CTs in their collaboration and that, during the semester, their choice of particular technology depended on their previous experience of its use, and the activities that needed to be done. Many used several CTs in parallel and multitasked in order to collaborate. Another interesting result was that student perception of usefulness depended on factors such as the possibility of using the CTs on a smart phone. In this respect, a CT without an app-technology was perceived as less practical. In addition, being forced to log on to a web page before being able to use a technology affected the perceived usability in a negative way. Indeed, many students simply did not log into those systems that used this method of access. Choice of CT was also much colored by the possibility of combining synchronous and asynchronous communication, such as the choice of Skype chat in comparison with similar technology.

Very few students appreciated that CTs were complex, multifaceted with many different features. Adobe Connect was replaced with Skype for meetings, even though former had more extensive functionality than the latter. In one of the teams, Teamlabs was abandoned for Dropbox, and most students reported that they would recommend the use of Dropbox in future projects despite the fact that Teamlabs had more features specifically designed for collaborative projects. Most students in the study preferred to put together a package of CTs which suited their needs for the project, and which had the lowest possible accessibility threshold, as described thus: "Use simple tools for the collaboration" and "KISS. Keep It Simple Silly". Despite many students' view of TeamLabs as something they would not recommend, faculty nevertheless strongly believe that a tool that enhances the awareness of other students' work and give a context to one's own work is necessary for a good collaboration. This is in accordance with much research on computer supported collaborative work, (e.g. [22])

Surprising results revealed that email was much less frequently used than expected and had been replaced by asynchronous use of Skype chats. A further interesting finding is that the students chose not to use online social networking technologies in their collaboration. The forums available at TeamLabs were all silent, and the students did not use Facebook, blogs or Twitter for the project. Other researchers have noted that students are increasingly inclined to use social networking sites such as Facebook, Xanga and MySpace. Active engagement in these websites to establish virtual

relationships provides individuals with access to a diversified set of information from multiple sources [23]. Nevertheless, these technologies were not chosen by the students despite the fact that many of the students met new friends, and are planning to continue social interaction in the future. Selg's [13] discussion concerning the differentiating between professional and private use of CTs may be relevant here.

One cause of irritation in virtual group conferences was that many participants were unaccustomed to using shared microphones/speakerphones. This might be a contributing factor behind the counter-intuitive but recurring observation made by ULL staff that open discussions and exchange of ideas using Skype or Adobe Connect seem to work better if the participants take part from computers in their own homes. Participation from one's own computer tends to favor a more open climate, and allows for additional communication by way of chat. An alternative to Skype and Adobe Connect is the professional video conference, which allows for video and audio of a quite superior quality, and where students gathered together to participate works smoother - but at a price.

It is interesting to look at the use of scaffolding with regard to use of CTs and student collaborative projects. From the discussion of Digital natives or Homo zappiens, it is evident that the basic view and underlying assumptions of faculty in relation to effective use of CTs might be mistaken. Faculty's use of CTs is not the same as the student's use, and consequently, scaffolding in this area is something that needs to be done with care, with more attention to the general principles of communication than to specific technology. Wiggberg [24] elaborates in his thesis that students often experience something quite different from what the staff expects in project courses, and this might also be the case with the use of CTs.

Another interesting results from the study is the reported usefulness of LaTeX despite the fact that most students spent considerable time trying to integrate its operation with Github. This can be contrasted with the perceived lack of utility of Adobe Connect that was abandoned when problems occurred in two meetings. It would appear that LaTeX and Adobe Connect are seen by students as two different kinds of CTs and that they apply different criteria for utility to each. Perhaps one reason for LaTeX perceived usefulness is that most students believed that mastering LaTeX is a competence which is relevant for their future careers. Faculty also felt that discussion about LaTeX in relation to MS Word or similar programs, was, for many students, akin to a political discussion with many layers of values affecting what was being said.

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Student and Instructor Experiences in the Inverted Classroom

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Abstract—This paper discusses our ongoing experiences with teaching software engineering through an inverted classroom. This course format moves traditional lectures out of in-class hours and into the student's personal study time with prerecorded lectures. We support the inverted classroom with complementary techniques, such as structured discussions, weekly quizzes to ensure students watch the lectures before discussion, an innovative Lego-based workshop, a term project, and guest lectures by industry professionals. The inverted classroom allows the students to have an effective educational experience that encompasses both traditional lectures and an active learning environment. To evaluate the efficacy of this format, we use surveys and interviews of both instructors and students. We examine the time commitment of teaching with this method, from both the instructors' perspective and the students'. We also discuss the time commitment for instructor preparation, and quantitative measures of how the inverted classroom helps smooth the variance in the quality of each instructor's teaching. We also analyze the effectiveness of this technique and our methods for mitigating unintended consequences, such as students having an inexact understanding of the material. Through this evaluation, we distill the effects on student learning and instructor teaching.

Index Terms—Instructor experiences, Inverted classroom, Software engineering education, Student experiences

I. INTRODUCTION

The software industry expects fresh graduates to enter the workforce with an ever-increasing amount of knowledge. Universities struggle to balance program length with content, often teaching fundamentals in lieu of hyper-focused tools and techniques that are popular in the moment. To give their students the right balance of abstract and concrete understanding, faculty members must constantly innovate within the classroom and provide more value to the students per hour of instruction.

One such innovation is the inverted classroom format [1]. By taking the traditional lecture out of the classroom and putting it online for students to consume during their study time, educators can provide concrete lessons through active learning activities like workshops [2], interactive work time with the instructor [3], and interactive demonstrations [4].

We implemented an inverted lecture format for our senior and graduate-level software engineering course. After using the format for eight quarters, we discovered interesting questions regarding the burden placed on students by an inverted

classroom, the preparation time for instructors, the homogeneity of the instruction quality across instructors, the quantity and quality of discussion within the classroom, and methods to ensure that the students watched the prerecorded lectures before class.

This paper addresses our attempts to answer these questions. Section II provides background and related research for this work. Section III describes our inverted classroom and the materials used. Section IV discusses the purpose of this study. Section V lists the methods we used to acquire data for analysis. Section VI illustrates our data analysis. Section VII describes our results and section VIII lists our conclusions and ideas for future work.

II. BACKGROUND

This section presents work related to this research.

A. Inverted Classroom

Instructors have used the inverted classroom in a number of contexts. Lage et al. originally intended to address the breadth of learning styles found in introductory economics courses [1]. The course format allowed the instructor to present diverse material in a manner that is attractive to a broad audience, yet still maintain control over course content.

Within engineering disciplines, Gannod et al. used the format in a software engineering program as a pilot to revamp their department's curriculum [3]. In this paper they discuss a framework and its possible implementation in eleven courses in the software engineering curriculum, and addresses proposed arguments against the inverted classroom. We have provided an evaluation of the authors' issue of whether students watch the pre-recorded lectures.

Day and Foley conducted an in-depth analysis of Web lectures for learning [5]. Their quasi-experimental study evaluates the efficacy of online lectures versus a traditional lecture-based course. This setup parallels the inverted classroom, where shorter lectures are provided for the students to watch during their study time. The experiment showed a significant increase in student grades, indicating that the method was successful. We have expanded upon this base of validation to further investigate the effects of pre-recorded lectures.

The inverted classroom has also been used to instill lifelong learning skills in electrical engineering students [6]. The

reactions of our students parallel the results found in this usage. Additionally, Toto et al. utilized the inverted classroom to teach select lectures within a junior-level industrial engineering course and showed significant correlations between student learning styles and attitudes toward the format [7]. We have similarly analyzed student reactions to the inverted classroom to verify their claims.

B. Instructor Concerns

A notable trend in education research is the student-centric viewpoint that most research assumes. Since, ultimately, education is about teaching the student, this view is acceptable. However, to the best of our knowledge, there is a lack of research on the effects and unintended consequences of distance learning on the instructor. We feel that the impact on the instructor is also important in evaluating teaching methods and thus we include this in our analysis.

III. THE INVERTED CLASSROOM

This paper focuses on the student and instructor experiences in a course redesigned to use the inverted classroom. This course is a senior and graduate level software engineering course.

In an effort to bring a more industry-centric view to software engineering, this course was redesigned to be an end-to-end course focused on enterprise architecture. The addition of this content to an otherwise large set of material proved to be unattainable in a traditional lecture-based class.

A. Course Demographics

The course has a diverse population of students, as it is cross-listed in both the undergraduate and graduate curricula. For most of the undergraduate students, the course is required as part of the Software Systems option for the B.S. in Computer Science and Engineering. The graduate students primarily take the course as an elective, though some are required to take it by their advisor.

In the case of this study, the students were distributed across three sections that were fairly equal in total enrollment but disparate in enrollment by standing, with 36 (19 graduate, 17 undergraduate), 38 (3 graduate, 33 undergraduate), and 32 (15 graduate, 17 undergraduate) students respectively. The first section was taught in the morning, while the latter two were taught in the evening. All sections met twice per week.

B. Course Structure

The structure of the course attempts to motivate students to keep up with the lectures during their study time. We provide electronic lectures to the students before the module is assigned. These lectures come in three forms: as a video, as a slide presentation with audio attached, and as lecture notes with the slides. Each week, the students are expected to consume a lecture in any of the three forms, take notes, and engage in discussion in an email discussion group. The instructor uses the in-class time during the week to add his or her personal experience to the lecture in discussion, conduct

activities with the students, and answer any questions the students have about the lecture content.

To motivate students to watch the lectures before the class session in which the lecture is discussed, we issue a quiz each week on the topic. These quizzes consist of one or two short essay questions and make up 10% of the students' grade. The wording is such that the students' answers are more about their argument and the support for it than whether they have a completely correct answer. The intent of this type of quiz is to motivate the students to internalize the concepts and think about how they interact, rather than have them focus on memorizing vocabulary and definitions.

The main component of the course is a project where the students go through all of the non-programming phases of the software development life cycle. First, the students must do a business analysis of a company of their choosing and develop an IT portfolio for that business. The students then choose one application from their portfolio and conduct each of the standard software development life cycle phases. The result is a project report detailing their work. A secondary goal of this project is to provide them with a reference for project proposals and workbooks later in their career.

C. Lecture Materials

In order to incorporate the new material within the fixed time frame of a one-quarter, three-credit-hour class, we designed the curriculum as an inverted classroom. The idea was, if we have the students watch lectures during their study time, more time would be available in the class sessions for activities and discussion.

The first iteration of the curricular materials simply consisted of slides with audio recordings that captured an entire traditional lecture. The audio was recorded to run in one contiguous segment for each slide. This produced a user experience that mimicked the problems in classroom lectures, such as the instructor not wanting to be interrupted or students forgetting questions by the time the instructor is ready to take questions; the format provided no good affordance to replay a piece of the lecture.

In addition to being frustrating for the students, the above mode of production was difficult for the instructor creating the lectures as well. Interruptions or background noise within the recording environment were more common and likely when recording long segments of dialogue, requiring major segments of the lecture to be redone.

The creation of these initial presentations provided a valuable experience in the creation of such resources. For our second iteration on the lectures, we broke the recording into smaller segments corresponding to sections of the slides that could be clicked on to replay. The shorter recordings allowed students to easily review specific sections of the lecture without having to listen to content that they already understood.

D. In-class Activities

Dale [8] found that students learn better from hands-on experiences, when compared to traditional passive methods.

This finding, called the Cone of Experience, shows that concrete experiences help inspire learning more than mere transmission. Because the inverted classroom frees up in-class time from the constraint of lecture, we utilize the in-class time through active, hands-on learning modules, as follows.

The most complex of these in-class activities is an interactive workshop in the form of a game, as discussed in [2]. In this game, the students form into small groups and learn about agile development principles. This activity takes an entire day of class, but results in the students having fun and enjoying the learning experience. Our evaluation in [2] requires further validation of whether the activity helps the students to learn better than a lecture.

Simpler experiential learning methods are also used. One instructor created an activity where the students simulate a call center. A small set of students are picked to stand in front of the class and act out the software architecture that the class as a whole designs based on the instructor's requirements. The instructor introduces conflicting requirements that the students must decide how to mitigate. After developing an architecture that meets the requirements, the students then determine how the architecture handles various incoming calls.

This short overview does not cover the entire course curriculum. For more information, see [9].

IV. PURPOSE OF THIS STUDY

After utilizing this curriculum over eleven quarters, we formulated several unanswered questions. Does the inverted classroom place a greater time burden on student study habits? Does the inverted classroom increase the quantity of discussion? What about the quality of discussion? Are weekly quizzes an effective means of ensuring students watch the lectures? Does the inverted classroom lessen the preparation time for instructors? Does the inverted classroom help make instruction quality more homogeneous across instructors than a traditional lecture format? The purpose of the present study is to address these questions and discover where the method succeeds and where it fails.

V. TEACHING AND EVALUATION METHODS

This study was designed to capture student and teacher experiences across three simultaneous sections of the senior-level software engineering course. A different instructor taught each section of the course. One instructor was an investigator in this study and is the course coordinator for the software engineering curriculum. The other two instructors were lecturers teaching in the department for the first time. Both of the instructors had teaching experience; one of them had previously taught university courses and had also taught in industry, while the other had no university teaching experience, but had taught in the Distinguished Engineer program at his company.

Each instructor used the same basic lecture for the ten course learning units. These lectures were made available in three formats: YouTube videos, PowerPoint presentations with attached audio, and written notes for each presentation.

All formats were available on the course website hosted on Google Sites. The students freely chose their own method for consuming the lecture material, but were provided an incentive to actually do so by the presence of a quiz on each topic prior to the topic's designated discussion day.

Interim questionnaires, as developed by the authors, were distributed to the students in each section at three points throughout the quarter. Each survey was distributed in class to the students in attendance. Post-quarter interviews were scheduled with nine students — three from each section — and both of the new instructors. Students were recruited via an email sent to the discussion group for each section. Interviews were conducted by the graduate student first author, rather than the faculty PI, to provide a more comfortable atmosphere for the interviewees and have them speak more candidly about their experiences. The students were provided a \$15 Amazon gift card for participating, whereas the instructors were not compensated.

VI. DATA ANALYSIS

This section discusses our analysis of the data obtained from three sources: surveys, interviews, and student grades.

A. Surveys

Descriptive statistics were computed for the surveys to explore the workload the inverted classroom placed on the students, as well as the level of engagement the students had for each topic. The overall response rate for the surveys was 90% (83% for the morning section, 95% for the first evening section, and 91% for the second evening section).

The surveys consisted of four items measuring three different variables of interest: two items measured time commitment, one item measured student learning, and one item measured student engagement. Time commitment was measured by one closed-ended item and one open-ended item, whereas student learning and engagement were both measured with a single closed-ended, 5-point Likert scale item.

The procedures for analyzing the surveys were as follows:

- 1) Compute frequency distributions for all surveys with classes aggregated to report general findings for the effect of the inverted classroom on student time commitment, learning, and engagement.
- 2) Compare differences between the classes for each topic to explore the effects of the inverted classroom in instruction homogeneity.

B. Interviews

The post-quarter student interviews were analyzed to check that the results of the surveys matched student experiences in the classroom. The analysis also yielded a qualitative measure of instruction homogeneity by comparing responses across the three sections.

The student interviews consisted of semi-structured question sets pertaining to five different topics: student satisfaction with the inverted classroom format (six questions), student evaluation of the in-class discussion (six questions), the efficacy of

the quizzes as a motivator (four questions), the value of the active learning activities (six questions), and the impact of in-class presentations on student projects (two questions). Three questions were in 5-point Likert scale form and the others were open-ended.

The instructor interviews, which were conducted during finals week, were analyzed to provide a measure of instructor satisfaction with the inverted classroom technique. In addition, the analysis afforded a qualitative measure of the effect of the inverted classroom on instructor preparation time.

The semi-structured question sets for the instructor interviews pertained to five topics: knowledge elicitation about instructor background (two questions), teaching preparation (three questions), the efficacy of techniques to motivate students to watch the lectures (two questions), and the effect of the inverted classroom on the instructor's teaching (six questions). One question was in 5-point Likert scale form and the others were open-ended.

C. Student Grades

The anonymized grades for the three sections were compared via a one-way ANOVA. There were eight quizzes, each covering a different topic. Each quiz was taken as a variable for analysis, with missing grades excluded.

Student grades provide a quantitative measure of instruction homogeneity. As the instructors were free to grade the student projects as they saw fit, the projects were ruled out as indicators. The quizzes for all three sections were graded by teaching assistants under the guidance of the authors, so the quality of the grading between classes was equivalent; thus the grading bias across sections was judged to be minimal.

VII. RESULTS

The analysis for this study amalgamates the results of the three data sources to provide a holistic view of the student and instructor experiences within the inverted classroom. Qualitative data, in the form of interviews with both instructors and students, provides grounding for the quantitative data obtained from surveys, student evaluations of instruction, and student grades.

A. Impact on Student Study Time

The course in question is a three-credit-hour, senior level software engineering class. It is intended to be of average difficulty; this fact, combined with the popular heuristic of three hours of study per credit hour says that students should expect to spend nine hours studying per week.

The student interviews included three questions about the time impact of the inverted classroom on the students' study practices. Of the nine students interviewed, two students said the class required significantly more (1.75 and 2.00 times as much, respectively) out-of-class work than a standard class. Four students believed the course required about the same amount of out-of-class work as a comparable course, and two said that the course required less work than a comparable one.

The differing opinions of the students stemmed from many reasons. Three students said that they appreciated the lectures

because they were forced to keep up with the work from week to week; this resulted in less cramming for the final exam. One undergraduate student said he felt an increased burden from the course format and that the burden affected his study in a negative way. However, he also stated that he was taking 22 credit hours in an effort to finish his courses before the university transitions from quarters to semesters. Additionally, the students rated their time commitment in relation to their study habits for other courses; depending on the study habits of the interviewed students, there could be a hidden bias within their responses.

Because the interviews provided conflicting data about whether the inverted classroom format placed more study burden on the students, surveys were administered to check whether students spent more than nine hours studying per week. Out of 128 responses, 84.4% of students responded that they spent one to six hours per week studying outside of scheduled class time. Broadening the window to six to twelve hours increases the percentage to 99.4% of the responses; only one response (0.06%) indicated more than twelve hours of study for the week.

Between the interviews and the survey data, there is evidence that the study burden is, on average, no more than that of a comparable course. That is, none of the data indicate an unacceptable increase in the amount of time required by the inverted classroom.

B. Quantity of Discussion

One of the stated goals of the inverted classroom was that it helped to increase the amount of two-way dialogue during class time, as the instructor was freed from lecturing and was thus able to hold hour-long discussions. In order to verify whether this was actually true, we asked students during the interviews about their beliefs regarding the quantity of discussion in the inverted classroom in comparison to discussion in a comparable, traditional course.

Of the nine students interviewed, eight of them said that there was noticeably more discussion during class than in a comparable class. The one dissenting student stated that there was often the traditional long pauses while the instructor waited for students to add to the discussion, but that discussion did eventually occur. His account does not match with the other two students from his section, thus weakening the conclusion that more discussion did occur than in a traditional class. However, the evidence did suggest an increase in the quantity of discussion.

C. Quality of Discussion

In addition to increasing the quantity of discussion, the inverted classroom was intended to increase the quality of discussion. To test whether this truly happened, we asked students during their interviews about the quality of discussion in the course relative to a traditional course.

Four of the nine students said the quality of discussion was better than in a comparable course. One of those four students said that she felt discussion was better, even when

compared to a traditional course that has a large discussion component. However, none of the students felt that the quality of discussion was substantially better.

The other five students said that they felt the quality of discussion was not necessarily improved by the inverted classroom, but was highly dependent on the questions that they and their classmates had for each topic. Since the course does not have a rigorous set of prerequisites, students enter the class with widely different knowledge bases. As such, the five interviewees said that some of the questions that their peers posed ranged widely afield from the heart of the course or were too simplistic to ask. They felt that the quality of discussion was lowered, not due to the inverted classroom, but due to the variance in the questions that were asked.

Based on these results, the evidence is inconclusive whether the quality of discussion is measurably better in the inverted classroom than in a comparable, traditional course.

D. Quizzes as Motivators

One concern within the inverted classroom is that students do not watch the lectures outside of class. To counter this, we introduced quizzes on each lecture that occurred at the beginning of the discussion day for each lecture. To test the efficacy of the quizzes as a method of motivating the students to watch the lectures, we asked the interviewed students and instructors whether or not the quizzes were effective.

Eight of the nine students stated that they felt the quizzes were effective. They also said that the quizzes helped to guide their study, once they were acclimated to the format of the quizzes. One student did not think the quizzes were effective as a motivator because he felt that one could skim the lectures and get “good enough” partial credit on each quiz.

Both instructors considered the quizzes effective. However, they both disliked the anxiety that the quizzes introduced. One instructor said that the time limit on the quiz made the students feel rushed and felt that their performance was degraded by that worry. The other instructor thought there were too many quizzes during the quarter and that the students felt too pressured by the presence of a quiz each week.

From these results, we concluded that the quizzes were effective as a means of ensuring students watched the lectures before the discussion date. However, there were unintended consequences in the form of increased student anxiety. Course instructors who wish to implement an inverted classroom must weigh that concern against the benefits of the format.

E. Instructor Preparation Time

Preparing for a traditional class requires creating a lecture and anticipating student questions on that lecture. However, in the inverted classroom, there is no in-class lecture, but either a discussion or activities intended to hone student understanding. As such, an important question is how the inverted classroom affects the preparation time for the instructor. To study this, we relied on self-reporting in the form of interview questions with each instructor.

TABLE I
THE MEANS AND P-VALUES FOR QUIZ SCORES BETWEEN THE THREE SECTIONS. QUIZZES WERE GRADED ON A SCALE OF 0–3.

| Quiz | μ_1 | μ_2 | μ_3 | p-value |
|------|---------|---------|---------|----------|
| 1 | 2.47 | 2.37 | 2.67 | 0.353 |
| 2 | 2.44 | 2.63 | 2.12 | 0.0307 |
| 3 | 2.36 | 1.71 | 2.82 | 5.31e-07 |
| 4 | 1.83 | 2.08 | 1.42 | 0.0301 |
| 5 | 2.33 | 1.84 | 2.27 | 0.0504 |
| 6 | 2.42 | 2.03 | 2.58 | 0.0237 |
| 7 | 2.58 | 2.03 | 2.70 | 0.000672 |
| 8 | 1.83 | 2.26 | 2.76 | 8.45e-05 |

One instructor was experienced with teaching in academia, while the other was only accustomed to teaching in the context of his industry career. Both instructors stated that there was radically less preparation time required to teach this course than a traditional course, but for very different reasons.

The academic instructor found that he spent two to three times less time preparing for each class because he focused on finding the weaknesses in the recorded lectures and spent class time addressing those weaknesses. To address the lecture weaknesses, he first watched each lecture while taking notes, and then found freely available videos from outside sources to cover the topic, which consumed most of his preparation time. He used in-class examples from his industry experience to provide some grounding for his students.

The non-academic instructor teaches a very similar curriculum for his industry career, so did not have to spend much time solidifying his understanding of the inverted lectures. He focused on finding good examples of the course concepts in practice, in order to ground the material for the students. Most of his preparation time was spent on arranging time for coworkers to come in and present their work to his class. He also spent time finding job-related work products that he could share with the class to show the students what each topic looked like when translated to a real work process.

Because the instructors did not have to prepare a lecture for each day of class, the preparation time was less than for a traditional class. However, the depth to which the instructor went to address perceived lecture weaknesses varied depending on personality. Thus, the inverted classroom lessened preparation time in some respects compared to a traditional class, but highlighted additional preparation challenges for the instructors.

F. Homogeneity of Instruction Across Instructors

The inverted classroom takes the responsibility of creating lectures out of the hands of the instructors and places it into the curriculum designers. As such, the quality of instruction for different instructors should be more homogeneous than in a traditional classroom where different lectures are used by different instructors. To test this, we used the anonymized student grades as indicators of the instruction quality.

The student grades were analyzed via a one-way ANOVA between each quiz for each instructor. The null hypothesis was that the means for the two sections were equal. The

alternative hypothesis was that the means for the two sections were not equal. As seen in Table I, for quizzes 1 and 5, there was insufficient evidence to reject the null hypothesis ($p = 0.05$), whereas there was sufficient evidence to reject the null hypothesis for quizzes 2, 3, 4, 6, 7 and 8. Thus, as a measure of instruction homogeneity, the student grades suggest that the quality of instruction varied across instructors.

VIII. CONCLUSIONS

The inverted classroom is a new method of teaching that requires a different balance of commitment from both the students and the instructors. As such, we had several questions that came to light after teaching in the format for several quarters. We designed metrics to validate our hypotheses about each of these questions.

Since students are required to watch lectures during their own time instead of during scheduled touch points with the instructor, we wanted to ensure that the students were not overburdened by this single class. We issued surveys to measure how much time the students were spending each week on the course. We also interviewed students to provide qualitative data on the subject. No indication of overburdening was present in any of the instruments, so instructors looking to implement an inverted classroom approach should not be concerned with it creating a burden on students.

A goal of the inverted classroom is an increase in the quantity and quality of discussion in the class. By interviewing students, we were able to assess the general feelings students have about discussion within the classroom. The evidence shows that there is a measurable increase in the quantity of discussion. However, we were unable to show an increase in the quality of discussion. According to the student interviews, the quality of discussion was highly dependent on the students in the class. As such, we must further investigate the question of measuring discussion quality.

One of the concerns with the inverted classroom approach is that students do not watch the prerecorded lectures. In order to combat this concern, we implemented a series of quizzes that were held on the discussion day for each topic. We validated the efficacy of this technique via our interviews with students and instructors. Students stated that the quizzes were an effective means of ensuring they watched the lectures. However, instructors noticed student anxiety regarding the quizzes. This shows that there is a trade-off inherent in this enforcement policy, where instructors must consider the ramifications and whether the increase in students watching the lecture is worth the additional anxiety associated with quizzes.

Given that the inverted classroom changes the way instructors have to prepare for class, we interviewed two instructors to confirm our hypothesis that the inverted classroom lessened the burden of preparation on the instructors. Both instructors indicated that it was easier to prepare for this class than for a

traditional one, additionally stating that they were free to look for examples of the course concepts to share with the students.

Lastly, we hypothesized that the inverted classroom made instruction quality more homogeneous between different instructors. We were unable to validate this claim by using quiz grades as an instrument. We believe that the variance between classes is related to the instructors' use of supplementary materials, such as industry examples, extra in-class videos, and the discussion within the classroom. We will work to provide a better measure of instruction quality to further investigate this claim.

In the future, we will perform a longitudinal study to see how much of this course the students retain and can later apply. We also will investigate extending the longitudinal study into the workplace, as several students from the course graduate and begin working for local companies. Additionally, we will convert and extend the curriculum into a professional development series for local professionals.

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Lessons Learned Implementing and Optimizing Guided Discovery Modules

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Abstract—Students notoriously struggle with common misconceptions in Engineering Mechanics curriculum that negatively impact later courses in Mechanical Engineering and related disciplines. Moreover, traditional, lecture-based curriculum for Statics and Dynamics does not promote sustained student engagement. This paper presents a series of Guided Discovery modules that target key concepts.

Guided Discovery is a methodology that borrows aspects of challenge-based instruction and discovery learning. The method is designed to facilitate students paths to discovery of key concepts that are often misinterpreted or not readily mastered. This is accomplished by facilitating students timely discovery of the underlying fundamentals through physical or virtual interaction with Statics and Dynamics challenges.

The key difficulty to insuring positive impact on concept mastery is sustaining student engagement throughout the process. When students actively participate in every step, there is a significant improvement on comprehension and retention of commonly misinterpreted concepts. In this paper the authors summarize existing modules and present some of the results. Additionally, the authors detail typical shortcomings that resulted in early implementations of the modules and strategies for overcoming those shortcomings.

I. INTRODUCTION

Part of the difficulty of encouraging students to think critically about Engineering Mechanics is that some view the material as disconnected facts and formulas as opposed to an interconnected web of concepts [1]. There is a tendency to approach Mechanics problems by identifying the applicable equations as opposed to recognizing underlying concepts. It is not always students' tendency to critically evaluate the information given and methodically analyze it using their engineering intuition. Even when they do, often times they have preconceived misconceptions that hinder effective analysis. Effort must be made to refocus students so they approach Mechanics as an interconnected web of concepts. Traditional pedagogical approaches alone do not encourage this. As such, alternative methods must be devised.

A number of studies have developed strategies to improve mastery of Mechanics concepts. Elby et al. [1]–[3], researched the role of students perceptions of Physics in hindering concept mastery. The North Carolina State University Physics Education Research and Development Group, the largest physics

education research group in the Nation, developed and researched the use of animation to assess physics concepts mastery [4], [5]. Gray et al. [6], [7] devised a format for Dynamics curriculum deemed Interactive Dynamics. The format involved collaborative learning, computer simulations, and experimentation. Magill of Purdue University designed a series of inexpensive bench-top exercises used to demonstrate basic Mechanics principles [8], [9]. Steif and Dollár devised a series of simple experiments and web applets used to demonstrate Statics concepts [10]–[13]. Everett et al. [14], [15] developed counter intuitive Dynamics examples designed to expose students misconceptions.

Challenge Based Instruction (CBI) [16]–[19] utilizes backward design to develop challenges that target specific student learning outcomes. The challenges are implemented through a process known as the STAR.Legacy Cycle. The steps of the cycle include look ahead (or reflect back), generate ideas, gather multiple perspectives, research and revise, test your mettle, and go public. The challenges are designed to instill an increasing depth of knowledge through enhanced student engagement and the method is synergistic with the How People Learn framework detailed in [20]. They typically involve several lectures and homework assignments

Education experts continue to urge Engineering educators to transform from a lecture-based paradigm to one that is more inquiry-based. Despite advancements, widespread reform has not taken place because of (1) a reluctance to implement pedagogical changes and (2) deeply rooted student misconceptions.

Guided Discovery is a methodology that borrows aspects of challenge-based instruction [16]–[19], discovery learning, and counter-intuitive examples [14], [15]. The method is designed to facilitate students paths to discovery of key concepts that are often misinterpreted or not readily mastered. The method is optimized for short, in-class activities and is intended to strategically target specific misconceptions in a focused and timely manner.

The authors contend that through the use of well-devised Guided Discovery modules, students become more engaged and are more prone to correctly interpret Engineering Mechanics concepts. Such modules can better engender properly conceived engineering intuition and better help contextualize

concepts. These modules place emphasis on understanding the problem and not on simply trying to find the right answer(s). Moreover, they require the student to be actively involved in the process of discovering the answer.

II. GUIDED DISCOVERY METHODS AND PROCEDURES

Guided Discovery is an active-learning method intended to bring laboratory-like experiences into the classroom to improve concept mastery and student engagement. The modules target concepts that students commonly fail to master and that negatively impact learning outcomes in later courses. This is accomplished by facilitating students timely discovery of the underlying fundamentals. Throughout the process, students are consistently prompted to answer probing questions and exchange ideas.

The methods and procedures described herein were originally introduced in [21] and are discussed in more detail in [22], [23]. The intent of these modules is to complement but not fully supplant existing curriculum.

The modules share some common characteristics:

- *Inquiry-Based.* Modules, when possible, are purposely posed with open-ended questions that force students to demonstrate concept mastery by expressing through tasks and words a deeper understanding.
- *Collaborative-Learning.* The modules incorporate steps that require students to share knowledge, discuss answers, and arrive at conclusions through collaboration.
- *Interactive.* The modules require students to interact physically or virtually with the physical system to solve problems.
- *Common Misconceptions.* The modules target common misconceptions or fundamentals that students struggle to master early on.
- *Discovery.* The modules are designed to guide students to discover underlying principles and build properly formulated engineering intuition.

In addition to having common characteristics, these modules are implemented using similar processes developed by Kypuros et al. [22]. The overall process involves lecture, a pre-module assessment (to establish a baseline), a primary exercise, an intermediate assessment, a secondary exercise, and a post-module assessment. Each module includes the assessment questions, handouts, supporting materials (such as videos, worksheets, reading material, etc.), list of equipment, and procedures.

The primary exercise is the actual Guided Discovery activity. A flowchart and detailed description of the process are provided in [21]. The procedure is summarized below for convenience:

- A problem or challenge is posed with a set of seemingly plausible answers,
- Students are polled for an initial answer,
- Students are asked to discuss the problem,
- Students are allowed an opportunity to change their answer based on their discussion,

- A bench-top or virtual experiment is conducted to allow the students an opportunity to discover the answer,
- The instructor or assistants observe and pose probing questions to help redirect or reinforce students' critical thought process,
- Students are allowed a final opportunity to change their answer.

The experiment may be the actual challenge posed or a problem that operates on the same basic principles that are targeted by the module.

The modules, whenever possible, center around a real-world, semi-open-ended challenge. The challenge for the Pulley Module, for example, is,

"You stalled your prize 6500 lb, heavy-duty, 4x4 in a creek bed at the bottom of an embankment about 15 ft away 9 ft down and 12 ft over. The engine will not turn over because the ignition circuit was damaged when it got wet. Unfortunately the only winch available is attached to your friends ATV. It is only rated at a maximum 1750 lbs and operates with a constant line speed of 15 feet per minute (FPM). However, it has plenty of cable (200 ft), and you have access to a winch kit with one heavy-duty pulley block (rated at 10,000 lbs), two light duty pulley blocks (rated at 2500 lbs), two 10-ft tow straps (rated at 20,000 lbs), and two shackles (rated at 3000 lbs). Shackles and two straps may be used to attach cable, pulleys, or tow straps to the bumper of the truck. There are numerous trees that could be used to anchor the ATV and to attach tow straps with pulley blocks. From the choices provided, choose an option that will pull your truck up the embankment without exceeding the rating of any of the components used. Determine the tension in the cable and the time that will be needed to move the truck up the embankment. Also, explain any assumptions you made."

The students are provided four possible configurations illustrated in Figure 1 two of which will work – one requiring the least amount of force and the other the least amount of time.

A series of modules have been developed and tested including the following:

- The Gravity Module [22],
- The Vectors Module [22],
- The Pulley Module [23],
- The Free Body Diagram Module [24],
- The 2D Particle Kinematics Module, and
- The Moment Module [24].

Of these, the Gravity and Vectors Modules have been implemented at least two semesters and have matured through at least one iteration.

III. RESULTS

The results presented herein are just a subset of a larger data set. Results for just a few modules and their initial

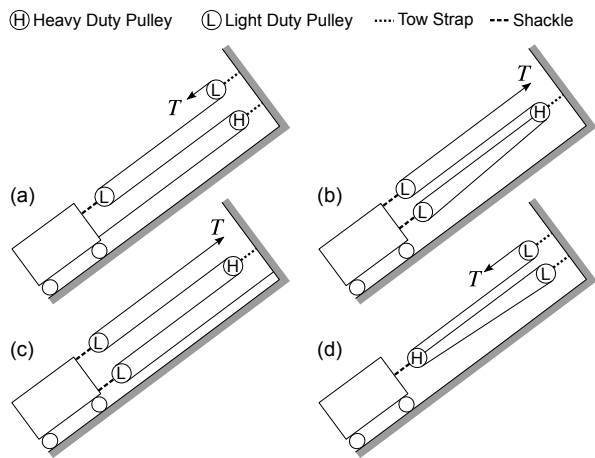


Fig. 1. Pulley Module possible solutions

implementations are discussed below. A more comprehensive review is in preparation for a forthcoming journal publication.

A. The Vectors Module

Students have difficulty understanding, visualizing, and differentiating position, force, and unit vectors in 3 dimensions. They often fail to connect numerical solutions with physical concepts. Case in point: students may miscalculate the unit vector along a direction of a supporting cord resulting in a vector that is obviously in the wrong direction. The students do not always take a moment to step back and assess if the result makes physical sense. The concepts and mathematical constructs are treated as abstract without contemplation of their physical implications.

In the first implementation of this module, the instructor presented the concept of unit vectors in lecture and reviewed several examples. A pre assessment was administered to establish a baseline. The pre assessment measures whether students can identify an appropriate unit vector from a list of options just by looking at a figure. The students were posed the following question and given three minutes to answer:

“A block is hanging at point A and held in static equilibrium by three cables as shown in Figure 2.

The unit vector from point A to D could be:

- (a) $\mathbf{u}_{AD} = 0.47\mathbf{i} + 0.69\mathbf{j} - 0.56\mathbf{k}$
- (b) $\mathbf{u}_{AD} = -1\mathbf{i} - 1\mathbf{j} + 1\mathbf{k}$
- (c) $\mathbf{u}_{AD} = -0.47\mathbf{i} - 0.69\mathbf{j} + 0.56\mathbf{k}$
- (d) $\mathbf{u}_{AD} = 0.74\mathbf{i} - 0.60\mathbf{j} + 0.30\mathbf{k}$
- (e) $\mathbf{u}_{AD} = 1\mathbf{i} - 1\mathbf{j} + 1\mathbf{k}$ ”

In a separate lecture, the students experimented with a setup similar to that depicted in Figure 2 using a mass, string, load cells, rods, and clamps. They were tasked with measuring tension in each chord and expressing each as a vector using a coordinate system of their choosing.

Immediately after the exercise and later as a follow-up on the final exam, the students were again administered the same or similar question as that posed above. The assessment results

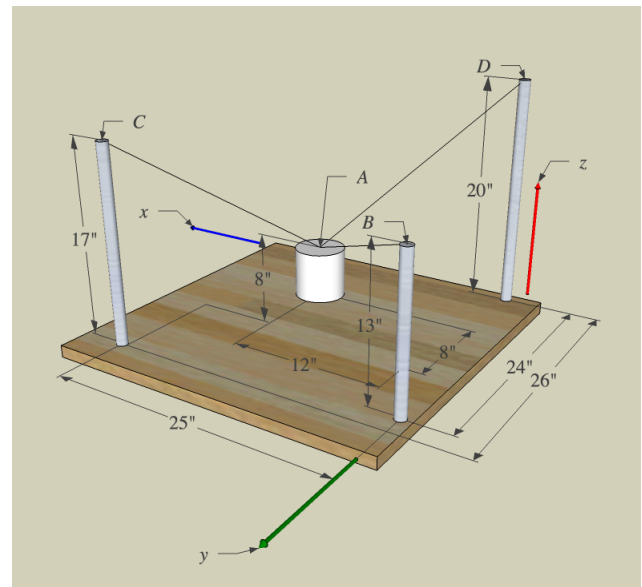


Fig. 2. Schematic of Vectors Module challenge

for pre, intermediate, and post assessments are provided in Figure 3.

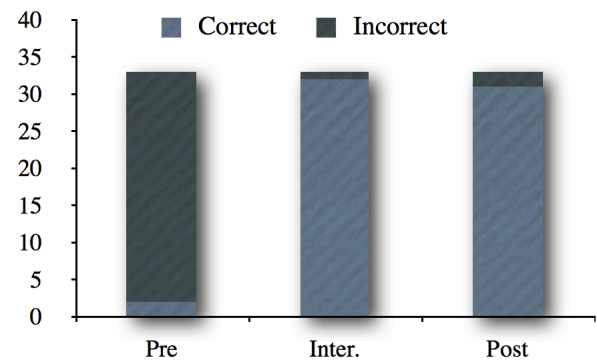


Fig. 3. Results for pre, intermediate, and post assessments for Vector Module

For this study, 33 students participated in all three assessments. In the pre assessment, 2 of the 33 answered correctly. In the intermediate and post assessments, 32 and 31 students answered correctly. The results imply that the exercise had a positive and statistically significant impact on the immediate understanding and longer term retention of knowledge. However, results for subsequent semesters varied and did not show quite as drastic a positive impact. This can be traced to modifications made in an effort to improve the module which had unanticipated negative influence. This will be discussed later in the section titled “Lessons Learned.”

B. The Gravity Module

Students tend to struggle with the idea that the size of an object is not what dictates its vertical acceleration. It seems counter-intuitive that, barring the influence of air drag, a feather

will fall at the same rate as a bowling ball. It may be inconceivable that acceleration due to gravity is mass independent because students tend to associate acceleration directly with force (or weight in this case) and do not always distinguish the subtle differences between the two. Moreover, it is not entirely intuitive that when looking at two dimensional (2D) particle motion in a gravity field the horizontal displacement is decoupled (independent) from the vertical displacement.

This module is intended to demystify some of these misconceptions and elucidate the nuisances that do cause vertical acceleration to change. In this module, students experiment with a variety of spheres of varying size and mass. They are presented a challenge. For example, they are presented two spheres and asked which will hit the ground first if released simultaneously from the same height. The variety of spheres is chosen to illustrate the concept and its exceptions. That is, spheres range from solid wood to a wiffle ball. This module, its assessments, process, and preliminary results are detailed in [23].

The process utilized for this module was similar to that used for the Vectors module. The instructor discussed basic one- and two-dimensional particle motion. In a subsequent lecture, the following pre assessment question was administered to establish a baseline:

“Two metal spheres are the same size but one weighs twice as much as the other. The spheres are dropped from the roof of a single story building at the same instant. The time it takes the balls to reach the ground below will be

- (a) about half as long for the heavier sphere as for the lighter one,
- (b) about half as long for the lighter sphere as for the heavier one,
- (c) about the same for both,
- (d) considerably less for the heavier sphere, but not necessarily half as long, or
- (e) considerably less for the lighter sphere, but not necessarily half as long.”

As a homework assignment, the students were tasked with experimenting with a variety of spheres of their choosing. Additionally, in the next lecture, some demonstrations were conducted with pairs different spheres. They were then re-administered the same or similar question. As a follow-up they were then posed the ensuing question:

“The same metal spheres roll off a horizontal table simultaneously. In this situation

- (a) both hit the floor at nearly the same horizontal distance from the ledge,
- (b) the heavier sphere hits the floor at about half the horizontal distance from the ledge as the lighter sphere,
- (c) the lighter sphere hits the floor at about half the horizontal distance from the ledge as the heavier sphere,
- (d) the heavier sphere hits the floor considerably

closer to the ledge than the lighter, but not necessarily half the horizontal distance, or

- (e) the lighter sphere hits the floor considerably closer to the ledge than the heavier, but not necessarily half the horizontal distance.”

Unlike the Vectors Module, the follow-up assessment was administered soon after the intermediate and not as a final exam question.

The results for all three assessments are illustrated in Figure 4. The pre assessment showed a near even split between those who answered correctly and those who did not, 13 versus 12. After the homework assignment and demonstrations, 19 answered correctly versus 6 incorrectly. The follow-up question showed a decline, 12 versus 13. This pointed to a key issue. Students failed to connect one-dimensional motion in a gravity field with two-dimensional motion in the same gravity field. There was a conceptual disconnect between the two related problems. Several strategies were implemented in succeeding iterations with similar mixed results. Though subsequent implementations have shown better results when comparing the pre and intermediate assessments, the students regularly answer incorrectly on the follow-up assessment. This too is discussed further in the section “Lessons Learned.”

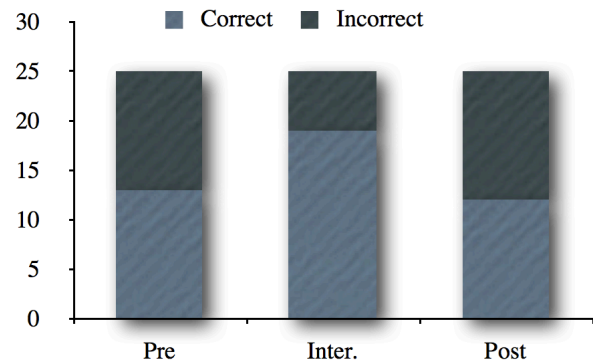


Fig. 4. Pre, intermediate, and post assessment results for Gravity Module

IV. LESSON LEARNED

Preliminary implementations pointed to some clear challenges and shortcomings. The key challenge to insuring positive impact on concept mastery is sustaining student engagement throughout the process. When students actively participate in every step of the process, there is a significant improvement on comprehension and retention of commonly misinterpreted concepts.

Both modules discussed in “Results” were implemented over the course of several lectures. In subsequent iterations, videos and materials were prepared for students to review before the primary exercise was conducted. A video was provided for the Vectors Module which details how to setup the experiment and collect data. The intent was to minimize the time in lecture necessary to collect data and maximize time for discussion and probing questions. For the Gravity

Module, a similar video was prepared, however, the focus was to demonstrate the basic principles for one- and two-dimensional particle kinematics. Unfortunately, in both cases less than 50% of the students actually came prepared to the lecture having reviewed the materials provided.

The Vectors Module in particular can be excessively time-consuming. Until recently, the day of the primary exercise, the module was implemented such that students would come into lecture and set up the experiment. The instructor had hoped that the hands-on experience of setting up the experiment would help the students with other important skills. However, those skills are not strategic to the misconception that the module is designed to target. Hence, in future implementations, the experiment will be set up and ready for the students to measure and collect data. This allows more time for the student to discuss results and allows the instructor(s) and teaching assistants more time to interact with each group to ask probing questions that redirect them along the path to discovery.

The Gravity Module has consistently shown that students do not associate one-dimension vertical motion with two-dimensional vertical motion. Though most are convinced after the primary exercise that the vertical motion of a particle is independent of its weight, they appear to think otherwise if the motion is two-dimensional. Even after several demonstrations with varying spheres released from rest atop a ramp placed on a table edge as illustrated in Figure 5 the students were still not uniformly convinced that the two spheres would travel the same horizontal distance. Even the slightest difference in results due to the spheres not being released at exactly the same moment or in the same manner was reason enough for many to believe the spheres would travel different horizontal distances before impacting the ground. Despite the theory and equations supporting the contrary, many students failed to see the connection between one- and two-dimension particle motion in a gravity field.

The authors continue to investigate this phenomena and formulate strategies to overcome this misconception. One of the strategies that will be tested in future iterations is to task one group of students with theoretically and experimentally proving what many believe to be the case – the heavier sphere should travel further horizontally before impacting the ground. Yet another group will be tasked with proving the actual truth. Each group will present their case to the class and the class must judge which is in fact the properly conceived fundamental concept.

In implementing the various modules, the authors have identified a number of issues that should be considered when designing a module:

- Some modules, in their current design, span several class periods which can result in inconsistencies if students miss a lecture or fail to complete an associated homework assignment.
- Lack of consistent student participation throughout the process has severe ramifications on results.
- If the scope of the module is not strategically limited to addressing the key concept/misconception the module

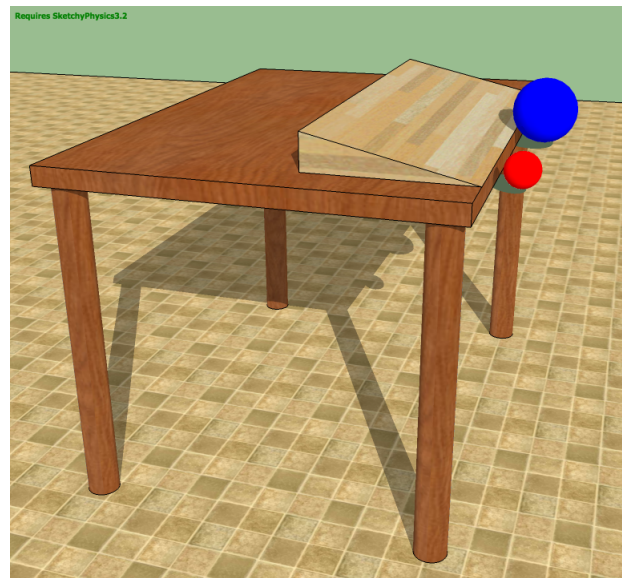


Fig. 5. Gravity Module secondary exercise

becomes unwieldy.

- Sufficient time must be allotted for probing questions and student interaction.

Though modules have shown to be effective at elucidating misconceptions or challenging concepts, success is contingent on active student participation. Modules must be designed to insure that each student actively participates otherwise results can vary. Students must come to recognize the cost benefit and be vested in participating. The following outlines some strategies to insure consistent student engagement and persistence throughout the process:

- *Limit the scope.* Start with the expected student learning outcomes which should not exceed but a few items and limit the scope of the module so that it targets only those outcomes. Avoid ancillary objectives that are not critical to the primary student learning outcomes. Make sure the module is self-contained to insure student engagement and persistence from start to finish.
- *Get students vested.* Do not assume they recognize the benefit at the start of the module. Minimize the amount of work they must expend in preparation for the module. Rather, back load the effort because they may begin to see the benefit later in the process. Remember that the goal is not the lab-like exercise but rather mastering the concept in a timely manner.
- *Limit to one lecture.* The most significant impediment to persistence throughout the process is the lack of participation at all stages of the process. By extending the module over several lectures, the instructor runs the risk of students dropping in and out of the process because they miss a class or do not complete an assignment associated with the module. Though it would be ideal for students to think critically about the challenge outside the classroom, it is more important that most if not all of the

students are on the same page.

- *Do not forget the probing questions.* Instructors should anticipate the most common mistakes or misinterpretations and develop a series of prescribed questions that elicit the desired thought process and discovery.
- *Optimize data collection.* The procedure includes several steps where students select an answer and the results are reported to the class. This can be done by a show of hands and a quick count, but one should make sure whatever the method used, it should not consume too much time. The focus is on the results and not the data collection. Survey systems or clickers might minimize the effort and time expended.

V. CONCLUSIONS AND FUTURE WORK

Guided Discovery shows much promise in overcoming misconceptions and improving properly conceived engineering intuition. Persistence throughout the process is key to insuring positive results. Modules need to be optimized to minimize time and maximize student engagement.

Each of the modules described herein have been implemented at least once. Some shortcomings have been identified and need to be addressed in subsequent iterations. Many of the modules in their current form require more than one lecture. To expedite the process, pre-module material in the form of handouts, videos, and the like have been used, but have not proven to be effective. Students do not uniformly complete these activities before coming to class. These inconsistencies have undoubtedly had a negative impact on assessment results. In future iterations, measures must be implemented to insure consistent participation throughout the process.

In future implementations, we will adapt strategies to improve persistent participation and separate out the assessment results of those who do not complete pre-module activities. Moreover, module procedures will be minimized to include only critical steps deemed necessary to improve understanding.

ACKNOWLEDGMENT

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Work in Progress: Student-Directed Learning:

An Approach to Sustainability and Engineering Education

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Abstract — An increasing focus in K-12 educational outreach is on the fields of science, technology, engineering, and mathematics (STEM). A challenge in educating students about STEM topics is the ability to communicate the key concepts on a level that engages the students. The student-directed learning approach allows the students to create educational content and the teacher to oversee the development. The student's peers serve as the audience, shifting the interface of students and teachers, as well as increasing student to student interaction. The proposed approach is based on the outcomes of a preliminary internship, which challenged students to develop a week-long module to communicate one of four sustainability concepts: green building, energy, water and green materials. The proposed study will focus on a larger sample of middle school students developing educational modules focused on sustainability and engineering. In-depth assessment of the student developers will provide information on audience awareness, self-efficacy, as well the effectiveness of the approach.

Keywords—sustainability; engineering education

I. INTRODUCTION

Through partnership between the University of Pittsburgh's Learning Research and Development Center (LRDC) and the Mascaro Center for Sustainable Innovation (MCSI), a proposed approach for student-directed learning is explored to increase student engagement in sustainability and engineering topics. The approach stems from the preliminary study in which an NSF funded program provided rising tenth grade high school students with the opportunity to serve as interns [1]. The interns were tasked with development of a sustainability and green building module for their fellow peers in the hope that students would share the best ways in which they learn. The internship provided them with a unique opportunity to develop a module for a high school class, while learning about sustainable engineering topics. This paper discusses this less common approach to engineering education, as well as future studies to further assess the impact of student as developer on student learning.

Based on the preliminary internship an additional study, presented here, was developed to further explore what motivates students to engage in extracurricular course content and how to meaningfully impact student learning. The study expands on established methods (i.e. active, collaborative, and problem based learning) of engaging students in engineering [2]. The approach aims for students to independently achieve high levels of synthesis and evaluation through self-directed

learning. The approach allows the students to create content and the teacher to oversee development. The student's peers serve as the audience, shifting the interface of students and teachers, as well as increasing student to student interaction.

II. STUDENT AS DEVELOPER

A. Approach

Designing materials for other learners may have potential as another strategy for K-12 engineering education. While conceptually, "student as teacher" has been considered in the reciprocal teaching model, "student as developer" has received little attention. Design-based learning shifts the role of the student from "consumer" to "designer" in an effort to teach engineering. While students remain consumers of a "prescribed" curriculum, the design of the unit gives them a sense of autonomy to "design a product that meets a need in your own life." This approach has shown to increase student engagement and motivation for learning science [3]. In addition to a design based approach, methods which relate the topic to real-world context also an increased impact on student learning. This is essential to introduce and teach students the concepts of sustainability and engineering.

Traditionally, curriculum is created by an external source (*developer*) and imported into the classroom. The teacher (*user*), an internal classroom source, is tasked with translating and communicating the developed curriculum to the students (*audience*). The LRDC-SSOE model, as shown in Fig. 1, integrates the role of developer and user through teacher experience. Teachers develop curricular material, which translates their own engineering experience into classroom learning. In this way the teacher assumes a dual role of developer and user for their students who remain in the role of audience. The student as developer approach (Fig. 1) explores how shifting the role of a student impacts student learning.

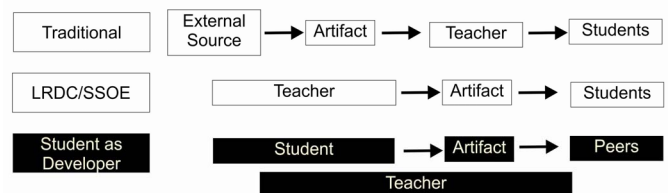


Figure 1. Comparison of Curriculum Development Models and Internship Design Framework.

The approach places students in the role of developer, while their peers remain in the audience (Fig. 1). The teacher assumes a role in which they are able to oversee the development and facilitate a learning experience for both the developer and the audience. The student as developer approach seeks to be a bridge between individual student learning and classroom, or peer, learning by tapping into the ways in which students communicate and understand. Rather than a top down approach from external curriculum developer to students, this approach may be a more organic way to access student interests and understandings about sustainable engineering topics.

I. STUDENT-DIRECTED LEARNING

To explore the student-directed learning approach, in the proposed study, the peer review process will be utilized to determine the impact of student as developer on individual and on peer learning. The use of peer assessment aims to provide students with skills of recognizing an audience, as well as communication and evaluation skills [4]. The proposed study will build on the outcomes from a preliminary internship and will further assess the impact of student as developer on student learning.

A. Preliminary Internship

The preliminary internship design included specific constraints designed to address the difficulty of integrating engineering education into existing curricula. The students were required to develop a week-long module to communicate one of four sustainability concepts: green building, energy, water and green materials. Additionally, the students were required to link the topic to one of the following content areas: math, science, and history. In this way, the interdisciplinary nature of sustainability would be naturally integrated and provide a lens through which to situate their module. In contrast to the content requirements (proposal letter; teaching plan and materials; assessment tools; summary presentation and poster), the students were not constrained in the methods used to engage students learning of the concepts, (such as hands-on demonstrations, experiments, games, etc.).

At the start of the preliminary internship, the students stated they were unfamiliar with the subject of sustainability. The selection of a content area (often a favorite subject) served as a lens to situate their module and supported their emerging understanding of the concept. For example, one of the female interns enjoyed mathematics and used that as a lens for her unit on Energy, which utilized mathematical models that describe energy conversion to help understand sustainable energy concepts [1]. Curricular materials were created for teachers, which included lecture and review notes (PowerPoint to support classroom discussions), in-class worksheets (word searches, fill in the blank about, and well specified word problems), and homework assignments. The materials reflected the traditional tools and methods that the student developers associated with teaching. In the approach of student as developer (Fig. 1), the development of an artifact served as the process in which the interns deepened their understanding of sustainability engineering through the lens of a self-selected alternate discipline area. This supported the

widely accepted belief that we understand at one level when we learn for ourselves, but at a different, often deeper level, when we have to “teach” that understanding to someone else [5]. An additional outcome of the study was an intern, who previously showed no interest in engineering, developed a new intent to pursue engineering as a field of study. The outcome suggests that the impact of student-directed learning may expand beyond comprehension of the concepts and increase accessibility to engineering.

B. Proposed Internship

The proposed study will focus on a larger sample of middle school students developing educational modules focused on sustainability and engineering. The four content areas will be implemented in the Science and Social Studies classes as part of a larger program to explore engineering. Assessment will include an iterative peer review process, through which the interns (n=10) will obtain feedback from a community of their peer interns. The iterations will provide the opportunity for optimization of the material, as well as reveal the impact of the act of creating as a learning tool. Through pre- and post-surveys of the peer review community (n=60), student learning as a recipient and reviewer will be assessed. In-depth assessment of the student developers will provide information on audience awareness, self-efficacy, as well the use of the engineering design process. To address the dynamic field of sustainable engineering and technology, the modules from the previous year will be utilized and revised by the new interns. The revisions will provide additional layers of assessment and the understanding of the depth of knowledge gained over three years. External assessment will be obtained through classroom observations, intern and teacher interviews.

II. SUMMARY

In summary, this paper explores the less common approach that has students design materials for other peer learners. The preliminary internship approach explored the potential of student as developer of materials for other learners as another strategy for K-12 engineering education. The student as developer module has the potential to impact K-12 engineering education, through an approach that increases student engagement and motivation for learning sustainable engineering concepts.

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Effective Teaching of Technical Teamwork to Large Cohorts of Engineering Students in China

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Abstract—Teamwork skills are recognized internationally as important skills for engineering professionals. Literature shows that professional skills, especially teamwork skills, have not been included into the curriculum design and assessment in Chinese engineering programmes, and little work has been done to find the effective way to learn teamwork for engineering students in academic settings in China. This work attempts to implement successful cooperative learning practices from the West to a Personal Development Plan module with teamwork skills as one of its main teaching objectives in a joint Sino-UK degree programme in China. This paper reports the real situation of cooperative learning for Chinese engineering students. Experimental results indicate that there is no significant difference between different grouping methods on both academic and teamwork performance, although self-selected groups do not appear to be the best approach for Chinese students. No statistical correlation was observed between peer rating and the mark obtained for the task. Students can rate themselves and others, and different genders without bias. In the MBTI test, we found higher frequencies of Feeling over Thinking, and Judging over Perceiving. These students need more knowledge and training on conflict resolution skills and multi-task management skills to overcome their intrinsic weakness in cooperative learning.

Keywords- Chinese engineering students; cooperative learning; teamwork skill; MBTI; peer rating; correlation; grouping methods

I. INTRODUCTION

The study was initiated by a complaint in 2007 from a top Year-3 student on the Joint Programme (JP) between Queen Mary (QM) and Beijing University of Posts and Telecommunications (BUPT). She complained about her teammates not pulling their weight in a group coursework. After an interview with her, it was found that she was really upset about having to complete a coursework exercise in a group, although she performed very well in leading a student union department and in relating with her peers. She preferred individual work, or self-selected groups. In her words, “teamwork and communication skills can be practiced in extra class activities or sharing dormitories, but should not be included in the academic arrangement”.

This caused a re-consideration of engineering education in China. In such a highly collective society, almost all activities are organized in groups. Has it been a problem for young people to cope with others? Is the cooperative spirit in

daily life the same as the technical teamwork in academic or working settings? The answer seems to be “No”.

In China, more than 600,000 engineering students graduate in each year [1]. However, many western countries are not producing enough engineers; in America, nearly two-thirds of industries reported that the engineering and science related jobs are the hardest posts to fill [2]; in Australia it is even worse with Engineers Australia estimating a shortage of 20,000 engineers [3-4]. Chinese engineering students should be prepared for the global work force as there will be plenty of opportunities out there for them.

Compared with the quantity (the enormous number of annual graduates), the quality of Chinese engineering education is not rated that highly. One study [1] showed that “only 10% of Chinese engineers can compete in the global market”. Engineers educated from the Western countries have more advantages in interpersonal skills and innovation; they understand better customers and markets, and are productive from the time they graduate [2]. Chinese engineering education need to be enhanced in the soft skills (professional skills) although they are good at hard skills in mathematics and physics.

China’s engineering education has not formally included professional skills, especially teamwork skills, into its curriculum design or assessment. Such kind of soft skills are mainly fostered in after-class activities and moral education, so that this research on effectively teaching technical teamwork to large cohorts of engineering students in China is a pilot work with great significance. This work might be the first concerned with professional skills training in engineering education from mainland China.

The paper describes research on how teamwork can best be learned in an academic setting on the BUPT/QM joint programme, which aims to mix the best of teaching approaches from China and from the UK; in achieving that mix it includes more emphasis on professional skills than is usual in Chinese degree programmes. One of the important skills that need to be studied is team working.

This work attempts to implement successful cooperative learning practices from Western education to a Personal Development Plan (PDP) module that takes team working as one of its key teaching objectives and tries to find out how successful that is in a Chinese context.

II. RELATED RESEARCH

The usual strategy instructors adopt to teach teamwork skills is *Cooperative Learning*, defined by Johnson, Johnson, and Holubec [5] as an “instructional strategy that draws benefit from the interaction of students working in small teams to maximize their own and each other’s learning”. Unlike the Individualistic Learning or Competitive Learning, Cooperative Learning involves students working together in teams towards a common goal and emphasizes cooperation, positive interdependence and individual and group accountability [6]. It is also different from Collaborative Learning, which has a “social constructivist” philosophical base. Collaborative Learning believes that learning is the construction of knowledge within a social context, and encourages the participation of individuals to a learning community [7]. Cooperative Learning is a more structured form of group work, and requires individual accountability whereas Collaborative Learning does not [6].

Cooperative Learning was first introduced to engineering education by Smith in 1981 [8] and in the time since then, it has become widespread practice in America. As indicated by the UCLA Higher Education Research Institute Survey of Faculty [9], almost 60% of the faculty used CL in their classes in 2008.

In China, most of the teaching and learning is organized individually or competitively. Students are encouraged to join a learning community to learn collaboratively in a social context or to finish lab experiments in groups, but the evaluation is based on individual work, and no interdependence or individual accountability are structured into their work.

Chinese pedagogy is quite different from the rest of the world, with emphasis traditionally being on individual study of complex mathematics, physics and the deduction process of equations and theories. However, to work in the global workforce, Chinese students need to know how to consult, compromise and negotiate with others, but not always to accept that the other’s view is always right. Superficial unanimity is not the kernel of teamwork: teamwork encourages different opinions. In Chinese companies, the boss makes the decision and nobody would disagree with the boss as they do not want to make the boss lose face; moreover, the boss tells the workforce specifically what they should do, but in the global industry, a greater degree of self-motivation is expected. Students, therefore, need the abilities of problem-solving and synthesis in addition to their basic scientific and mathematical knowledge.

Many studies report successful practices in classroom-based teaching of team work, the most popular practice being to assign group projects in technical modules. Many approaches to design and manage group projects can be found from the literature, for example [10-11]. Researchers often comment on the teacher-controlled factors that influence students’ team experience [12-13], and many computer systems have been developed to help the process of group formation, administration and teamwork assessment [14-17]. Lingard and Barkataki suggested an approach to teach team working skills using free web-based tools [18].

Students communicate, manage the project, and share information online; they are assessed using the message records generated through that process.

However, other researchers and educators argue that teamwork skills cannot be learned through ad-hoc project experience without teaching; it is a learned skill, and should be taught, practised and assessed as other academic skills. Among the ways suggested to teach teamwork skills as directly as academic skills are: (i) setting up a project module with teamwork as its main objective [19]; (ii) developing a specific programme that teaches interaction skills [20]; and (iii) building up a minor in Engineering Communication and Performance [21].

The research on Cooperative Learning in the Chinese context mainly focuses on language study and management course, but seldom on engineering education. A few instructors also assign group projects in engineering modules, but none by purposely developing strategies and mechanisms to enhance team working and cooperation; the team effectiveness is also not generally assessed.

Moreover, when an educational method is imported to a new country, it should be culturally appropriate [22]. Such kind of research has been done in other Confucian Heritage Cultures (CHC), like Vietnam, Singapore, and Hong Kong, but not in mainland China. Economic globalization and opening has brought many changes in people’s thinking in China, especially to those of the youth. Cultural analysis should be based on the current approach of the population involved, and the BUPT/QM Joint Programme can well reflect that current position.

III. EXPERIMENT STRATEGY

The experiment is conducted in a Personal Development Programme (PDP) module for Year 1 students. One of its main objectives is to learn and practise teamwork skills within the PDP task. Four classes (134 students) from a total of 16 classes (around 500 students) were selected to do the experiment. Students are put into groups of 5 or 6 by a different method for the 4 classes:

- self-selection;
- random assignment;
- academic merit (grouping students with the same ability range);
- fair system, mixing the academic rank with good, middle and bad together.

Students work in groups to produce an advertising video for a Chinese product to be sold in the UK in order to develop their ability to make a point succinctly, a skill all engineers need. At the end of this course, students will play the video and make a short presentation introduce their work in front of instructors and other students.

In the experiment, we adopted many practices suggested by Barbara and Richard [10]. The detailed strategies can be found in one previous paper [23]. Introduction on teamwork skills and instructor guidance were provided and students

were asked to designate different roles in their group instead of a single leader. The instructor formulated the policies for taking responsibilities and for the practices expected, and each group drafted their own agreement of expectation at the beginning. During the process, a teamwork evaluation form and a peer rating form were distributed to groups to complete.

IV. PARTICIPANTS

The participants are all formally registered students of both BUPT and QM, having been recruited through the national Chinese university entrance examination system achieving a score above the BUPT minimum, which is above the top line¹ in the examinations. They are, therefore, representative of Chinese students in a national key university.

There are about 500 students in each cohort, divided into 16 classes. The four classes that were chosen all contain students studying for the degree of Telecommunication Engineering and Management, where the management is an add-on subject. The particular four classes were chosen for the convenience of timetabling and they do not perform better or worse than the other classes not used for the experiment.

V. RESULTS

A. MBTI Test

Before the task, students were asked to do the Myers-Briggs Type Indicator (MBTI) test that indicates personality styles. This appears to be the first MBTI test done to mainland Chinese engineering students, and many interesting results have been found.

The MBTI assessment is “a psychometric questionnaire designed to measure psychological preferences in how people perceive the world and make decisions” [24]. It indicates personality types but not personality traits; it does not represent ability or aptitudes. All types are equal, and there is no type better or worse than the others.

The MBTI sorts the psychological differences into four opposite pairs based on the following [25]:

- *Favourite world*: Do you prefer to focus on the outer world or on your own inner world? **Extraversion (E) or Introversion (I)**.
- *Information*: Do you prefer to focus on the basic information you take in or do you prefer to interpret and add meaning? **Sensing (S) or Intuition (N)**.

¹ The results in the Chinese university entrance examinations are group in bands, and to be admitted to a national key university (universities in the 985 or 211 groups) a student must achieve above the top line. This line varies by province and in addition each university may have a requirement (like BUPT does) of scoring at a certain level higher than that line.

- *Decisions*: When making decisions, do you prefer to first look at logic and consistency or first look at the people and special circumstances? **Thinking (T) or Feeling (F)**.
- *Structure*: In dealing with the outside world, do you prefer to get things decided or do you prefer to stay open to new information and options? **Judging (J) or Perceiving (P)**.

The interaction of preferences results in 16 distinctive personality types and the description of these types can be found from [26].

The MBTI test result of the 134 Chinese students is shown in Fig. 1; the type ISFJ forms the largest group 16%.

The most popular type of personality cannot show the overall preference difference. We summarize the result and compare the frequencies in each opposite pair of preferences as shown in Table I. It was found that in the categories of *Favourite World* and *Information*, there was not much difference overall in distribution between the two opposite preferences.

However in the category of *Decisions*, 71.64% of the 134 students chose “Feeling” indicating that the majority had the inclination to “instinctively employ personal feelings and impact on people in decision situations, naturally sensitive to people needs and reactions, naturally seek consensus and popular opinions, unsettled by conflict; have almost a toxic reaction to disharmony” [27]. This finding is consistent with the characteristics of people in CHC cultures: (i) they prefer to react to their feeling about people rather than logic and consistency when making decisions; (ii) they are easily

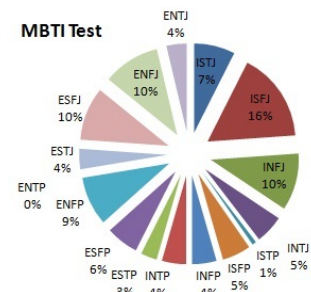


Figure 1. MBTI Test result of 134 Chinese university students

TABLE I. SUMMARY OF STUDENTS' PERCENTAGES IN EACH OPPOSITE PAIR OF PREFERENCES

| Category | Type | Total |
|----------------|------------------|--------|
| Favorite World | Extraversion (E) | 54.48% |
| | Introversion (I) | 45.52% |
| Information | Intuition (N) | 47.76% |
| | Sensing (S) | 52.24% |
| Decisions | Feeling (F) | 71.64% |
| | Thinking (T) | 28.36% |
| Structure | Judging (J) | 67.16% |
| | Perceiving (P) | 32.84% |

influenced by others; (iii) they are more likely to have group thinking; and (iv) they try their best to avoid confrontation and feel upset and helpless in a conflict.

However, team working requires objective judgments, critical analysis, and the capability to solve conflicts. It is necessary to explain this clearly to these students, and to teach them conflict resolution skills.

In the category of Structure, 67.16% of the students chose “Judging”. This means that two-thirds of the students prefer (i) planning in detail in advance before moving to actions, not planning on-the-go; (ii) focussing on task-related actions (but they do not like multiple tasks); (iii) working best without stress when working ahead of deadlines but cannot tolerate time pressure; and (iv) using targets, dates and standard routines to manage life (but they do not like flexibility, freedom or variety) [27]. This may relate to the characteristics of people in CHC countries - high uncertainty avoidance; they feel threatened by uncertainty and unknown situations [28]. The lack of people preferring “Perceiving” hinders the performance of groups in staying open to new information and options.

Though the majority instinctively prefers working with plans and ahead of deadlines, it does not mean they will definitely be able to achieve this, because that requires more self-discipline and time management skills. There are quite a few students on the JP who only start to work hard on an assignment just before the deadline. Phuong-Mai, Terlouw and Pilot also found out in their study that Hong Kong students started to work just before the deadline [22]. People in CHC countries value a time rhythm in which they might often change plans and deadlines [22] and it is difficult to manage and cope with time pressure with this fluid time habit. The MBTI result also found that two thirds of students did not tolerate time pressure. However, coping with time pressure is required in cooperative learning in the Western model.

Students on the JP often complain when several pieces of coursework from different modules are due in the same period of time. The MBTI result also reflects this in that many students do not like to multitask, even though around 30% are female and women (in the West) are generally thought to be better at multi-tasking than men. Though the deadlines were near to each other, each coursework was assigned at a different time and all had sufficient time before the submission date. Students need to learn to get used to this kind of multitasking model as this is the situation in the work place.

A similar test was done in America [29], but the type distribution is different as shown in Table II. The case that

TABLE II. ESTIMATED FREQUENCIES OF THE TYPES IN THE UNITED STATES POPULATION FROM[29]

| E | I | S | N |
|--------|--------|--------|--------|
| 45-53% | 47-55% | 66-74% | 26-34% |
| T | F | J | P |
| 40-50% | 50-60% | 54-60% | 40-46% |

shows a significant difference is that of S-N, where it was found 66-74% of the US population prefer Sensing (S) over Intuition (N), whereas almost half of the experiment group in China prefers Intuition. This indicates that more American people live for now and attend to present opportunities, use common sense to create practical solutions, recall memories of facts and past events and like clear and concrete information [27, 30].

B. Comparison of Team Formation Methods

There were 32-35 students in each class, divided into 6 groups with 5-6 members in each group, so it is statistically a small sample. A future experiment with a big sample is being planned. The same group mark of the PDP task was given to all members of a group.

Analysis of variance (ANOVA) was used to evaluate whether the PDP result and the average group peer rating result were significantly different between groups that were formed by the 4 different methods. ANOVA showed that there was no statistically significant difference between team formation methods on PDP result and peer rating result:

- PDP result: $p=0.09>0.05$, $F=2.484$, $df=3$;
- Peer rating result: $p=0.281>0.05$, $F=1.369$, $df=3$.

The means of PDP result and average group peer rating result are provided in Table III. Groups formed by the “fair system” got the highest score for PDP task of 82.5, “by random” 78.3, “academic merit” 77.5, and “self-selection” the lowest of 70. For the average group peer rating results for teamwork, groups formed by “academic merit” got the highest mark of 94.4, and “self-selection” the lowest mark of 90.1. The interesting point is that the self-selection groups performed worse in both the PDP task mark and the average group peer rating.

Students prefer to choose their own groups by themselves. However interestingly in the class where self-selection was allowed, groups are either all male or all female. During the lecture, a male student tried to persuade a female group to mix with their group, but was refused. Self-selection may shorten the time of getting the team acquainted

TABLE III. PDP RESULT AND AVERAGE GROUP PEER RATING RESULT BY DIFFERENT GROUP FORMING METHODS

| | | N | Mean | Std. Deviation |
|----------------------------------|----------------|----|---------|----------------|
| PDP Result | self-selection | 6 | 70.0000 | 7.74597 |
| | by random | 6 | 78.3333 | 7.52773 |
| | academic merit | 6 | 77.5000 | 8.21584 |
| | fair system | 6 | 82.5000 | 8.80341 |
| | Total | 24 | 77.0833 | 8.83627 |
| Average Group Peer Rating Result | self-selection | 6 | 90.1167 | 5.33850 |
| | by random | 6 | 92.9933 | 2.99515 |
| | academic merit | 6 | 94.4433 | 3.70390 |
| | fair system | 6 | 92.2483 | 2.41191 |
| | Total | 24 | 92.4504 | 3.86487 |

with each other, but it is also likely to stop the possibility of being grouped with new people, as people generally choose to join the same group with friends, roommates or acquaintance. This situation is very typical in China: people avoid losing face for both themselves and others. They would not like to upset friends by choosing others as group mates instead of the friends; neither would they leave their friends to join a new group as that would seem like a betrayal. In China, self-selection groups may not be selected as student really wish for doing the work, but are influenced by “face” and “guanxi” (relations). The results indicate that self-selected groups can neither cooperate better nor perform better academically compared with other formation methods, indeed they are worse.

Phuong-Mai, Terlouw and Pilot suggested affect-based grouping (based on existing friendship, geographical origin, family connections, etc) for Asian students and involving extended social identity in the CL process [22]. Universities in China always deliberately break the original affinity relations (such as geographical origin, middle school attended) at the beginning of enrolment, mixing students up in different dormitory rooms and class units. In this way students should make new friends and learn more from different people.

C. Teamwork performance and academic performance

Running a Pearson product-moment correlation test showed that there was no correlation between teamwork peer rating results and academic PDP result ($r=0.15$, $\text{Sig.}=p=0.485>0.05$, $N=24$).

D. Teamwork peer rating

The students in the experiment are in Semester 2 of Year1. The academic result of the previous Semester² is regarded as their previous academic performance. A Pearson product-moment correlation test was conducted to find out the correlation between previous academic performance and individual teamwork peer rating result. It showed that there was a weak positive correlation between previous academic performance and teamwork peer rating result ($r=0.2$, $\text{Sig.}=p=0.021<0.05$, $N=133$). This indicates that if a student performs better academically he/she is more likely to cooperate well as a team member.

It also tested the gender differences on teamwork performance (individual peer rating mark). The means of individual peer rating marks for male and female are listed in Table IV. Individual peer rating marks for male and female do not follow a normal distribution, the box plot indicating that the data has a skewed distribution. Independent samples test showed that there was no significant difference between genders on the teamwork performance ($t=-0.442$, $df=131$, $\text{Sig.}=p=0.659>0.05$).

It has often been doubted whether self-rating is objective: people may over-rate or under-rate themselves. Two Related-Samples test showed that there was no significant

TABLE IV. MEANS OF INDIVIDUAL PEER RATING MARKS FOR MALE AND FEMALE

| gender | N | Mean | Std. Deviation |
|--------|----|---------|----------------|
| male | 85 | 92.2915 | 4.46501 |
| female | 48 | 92.7698 | 8.02904 |

difference between self-rating and average peer rating for individuals ($Z=-1.509$, $\text{Sig.}=p=0.131>0.05$). This indicated that the Chinese students in the experiment did not over-rate or under-rate themselves when evaluating their team working.

At the beginning of the experiment, two classes were told that an individual mark based on peer rating would be given at the end of the task; the other two classes were told that peer rating would not be used for differentiating individual marks but only for research purpose, and no individual mark would be given³.

This difference aims to test whether peer rating bring more competition within groups or coherence, and whether the marking scheme will influence the objectivity of peer rating. The Independent Samples test showed that students did not rate individual task mark differently when they know the peer rating will change their individual task mark ($t=-1.633$, $df=131$, $\text{Sig.}=p=0.105>0.05$). For the students who were told individual mark would be given, they did not compete to give lower rating to others or to raise themselves, neither did they collude together to give higher rating to all.

E. Team roles

Through class observation and final presentation questions, it was found that students got used to single leader groups even though they were assigned different roles immediately after the groups were formed: the coordinator was often considered as the sole leader. The task was often parcelled out into parts and each member did one part. Students got used to do and be responsible for their part of the academic task that they were assigned to do, but did not know how to undertake other responsibilities to the team. Therefore, getting them to perform the other roles (such as checker, sceptic) seems like a vain hope.

During the final presentation, one group made several typographical mistakes (Beijing Duke instead of Beijing Duck) in their slides. When the Checker and Sceptic were asked whether they checked the slides, they shook their heads and looked at a third person who made the slides. This implied that they thought this was the responsibility of the one who made the slides, but not theirs. In another group, when they were asked about the meaning of a sentence in the slides (“Wish you a fair wind” in a kite advert), nobody in the group could answer and all explained that the one who made the slides was ill and did not show up.

³ The contribution of this whole task to the overall Honours classification of the degree is only 0.2% so minor differences in the marking scheme between different classes would have no noticeable effect on a student’s overall degree result.

² On the JP there are examinations every semester.

In groups, members did not normally understand other's contributions. For example, students did not know what software was used to edit the video and how it worked except for the one who made the video. This is not the essence of teamwork suggested in the Western Cooperative Learning model.

VI. CONCLUSION AND LIMITATION

This is the first study of this kind conducted in China. The main objective of the work is to reveal the real situation when an attempt to use the Western Cooperative Learning strategy is made in a Chinese engineering programme, albeit a joint programme with an English university.

From the preliminary results, it is fairly obvious what Chinese engineering students tend to do and what they lack. There are no statistically significant differences (i) between genders on team performance and self-rating, (ii) between self-rating and peer rating, nor (iii) between grouping methods on peer rating and PDP task result. However it was found that self-selected groups achieved the lowest results academically and on teamwork performance.

There are no significant correlation between peer rating and PDP task result. We also found that some students gave ratings of 100% in self and peer rating; however, they justified the mark using literal commentary. This issue will be looked at in detail later to decide whether the peer rating is reliable.

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Work in Progress: Understanding Professional Competency Formation in a Service-Learning Context from an Alumni Perspective

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Abstract— Engineering educators daily negotiate the formidable task of developing the twenty-first century engineer's competence to enter and thrive in the workplace. With this focus, many have conducted investigations into both *what* defines such professional competence and *how* such competence forms within students. In this investigation, we study how professional competence has developed among alumni of Engineering Projects in Community Service (EPICS), as understood through their retrospective perceptions. We are conducting a mixed methods study in order to understand competence development, and this paper presents the design and administration of a survey questionnaire that is informing the qualitative portion of the study. Findings from both aspects of the study will be presented at the conference.

Keywords- alumni research, professional competence, service-learning, mixed methods

I. INTRODUCTION

The adaptability and readiness of students to enter the engineering workforce has played a central role in the current, national discourse on reforming engineering education. Noting that the National Academy of Engineering (NAE) and the ABET Engineering Accreditation Commission (EAC) have articulated calls for such change in post-secondary engineering education, such appeals may be characterized by their desire for engineering education to be more reflective of engineering practice [1]-[2]. They recognize that, in addition to disciplinary knowledge, graduates need professional skills such as multidisciplinary teamwork, communication, lifelong learning, understanding of professional and ethical responsibility, and understanding of global and societal contexts. Such calls reify and situate in an engineering context Dall'Alba's claim that, alongside the emphasis on appropriate knowledge, the emphasis of *being* a professional should characterize pre-professional education [3].

In light of these recent calls, some posit service-learning as a model for engendering competencies required for engineering practice by creating a learning environment imbued with authenticity [4]-[6]. However, given the flexible structure of such situated learning environments, the actual competencies that develop within students may extend those that are intended outcomes of the learning context [7]. Understanding how professional competencies form in such flexible settings is not a trite task.

The particular context of this investigation is a nationally recognized, engineering-focused, vertically-integrated, multidisciplinary service-learning program known as Engineering Projects in Community Service (EPICS) [5]. This program is intentionally designed to allow students to develop professional competencies while reinforcing the mathematical and scientific principles that define the traditional engineering education curriculum. Specifically, this program seeks to develop the students' engineering design, teamwork, communication, social awareness, and leadership skills. While emphasizing service, EPICS creates a simulated industrial experience for students who participate in the program. Students can participate for multiple semesters, which allows for a variety of experiences and opportunities to take on more significant leadership roles. Although EPICS regularly assesses and investigates the experiences of students within the program, we sought to explore alumni's perceptions of their experiences in EPICS.

The purpose of this study is to examine diverse experiences of EPICS alumni, investigating the research questions:

- RQ1: In what ways did EPICS prepare alumni for professional practice?
- RQ2: How did this preparation compare to other undergraduate experiences?
- RQ3: How have alumni perceptions of EPICS's professional preparation changed over time?
- RQ4: How do RQ1, RQ2, and RQ3 vary by gender?
- RQ5: How do RQ1, RQ2, and RQ3 vary by the semesters of experience in EPICS?

Studies that investigate engineering competence often investigate the formation of competence in students [6]-[7], or the nature of competence according to experts [2],[8]. In our study, we investigate how alumni—with up to 17 years of work experience—develop professional competency in order to assess what features of EPICS are most salient toward this development. These alumni provide a dual perspective by reflecting on both what competencies are required in their practice and what undergraduate experiences may have formed such competencies. This study has been approved by the university's Institutional Review Board (IRB).

II. METHODS

We approach the research questions of this study using an embedded mixed methods design. According to Creswell, such an investigation consists of primarily qualitative study with an embedded quantitative investigation designed to support the overall investigation [9]. The research questions, which primarily ask the overarching question about *how* EPICS contributed to competencies, are best understood by a qualitative approach [10]. However, we first conducted a survey-questionnaire in order to (1) understand the overall, quantifiable influence of EPICS alumni, (2) corroborate and generalize the themes that emerge from the interviews, and (3) collect information about participants in order to generate a meaningful purposive sample for interviews. The 78-item questionnaire was developed through multiple iterations of refinement within the authors' research group as well as pilot testing among undergraduate engineering alumni (that did not participate in EPICS). The questionnaire was designed to collect data on the alumni's:

- involvement in EPICS,
- experiences in their undergraduate years,
- initial and current work situations,
- perceived influence of EPICS on their professional practice (example provided in part A of Table I),
- perceived comparison of EPICS to other undergraduate experiences regarding professional preparation,
- open-ended reflective questions (provided in part B of Table I)

The survey was administered to every alumni of EPICS, since the program's inception in 1995 who had an address registered in the alumni database and who had not requested to be removed from EPICS's contact list ($n = 2667$). Those with registered email addresses on this contact list ($n = 1633$) received more frequent solicitation and could more readily take the survey by clicking a link within the email. Those who had not registered their email address were sent a postcard with the link of the survey printed on the card ($n = 1034$). Disregarding 77 invalid email addresses, the overall target population was 2590. Of these, 528 completed the survey, and as shown on Table II, these alumni represent a considerably diverse population with respect to their undergraduate majors and number of semesters in EPICS. We will further compare the breakdown of the sample population, as shown in Table II, with the overall alumni population of EPICS to assess sample and coverage errors.

III. RESULTS

Questionnaire responses suggest that alumni view their experiences in EPICS as having a significant influence in developing their professional competency. As evidence of this claim, for 15 of the 17 items on the questionnaire in the format of part A in Table I, over 70% of all respondents attributed EPICS to having *some*, *large*, or *very large* contributions to the development of that item's professional competency.

Additionally, approximately 1 in 5 respondents ($n = 109$) responded that EPICS influenced his or her career choice and elaborated on *how* EPICS did so.

As 73% of participants ($n = 388$) have agreed to be contacted for an interview, we are enthusiastic about the quality of upcoming interviews in terms of breadth of experience and depth of reflection. We analyzed data from the survey to purposively sample participants as well as inform the development of the interview protocol for the qualitative study. Particularly, we are ensuring that we oversample minority groups reflected on Table II for interviews. Additionally, we coded the questionnaire's open-ended responses (shown in Table I, part B) to ensure that the interview participants reflect a broad range of competence development that they attribute influence by EPICS. We conducted semi-structured interviews, coding their transcribed responses iteratively to achieve convergence among investigators, and classifying their responses into general themes that address the research questions. At the FIE conference session, we will present (1) a more detailed methodology of this interpretive thematic approach, (2) themes emerging from participant interviews, and (3) statistical analysis of the questionnaire responses.

TABLE I
EXAMPLE OF QUESTIONNAIRE ITEMS

| | | | |
|---|----------------------|-------------------|--|
| A. Participants answered 17 items in the following format with the <u>underlined portion</u> varying across each item: | | | |
| To what extent have your experiences in EPICS contributed to the following: <u>an ability to effectively communicate my ideas to my co-workers.</u> | | | |
| 1) No Extent | 2) Small Extent | 3) Some Extent | |
| 4) Large Extent | 5) Very Large Extent | 6) Not Applicable | |
| B. The following open-ended questions are being analyzed thematically in order to purposively sample interview participants: | | | |
| (If applicable) How did your experience with EPICS influence your career choice? | | | |
| What ways has EPICS influence you personally and/or professionally? | | | |

TABLE II
DESCRIPTIVE STATISTICS OF SURVEY PARTICIPANT DEMOGRAPHICS

| Type | Value | n | % |
|------------------------------|------------------------------------|-----|------|
| Gender | Male | 370 | 70.1 |
| | Female | 146 | 27.7 |
| Race | African American / Black | 14 | 2.7 |
| | Asian | 104 | 19.7 |
| | Native American / Alaska Native | 1 | 0.2 |
| | Native Hawaiian / Pacific Islander | 2 | 0.4 |
| | White | 371 | 70.3 |
| Ethnicity | Hispanic | 8 | 2.7 |
| | Not Hispanic | 493 | 93.4 |
| Number of Semesters in EPICS | 1 semester | 118 | 22.5 |
| | 2 semesters | 186 | 32.5 |
| | More than 2 semesters | 220 | 42 |
| Major | Non-Engineering | 96 | 17.5 |
| | Engineering | 428 | 81.7 |

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Characterizing Communication Instruction in Computer Science and Engineering Programs

Methods and Applications

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Abstract—“Incorporating Communication Learning Outcomes Across the Computer Science (CS) and Software Engineering (SE) Curriculum” is an NSF-funded project that aims to identify the communication skills, specifically those involving reading, writing, speaking, and teaming, needed by CS and SE graduates and then determine how these skills can be taught within CS and SE curricula. This paper presents the results of our first two years of studying the programs at Miami University and North Carolina State University to determine the kinds of communication utilized in our courses and how communication is taught and assessed. When looking at student attitudes towards communication our analyses suggest that students do not consider technical (professional) activities such as code reading, writing, and inspections as communication activities, and the same applies to more complex genres such as software testing or design. They also appear to have difficulty relating writing and reading that may take place in the context of the courses to what they might be doing as software engineers and computer scientists once they start working. On the other hand, initial results indicate that our students’ communications skills increase steadily throughout their stay in the university. We have also identified potential strategies for improved instruction in communication.

Keywords—communication across the curriculum, situated learning, software engineering, computer science)

I. INTRODUCTION

In our experience, one of the most common “desired” soft skills cited by employers for computer science (CS) and software engineering (SE) students is the ability to communicate. Successful CS and SE professionals need to be able to communicate with their clients, managers, and teammates. The importance of communication is indicated by its presence in the program outcomes identified by major accrediting bodies such as the Accreditation Board for Engineering and Technology (ABET), which evaluates US-based education programs in engineering, technology, computing, and applied science. Two of the eleven program outcomes for ABET’s Computing Accreditation Commission (CAC) explicitly involve communication [1]:

(Demonstrate) an ability to communicate effectively with a range of audiences

(Demonstrate) an ability to function effectively on teams to accomplish a common goal

Similarly, the SE2004 Software Engineering curricula guidelines highlight the importance of reading, writing, speaking, and teaming [2], while the CS2008 Computer Science curriculum guidelines recognize the importance of professional practice and communication skills through teamwork and presentations [3]. While ABET requirements and the SE2004 and CS2008 guidelines are not used in every part of the world, the demand for college graduates of CS and SE programs who are effective communicators spans the globe. Many studies have concluded that frequently engineering and computer science graduates lack the basic communication and teaming skills needed to succeed in their professional careers [4][5][6]. Companies typically require their employees to work on teams to complete a project. However, entry-level engineers may not have the experience to be fully successful in these situations if their academic experience does not foster teamwork [4]. New hires also often lack ability in written and oral communication. These problems seem to arise especially with students who focus their studies only on technical courses [4]. The problems may be exacerbated by students’ attitudes toward communication, insufficient course content, or poor teaching methods [7].

“Incorporating Communication Learning Outcomes Across the CS and SE Curriculum” is an NSF-funded project that aims to identify the communication skills needed by CS and SE graduates in order to determine how these skills can be taught within CS and SE curricula. We are focusing on four types of communication skills: **Reading**, **Writing**, **Speaking**, and **Teaming** (RWST).

The project is being led by CS and Communication across the Curriculum (CAC) faculty at Miami University, which has a relatively small CS and SE program (approximately 40 graduates a year), and North Carolina State University (NCSU), which has one of the largest programs in the country (approximately 250 graduates a year, about half with B.S.).

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Both programs are ABET-CAC accredited. We have partnered with CS and CAC faculty at eleven other institutions to assure that our results will be useful at a broad range of programs.

In this paper, we focus on our efforts during the project's first two years to characterize the communication instruction at Miami and NCSU. We illustrate the value of such characterizations as a tool programs can use to improve the ways they prepare students to communicate effectively in their careers. To begin, we describe the ways RWST skills are expressed in the program-level learning outcomes at the two schools (Section II), the courses in which Miami and NCSU incorporate RWST assignments and instruction (Section III), and student perceptions of the importance and instruction of RWST skills (Section IV). In Section V, we summarize strategies we have developed that any particular program could use to enhance its attention to communication at whatever points its characterization suggests would best increase students' abilities. In Section VI, we briefly outline plans for our project's next stage.

II. COMMUNICATION IN THE OVERALL CURRICULUM

In this project, we consider two varieties of communication skills: domain-specific skills and conventional skills. The former refers to types of communication one might engage in while performing a technical task specific to computer science and software engineering [8]. Reading program specifications or writing a test specification are communication tasks peculiar to CS and SE professionals. In contrast, making formal presentations is a conventional communication task important for CS and SE professionals but performed by specialists in other fields.

A first step in characterizing communication's role in a program could be to examine the program's high-level outcomes that identify abilities students must possess upon graduation. Miami has ten. Two of the ten (20%) explicitly address communication:

(Demonstrate the ability to) Work effectively as a member or leader in a team

(Demonstrate the ability to) Communicate technical information effectively, both orally and in writing

In contrast, at NCSU, 13 of the 20 (65%) primary program outcomes explicitly include RWST outcomes.

Examining more detailed program specifications reveals another difference. The Miami program has 29 performance criteria used to measure student ability upon graduation. Eight (roughly 25%) are explicitly related to communication. Of the 8 learning outcomes that explicitly mention communication, 7 are part of the program's core curriculum and therefore receive substantial attention in lower-level courses. At NCSU, the lower division undergraduate courses emphasize technical knowledge. As a result, students who took lower division courses and faculty who taught them would not have been expected to think of these courses as directly contributing to students' RWST skills—even though such domain-specific communication skills as code commenting and specification writing and comprehension figure prominently.

Even this very high-level characterization of the role of communication in our (or any) programs can yield potentially helpful insights. For example, the difference in the percentages of program outcomes that refer explicitly to communication (65% for NCSU and 25% for Miami) suggests that Miami might consider adding more. Similarly, the greater attention given to communication in lower-division courses at Miami suggests that NCSU might consider enhancing its emphasis on writing for newer students. Neither program has an outcome that refers explicitly to reading, which suggests that they should consider devoting time to teaching students reading skills that are specific to computer science, such as reading system specifications or APIs.

Of course, formal statements of program and course outcomes may not accurately reflect actual teaching practices. When we suggest possible interpretations of data from our two programs, we are merely illustrating the potential uses of such data, not making judgments on our curricula. Only persons in a program can correctly interpret data generated by characterizing it. Also, our illustrative characterization involves only six courses. At both institutions, students learn RWST skills in other classes as well as in internships and co-ops.

III. COMMUNICATION IN CORE COURSES

To characterize the presence of communication assignments and instruction in a program, one could also estimate the amount reflected in the learning outcomes for individual courses. We found more attention to communication abilities in our programs than many would have predicted.

In this project, we are focusing on six courses commonly included in CS programs. Five are offered at both schools: CS1, CS2, Software Engineering, Data Structures, and Capstone (Senior Design). At Miami, the sixth course is Database Systems. At NCSU, it is Automata, Grammars, and Computability.

When analyzing learning outcomes for these courses, we identified the number of *explicit* RWST items and the amount of *total* RWST (explicit plus implicit) coverage, relative to the overall number of outcomes. *Explicit* RWST outcomes are clearly communication oriented. Examples are, "Read and understand code written by people other than themselves" and "As a team, design and implement a data structure to solve a problem, coming to a consensus approach." *Implicit* RWST outcomes involve communication in some form but do not explicitly state this. For example, they use the words "describe," "explain," and "compare," but do not explicitly say to do this orally or in writing. Examples would include: "Apply asymptotic notations (e.g., O , θ) to analyze and compare algorithms." For reading, we chose to include reading code as well as documents.

Table 1 gives the percentage of explicit and total RWST coverage for the five focal courses shared by the two universities plus the sixth for Miami. At both schools, the capstone had a very high number of communication outcomes, as did software engineering. Some differences are striking. At NCSU, data structures had the highest number of communication-related outcomes while it had the lowest number at Miami. Perhaps Miami might consider the

possibility of missed opportunities in that course. Miami might also note that NCSU had more total outcomes for all five of the courses the two programs have in common, while NCSU might consider that Miami has more explicit outcomes for all five.

TABLE 1. Explicit and Implicit RWST Outcomes

| Course | Miami | NCSU |
|-------------------------|-------------------|-------------------|
| | Explicit/Implicit | Explicit/Implicit |
| CS1 | 13%/43% | 10%/40% |
| CS2 | 34%/14% | 0%/87.5% |
| Data Structures | 24%/5% | 0%/90% |
| Software Engineering | 100%/0% | 25%/50% |
| Database Systems | 6%/58% | |
| Senior Design, Capstone | 50%/15% | 25%/50% |

IV. STUDENT PERCEPTIONS OF COMMUNICATION

Student perceptions provide another important indicator of the place that RWST skills occupy in computer science programs. Consequently, as part of our characterization, we studied students’ perceptions of the importance RWST abilities would hold for them after graduation, the amount they would learn about these abilities in the core courses, and the amount they did learn. These data was gathered through surveys administered by our project’s external evaluator, Ohio’s Evaluation and Assessment Center for Mathematics and Science Education. Other means programs could use to assess student attitudes include focus groups and interviews [9].

Importance of communication abilities and amount of learning anticipated. Students’ perceptions of the importance of communication skills in their careers indicate the extent to which they understand the real work of CS professionals and influence their motivation to improve their RWST abilities in college. Similarly, the amount they expect to learn in their courses about communication reflects the level of emphasis they expect their program to place on developing their communication abilities. At the beginning of each core course, we posed questions on both of these topics. First, we asked students, “When you begin your first job after graduation, how important do you believe the following abilities will be to success in your career?” Our list of 36 skills included writing or speaking “to other computer specialists about computing-related concepts, methods, or projects” and “to help people complete computing-related projects or complete computing-related tasks.” In a slight variation, questions for students in the capstone course began, “When you begin your first job after graduation....” Students responded on a 5-point Likert-type scale ranging from unimportant (1) to important (5).

We also asked students how much they expected to learn about 15 communication and technical abilities using a 5-point Likert-type scale ranging from strongly disagree (1) to strongly agree (5).

Table 2 shows the composite results of students’ responses to the appropriate questions from each group. NCSU students begin with a higher perception of communication’s importance in their careers. Miami students’ perceptions grow as they progress through the program so that by the Senior Capstone

Courses their results match those from NCSU. At both schools, students’ expectations about how much they will learn generally increase as they progress through their programs.

TABLE 2. Average perceptions of the Importance of Skills at the Beginning of Six Courses and the Amount They Expect to Learn about These Skills in the Courses

| Course | Miami | | | NCSU | | |
|-------------------------|-----------------|------------------|-----|-----------------|------------------|-----|
| | Import- ance | Expect- ation | # | Import- ance | Expect- ation | # |
| CS1 | 3.9 | 3.2 | 122 | 4.3 | 3.4 | 169 |
| CS2 | 4.3 | 3.5 | 61 | 4.1 | 3.4 | 86 |
| Data Structures | 4.4 | 3.1 | 35 | | | |
| Software Engineering | 4.5 | 3.9 | 34 | 4.3 | 3.7 | 57 |
| Database Systems | 4.6 | 4.7 | 34 | | | |
| Senior Design, Capstone | 4.3 | 4.1 | 19 | 4.4 | 4.1 | 63 |

Seeking a more detailed understanding of changes in student perceptions, we found 12 domain-specific abilities for which the average responses by Miami students in both CS2 and SE were higher than the average response from students in CS1 at $p < .001$ according to Tukey’s HSD post-hoc test. Three were for reading (e.g., “Reading computer documentation such as comments in code and computing-related reference materials”); three for writing (e.g. “Using the style, organization, and formats employed in my workplace to communicate about computing-related concepts, methods, or projects”); four for speaking (e.g., “Speaking to other computer specialists about computing-related concepts, methods, or projects”); and one for teaming (“Using my computing-related knowledge to help a team of coworkers complete projects or solve problems”). Similar, but not identical, results were found in data from NCSU.

These results from both schools suggest that faculty are effective at persuading many students that communication is an essential part of their careers. The results also suggests that students are more aware of the importance of communication than many faculty believe—a significant possibility with practical implications. Perhaps the resistance they may show to communication assignments in CS courses arises from skepticism that the particular assignments being made will improve their career-related communication abilities, a possibility that suggests the value of explaining the purpose of communication assignments and also of replacing assignments that feature conventional communication with ones that are domain-specific.

Abilities gained in three core courses. At the end of each core course, we asked students to indicate how much their abilities in technical and communication areas increased as a result of their studies. Table 3 summarizes responses to selected questions by students in the three courses for which we have data from both universities.

While the differences among the mean scores in Table 3 are not statistically significant, the data do suggest several avenues of investigation for our two programs. For example, students seem to perceive that these three courses provided

greater gains in some RWST areas than others, with the largest gains in teaming and the smallest in reading. Our two programs could use other methods to determine whether these differences in student perceptions arise from the emphases of our courses or, perhaps, from differences in what students define as teaming versus what they define as reading. They may see any group work as teaming but perceive domain-specific reading tasks, such as reading code comments as technical activities, not communication ones. The data also suggest that students perceive that software engineering offered the largest gains in all four RWST areas, a point to which we will return later in this report.

TABLE 3. Students' Perceptions of Selected Communication Abilities They Gained in Three Core Courses (respondent numbers are the same as in Table 2)

| Experience in This Course | Course | MU | NCSU |
|---|--------|------|------|
| TEAMING ABILITIES | | | |
| This course prepared me for working on a collaborative team in my career. | CS1 | 3.4 | 3.7 |
| | CS2 | 3.7 | 3.9 |
| | SE | 4.4 | 4.3 |
| READING ABILITIES | | | |
| This course prepared me for the reading I will do in my career. | CS1 | 3.4 | 3.1 |
| | CS2 | 3.7 | 3.1 |
| | SE | 3.8 | 3.4 |
| SPEAKING ABILITIES | | | |
| This course prepared me for the speaking I will do in my career. | CS1 | 2.7 | 2.4 |
| | CS2 | 3.1 | 2.4 |
| | SE | 4.00 | 2.6 |
| WRITING ABILITIES | | | |
| This course prepared me for the writing I will do in my career. | CS1 | 3.2 | 2.9 |
| | CS2 | 3.6 | 2.9 |
| | SE | 3.9 | 3.1 |

Not shown in Table 3 are the means for students' perceived gains in their technical abilities. Generally, these means are higher than the means for their perceived gains in communication abilities. However, there are exceptions. For the software engineering course, students indicated greater gains in their abilities to work on teams than in their technical abilities, perhaps because their understanding of what is considered technical may not be broad enough to encompass the non-coding related technical topics covered in that course.

The differences among the results from our two programs may suggest that they attract distinct student groups, that cultural or context differences between the programs cause students to interpret differently the scales used in the surveys, or that the programs have different emphases that are reflected in their teaching. Investigation of the causes of these differences may identify strategies for enhancing the learning of students at both universities.

V. STRATEGIES FOR IMPROVING STUDENTS' COMMUNICATION ABILITIES

The results of our characterizations of the place of RWST abilities in our two programs demonstrate the ways computer science educators can use program characterization to identify strengths and possible weaknesses in the communication instruction they provide students. Our project also involves the next step of developing strategies programs can use to more

fully prepare their graduates for the communicating they will do in their careers.

Others have suggested various ways of achieving this goal, including creation of specialized courses in the technical curriculum that teach written and oral communication skills focused around technical outcomes. These courses teach beginning engineering students how to write technical documentation, such as design proposals, project management plans, status reports, instructions, and collaborative writing [10], as well as how to enhance their oral communication skills with technical presentations to various audiences [6] and group presentations and projects [11]. While these courses, like the technical writing courses taught by English departments, are helpful, one or two courses that focus on writing are insufficient for developing the sophisticated, domain-specific communication abilities employers want new CS graduates to possess. Some programs are also adding communication instruction into existing courses [4][5][7][10][11][12][13], often by adding oral communication assignments in technical courses [12] or having students work on client-based projects that involve a good deal of documentation, reporting, and presentations [10]. Having these skills taught by their technical instructors is thought to help students see the value of having the ability to communicate effectively [11].

Our project focuses on creating ways that programs can incorporate communication assignments and instruction broadly across their curricula and coordinate work on communication among their courses. This program-wide approach has the potential for continuously and progressively developing students' domain-specific communication skills throughout their college years. To enable programs to realize this potential, we are concentrating on addressing the feeling of many CS faculty that they are not capable of teaching and evaluating student writing. We are also seeking to devise ways that CS faculty can add instruction in communication skills to their courses without significantly decreasing the time allowed for technical skills. We have made initial steps towards addressing these concerns by developing a set of assignments that focus on communication that is situated within workplace scenarios in the domain that require students to communicate by reading, writing, speaking, and teaming as part of achieving the technical outcomes of the assignment. We have also identified where instructional supports are necessary to assist CS faculty in teaching communication.

At the heart of the approach is the concept of *Legitimate Peripheral Participation* [14]. As defined by Lave and Wenger, Legitimate Peripheral Participation indicates that students move from being novices to experts via engagement in learning activities placed within context. Specifically, through peripheral, but authentic and relevant tasks, novices become more experienced and eventually gain full membership into a community of practice. Our most significant application of this approach is to embed technical assignments in scenarios that reflect the contexts in which professionals perform the technical tasks the students are learning. Instead of merely turning in the solution to a technical problem, students communicate their results to a co-worker or client who must use the solution to perform his or her own technical work. One reason students perceive greater gains in their communication

abilities in software engineering than in other courses may be that in this class each technical task is studied in the context of the overall work of designing software systems. In contrast, technical tasks are often presented in a decontextualized manner, as if they were problem sets in a calculus class.

A. Example Assignments with Integrated Communication

In the six courses addressed by this project, writing assignments include creating development artifacts like software architecture documents or UML diagrams, which would be done in a software engineering course. Code documentation is another form of written communication taught in both introductory computer science courses. This documentation is taught by requiring students to write documentation as well as interpret and understand others' documentation. More conventional forms of workplace writing are taught in courses like software engineering and the capstone. These include writing memos, team meeting agendas and minutes, and progress reports as well as individual logs.

Reading assignments have a domain-specific focus, such as reading comments or navigating, understanding, and using technical documentation such as APIs.

Speaking assignments involve presenting a technical topic to a variety of audiences, conducting interviews, and participating in small-group discussion. Formal presentations occur in courses like software engineering, databases, and capstone. Small-group communication is taught when guiding students through the process of completing team projects, which occur in courses like software engineering, databases, and the senior capstone.

Teaming assignments are prevalent in all courses. These assignments range from large projects to ones completed in a single class period. Team code inspection is an example of an in-class teaming assignment, while a semester-long software engineering project is an example of a long-term team project. Each kind of assignment teaches students different aspects of working in teams. Teaming also overlaps with each of the other communication modes. In introductory courses, code inspections can be performed as a team, providing a way to work teamwork into low-level courses. Among formal presentation assignments, team presentations are prevalent. Team assignments in many courses involve preparation of written communications.

B. Preparing Faculty to Teach Domain-Specific Communication

Most faculty in the disciplines, computer science included, conceive communication as outside their domain, the territory of faculty in English or communication departments. But what is most important about communication is that it be effective in achieving a specific purpose for a particular audience in response to distinct situations. For computer science, faculty in the domain know much more about the professional purposes, audiences, and situations than faculty in English and communication. Teaching field-specific communication skills is important because it is through them that students learn what it means to think like computer scientists and to be professionals in the field.

NCSU used a process with three sequential goals to build faculty confidence for teaching communication. Goal one was to work with the faculty to identify communication already embedded in the courses. This was accomplished by an analysis of the technical outcomes of the courses and the explicit and implicit communication activities in those outcomes. Goal two was to engage the faculty in generating technical outcomes for the program and then derive communication outcomes from the technical ones: what all students are expected to be able to do by the time they graduate. Goal three was to identify the types of communication all computer science students should master (problem definition, program requirements, design document, etc.) and analyze the courses to determine how to distribute instruction throughout the curriculum to best prepare students for the senior design capstone course. This process was designed to help faculty see themselves as experts in communication in their field.

To develop tools faculty can readily use to teach domain-specific communication skills, we have focused on the instructional power of rubrics. For scenario-based assignments, the rubric identifies the criteria the faculty member will use to evaluate students' success in conveying the results of their technical work in a useful way to a colleague, client, or other audience. The skills required to select the details to include or omit, organize the communication, determine what should be conveyed graphically and what in prose are precisely the domain-specific communication skills the students are to develop through the assignment. They are also the communication skills that CS faculty are uniquely equipped to teach. While rubrics are most often used for evaluating student work, faculty can turn them into instructional tools by conducting discussions in which they and the students apply the rubric before students begin to prepare their communications. In the discussions, faculty can point out the strategies used in a sample communication of the type students are preparing to make it effective—and also good strategies that might have been used. For writing assignments, a sample document can be used. For speaking and teaming assignments videos can be used, including ones available at YouTube and similar sites. By using scenario-based assignments and rubrics as teaching tools, faculty situate students in Lave and Wenger's legitimate peripheral participation, i.e., a professional context. The instructor is a professional mentor guiding students in learning professional practice.

C. Instructional Supports

While working directly with faculty via workshops, meetings, and other small-group activities helps prepare them for providing communication instruction, the long-term viability of this project is dependent on the development of instructional supports and guidebooks that provide resources on communication pedagogy. These instructional supports form the foundation of how the results of this project will be disseminated to an audience that goes beyond the two main institutions and the project affiliates.

To date, communication specialists on the project have developed (or are in the process of developing) supports in each of the RWST areas. These instructional supports include

examples of embedded assignments and their associated rubrics, other resources for teaching the specific skills, as well as ideas for evaluation of student outcomes. In addition, these instructional supports will include community-created FAQ's and other materials meant to provide faculty with high-level strategies to address issues they are likely to encounter as they incorporate communication into their courses and curricula.

VI. SUMMARY AND FUTURE WORK

Participants of the CPATH project come from Miami, NCSU, and 11 partner institutions in the US and other countries. In this paper, we demonstrated some ways to characterize the role of RWST in CS and SE curricula, using our programs as examples. Our data are preliminary in the sense that we have not yet observed a student cohort that has received the full battery of RWST-enhanced courses over the four years of a degree program. While some students come to understand the value of developing their communication skills, many do not appear to believe that the communication activities in their courses are related to their future profession. Insights gained from characterizing communication's place in a program can lead to curricular improvements. If the characterization involves all of a program's courses, not just six as used in our example, it could foster a fully integrated, curriculum-wide approach to developing students RWST abilities. We have been preparing and piloting work-based assignments that simulate the practices of computer scientists, activities that researchers Lave and Wenger identify as necessary steps in moving towards membership in a community of practice. In the next stage of our work, we will move from analyzing student perceptions of the communication in their studies to evaluation of their work. Our goals include further development of instructional supports, so we can disseminate our outcomes, learning activities, assignments, and assessment tools to institutions outside the project team.

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Work in Progress: A Case Study of the Types and Frequencies of Conflict in Engineering Design Dyads

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Abstract—Conflict is a common subject of research on engineering teams. While some conflict may improve team creativity and productivity, it can also detract from team member satisfaction, perceived team efficacy, and overall team performance. In this paper, we present a preliminary framework for identifying conflict within engineering design dyads using a case study approach. Using this framework, we identified instances of conflict in one male-male and one female-male engineering dyad performing a brief engineering design task. We identified more instances of conflict in the male-male dyad than the female-male dyad; however, this conflict appeared to be productive. An implication of this research for educators is to encourage argumentation within the teamwork occurring in their classroom. Students should understand that conflict can be constructive and improve their team's ability to move iteratively through the design process.

Keywords: *engineering design, conflict, teamwork*

I. INTRODUCTION

Within engineering, there is a longstanding belief that teams consisting of members with different perspectives and skills are better equipped to solve difficult problems and make effective decisions. Gender diversity may indicate different perspectives, but studies within engineering education and meta-analyses of organizational literature have failed to demonstrate a significant positive effect on team outcomes [1-4]. Observations of mixed gender teams in engineering and science courses indicate that team conflict may decrease team participation, satisfaction, and performance [5-7]. In order to benefit from gender diversity, such conflict must be mitigated. As a first step, this exploratory study investigates team conflict within engineering student dyads. This study was guided by the following two research questions: (1) what types of conflict do female-male and male-male engineering student dyads experience during an engineering design task and (2) how frequently does conflict occur in female-male and male-male dyads?

II. LITERATURE REVIEW

Team conflict is often described as disagreement or incompatibility among members of the same project team [8]. Researchers classify team conflict into three categories: task, process, and relationship [8-10]. While a moderate amount of task-related conflict can improve teamwork outcomes,

relationship conflict is generally perceived as negative [8, 10]. In a more recent study, Jehn, Neale, and Northcraft [9] found that all three types of team conflict were negatively correlated with satisfaction, perceived performance, and actual performance.

Researchers suggest that demographic diversity, and gender diversity in particular, may result in all forms of team conflict because of differences in behavior, values, and perspectives among team members [8, 9]. An increase in conflict is especially evident in engineering course settings where male students have been observed to deny female students opportunities to contribute [5], respond critically to female speech acts [11], and rate female contributions to teamwork as less valuable or effective [6].

Researchers have also studied the context of the task in conjunction with conflict [8, 9]. These researchers have investigated whether task type influences the amount of conflict experienced by work teams. We propose that in addition to their teammates, team members can also experience conflict directly with their task. The operational definition of conflict in this study, described in the following section, allows for person-to-person and person-to-task conflict, with task, process and relationship as subcategories for each of the two dimensions.

III. METHODS

Research Setting and Data Collection. This study was performed in a laboratory setting at a research university in the Midwestern United States. Two dyads of first-year engineering students (one male-male, one female-male) completed an hour-long engineering design task. The design task prompted students to develop a way to reintroduce clean water into a small Midwestern town whose water supply had been contaminated in a flood. Students had access to relevant engineering texts and the Internet and were compensated \$10 for their participation. The dyads were aware that their discussions were audio- and video-recorded. These discussions were then transcribed verbatim.

Data Analysis. We began data analysis by coding the transcripts for instances of conflict. Coding consisted of two phases. First, each author open coded the transcripts for instances of conflict rather than relying on any preexisting

conflict framework. Here, we used a working definition of conflict: any instance when both members of a dyad did not demonstrate homogenous thought or purpose. Four unique types of conflict emerged from the data: conflict with partner, conflict with information, conflict with certainty, and conflict with process. Informally, conflict with partner maps to person-to-person conflict and the latter three types map to person-to-task conflict. We observed no instances of what could be classified as relationship conflict or person-to-person process conflict.

During a second round of coding, each author identified instances the four types of conflict on a portion of the data. As a team, we discussed any instances of conflict for which individuals were uncertain. After reaching consensus on those instances, we tallied the instances of each type of conflict within both the male-male and female-male dyads.

IV. INITIAL RESULTS AND FINDINGS

Table 1 provides descriptions of the four types of conflict we identified during open coding.

TABLE I. TYPES OF CONFLICT IN DYADS

| Type of Conflict | Description |
|---------------------------|---|
| Conflict with Partner | A participant vocalizes or implies that something the other participant has said or done is incorrect. |
| Conflict with Information | A participant does not trust the veracity of the gathered information or that it is feasible in the context of the problem. |
| Conflict with Certainty | A participant requests clarification of something the other participant has said, the problem statement, information previously gathered, or topics previously discussed. |
| Conflict with Process | A participant proposes new tactics or a new approach. |

Figure 1 displays the frequencies of each type of conflict in each dyad. We found 124 total instances of conflict. The male-male dyad accounted for 86 of these instances and the female-male dyad accounted for 38 instances. The male-male dyad demonstrated more instances of all four types of conflict. The largest differences were in *conflict with process* and *conflict with information*.

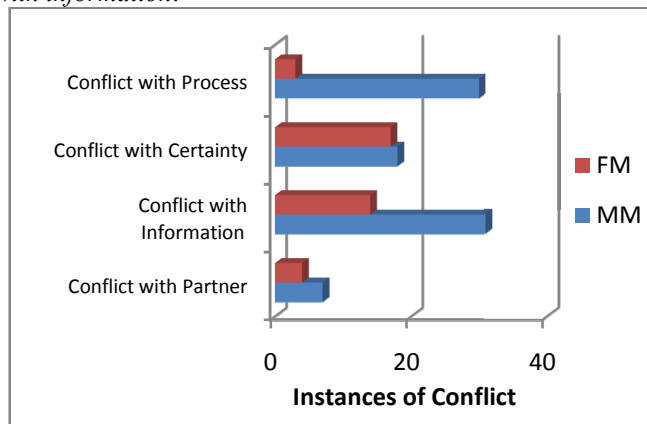


Figure 1. Instances of Conflict in Female-Male and Male-Male Dyads

Though the male-male dyad experienced more conflict compared to the female-male dyad, informal observations showed this conflict tended to be productive (i.e. it led to further discourse and iterations through the design process). A possible implication of this research is that both educators and students understand that constructive conflict can improve a dyad’s ability to move iteratively through the design process. Gender composition may reduce a dyad’s initial capacity for constructive conflict.

V. LIMITATIONS AND FUTURE WORK

This preliminary study was limited by a small sample size and a lack of formal reliability measures during data coding. While transcript data was the best standalone data source at hand, the use of videos and notes will be used to add context. Future work will include an increased sample size (adding female-female dyads), verification of a coding scheme, and analysis of the interplay of gender, argumentation, and patterns of conflict in collaborative design outcomes.

ACKNOWLEDGMENT

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Work in Progress: Enhancing Broader Communication among Courses Linked with Prerequisites

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Abstract— This paper continues our previous study on addressing the communication barrier among courses linked with prerequisites. By proposing an active feedback system, the instructor teaching the prerequisite can proactively report the student performance at each detail subject level and make it available to instructors requiring the course as prerequisite. This active feedback system serves three purposes: (1) the instructors receiving such information have a better understanding of the incoming student readiness for the class, and if necessary, can offer a review session before starting a new chapter; (2) the prerequisite instructor can assess and improve their teaching effectiveness at each subject level by re-assigning the appropriate amount of time in each chapter; (3) the academic advisor can also use this information to recommend additional study between semesters in certain weak performance areas to help student to achieve academic success. The actual course adopted for this active feedback system was an entry level engineering math course. In this work, we outline a plan that will allow us to expand this active feedback system into other engineering courses linked by prerequisites.

Keywords– Active Feedback, Advising, Prerequisites.

I. INTRODUCTION

The use of prerequisite is an important part of the academic process ensuring student academic success. Over the years, attempts were made to create innovative ways to enhance its' effectiveness and student retention. This includes Lanning's work [1] on Prerequisite Skills Testing in his Solid Mechanics class, Ohland's work [2] on adjusting calculus prerequisite requirement to reduce the bottleneck in Clemson's general engineering curriculum, and the consortium led by Klingbeil [3] on teaching engineering math by engineering faculty. Prerequisites are designed to ensure that students taking the course are adequately prepared. As indicated in our previous work [4], the prerequisite system works well for A-level students who have a good understanding of the broad subjects covered in the prerequisite course. However, a barely passing grade of C does not provide the detailed information on their understanding of the subject required to be successful in completing the subsequent courses. For example, a student performing poorly in trigonometry and complex analysis but did reasonably well in rest of engineering mathematics may still be ill-prepared for Circuit Theory. To compensate for this deficiency, we presented an active feedback system, where the instructor teaching the prerequisite proactively report the

student performance at each detail subject level and make it available to instructors requiring the course as prerequisite. We adopted this approach in our entry level engineering math course and improved the communication among courses linked by prerequisites. Our first implementation of the system was completed in 2010 with the following sample data (with only the C level performance students listed) in Table 1:

Table 1: student performance in subject areas 2010-2011

| grade | algebra | trig | vector analysis | complex analysis | derivative | integral |
|---------------|---------|------|-----------------|------------------|------------|----------|
| C- | 60% | 46% | 80% | 90% | 21% | 19% |
| C+ | 65% | 55% | 75% | 100% | 100% | 25% |
| C | 72% | 40% | 66% | 89% | 67% | 35% |
| C | 60% | 50% | 88% | 90% | 63% | 43% |
| C | 53% | 67% | 80% | 88% | 71% | 82% |
| C- | 78% | 35% | 90% | 95% | 21% | 52% |
| C+ | 70% | 62% | 84% | 88% | 21% | 45% |
| class average | 84% | 72% | 91% | 92% | 74% | 62% |

One noticeable observation from the table is that the average performances among different subjects are not even. The entire class on average did very well in vector analysis and complex analysis (both above 90%) while at the same time exhibiting some weakness in integrals (62%). Integrals were the last chapter of the course and usually suffered from not having enough time near the end of the semester. Efforts were made to increase the amount of time allocated to this chapter during the subsequent year. The following class average performance was achieved and is listed in Table 2. Students with failing grades of D and F are not included. The final grades also include performance in homework and lab reports.

Table 2: student performance in subject areas 2011-2012

| grade | algebra | trig | vector analysis | complex analysis | derivative | integral |
|---------|---------|------|-----------------|------------------|------------|----------|
| C | 63% | 58% | 100% | 70% | 25% | 38% |
| A- | 89% | 88% | 88% | 70% | 95% | 80% |
| B | 61% | 85% | 91% | 80% | 100% | 50% |
| B+ | 91% | 65% | 72% | 60% | 75% | 80% |
| A | 100% | 100% | 84% | 80% | 15% | 80% |
| B- | 70% | 94% | 59% | 70% | 95% | 63% |
| A- | 89% | 96% | 88% | 90% | 100% | 63% |
| A- | 95% | 73% | 94% | 50% | 95% | 68% |
| B | 94% | 77% | 50% | 70% | 100% | 50% |
| A | 97% | 92% | 100% | 90% | 90% | 80% |
| B+ | 52% | 96% | 94% | 80% | 100% | 25% |
| average | 82% | 86% | 81% | 79% | 84% | 68% |

It is clear that the class average performance among different subjects are more evenly distributed (all around 80%) except the last chapter on integral, which is particularly important to the calculus based Physics class. We are still having ongoing dialog between College of Engineering and the Physics Department on ways to improve the situation. One

approach we adopted was to make a B- as the minimum grade the students have to achieve in the engineering math course in order to enroll in Physics class. For students with performance below that, we recommend that they complete the regular calculus class before enrolling in Physics. The feedback from the Physics instructor shows significant improvement on overall class performance from the most recent semester.

Selected performances below C level in each subject area were highlighted for advising purpose. One student was advised not to take Physics course due to his poor performance on both integration and differentiation. The entire class performance was forwarded to the instructors requiring this course as prerequisite.

To reap the broader benefit of this work, we plan to expand this approach to other engineering courses linked with prerequisites.

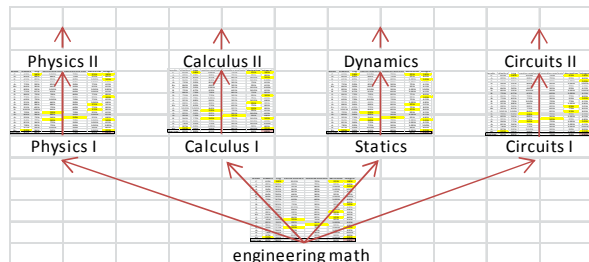
II. PLAN, METHOD AND PRCESS

We propose to expand the active feedback system used in our initial study in Engineering Math to subsequent courses as outlined in Table 3.

In order to establish a successful active feedback system among those courses linked with prerequisite, we shall follow the following steps:

1. Invite instructors of potential courses to join the study and solicit input;
2. Review and determine specific subject areas for feedback;
3. Determine frequency and method of assessment of performance in the determined subject areas;
4. Determine an reporting frequency of the overall performance among instructors linked with prerequisites;
5. Determine the objective method of student overall performance assessment to evaluate the impact of the active feedback system.

Table 3: Future Implementations



We plan to implement this system in the fall of 2012 and invite other institutions to join us on this project for a potential NSF grant to support the effort.

III. CONCLUSIONS

The active feedback system provides a simple tool in uncovering the weakness in student learning at the detail subject level, and therefore, facilitating better communication among instructors linked with prerequisites. The information included in this system is not new. The instructor records the performance at such detail subject level routinely for grading purpose. It is also related to the broad discussion on evaluating instructor's teaching through student grades in later courses [5]. The active feedback system presented here helps to standardize the process for advising as well as teaching improvement.

The active feedback system was initially adopted in an engineering math course and helped us to balance the time allocated in different subject areas of the class. It also helped us on our student advising process. The instructors who received this information are now better prepared in dealing with deficiencies in certain subject areas important to his or her teaching. We propose the current work so that the effectiveness of the system can be further verified and the benefits can be shared among other engineering courses with similar prerequisite structures. The implementation results will be reported in future FIE conferences once the relevant data are collected.

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A Model for Generating Proactive Context-Aware Recommendations in e-Learning Systems

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Abstract—A proactive recommender system pushes recommendations to the user when the current situation seems appropriate, without explicit user request. This is suitable in e-Learning scenarios in which a great amount of learning objects are available but it is difficult to find them according to the user's needs. In this paper, we present a model for generating proactive context-aware recommendations in the Virtual Science Hub (ViSH), a educational platform related to the GLOBAL excursion European project. The model relies on domain-dependent context modeling in several categories to generate personalized recommendations to teachers and scientists that will produce the learning resources the students will consume. The recommendation process is divided into three phases. First, the generation of the social context information related to the users in the platform. Then, the current situation considering the social, location and user context is analyzed. Finally, the suitability of particular learning objects to be recommended is examined. Therefore, details about the recommendation model proposed and advantages related to applying the model in ViSH can be found in the paper, in addition to some conclusion remarks and outlook on future work.

Index Terms—Learning Objects Recommendation; Context-awareness; Proactivity; Personalized Learning

I. INTRODUCTION

Traditional educational platforms usually have had a problem related to find the most suitable learning objects among all the items available for a specific user, taking into account his/her interests. Moreover, when this kind of platforms store a huge number of learning objects, it is difficult for users to difference between high and low quality pedagogical content. Sometimes the learning objects are gathered by categories using taxonomies or folksonomies. Despite this, it is still hard to find the best learning objects inside those groups as the number of them to check is commonly overwhelming.

This problem has been solved (or at least mitigated) by using recommender systems in areas such as book sale (e.g. Amazon) or video on-demand (e.g. Netflix). In these fields, the number of items to be analyzed is also huge and it is needed a system that recommends the best items to users in a personalized way considering their tastes and consumer history. However, the application of recommender systems in the e-Learning area is currently limited.

A proactive recommender system pushes recommendations to the user when the current situation seems appropriate, without explicit user request. This is suitable in e-Learning scenarios in which a great amount of learning resources are available but it is still difficult to find them according to the user's needs.

In this paper, we present a model for generating proactive context-aware recommendations in e-Learning systems. Our scenario is the GLOBAL Virtual Science Hub (ViSH), the social platform related to the GLOBAL excursion (Extended Curriculum for Science Infrastructure Online) European project. Its aim is to provide students and their educators across Europe with a range of e-Infrastructures and access to expert knowledge on its usage for a joyful exploration of e-Science. Specifically, ViSH contains a selection of e-Infrastructures, learning objects and a social network where scientists, teachers and students will be able to exchange and establish collaborations.

Bearing in mind the aforementioned scenario, we propose a model that relies on domain-dependent context modeling in several categories (i.e. social, location and user context) to generate personalized recommendations to teachers and scientists that will produce the learning objects the students will consume. As a result, simple pedagogical contents (e.g. videos, slides or images) and complex activities (e.g. virtual excursions or flashcards) can be recommended, as well as users registered in the platform that can be interesting for the target user (e.g. the system could recommend a biologist from London to a teacher from Madrid who wants to generate specific material related to the same area).

The rest of the paper is organized as follows. The next section reviews related work in the area of recommender systems and its applications in e-Learning platforms. Section 3 describes the GLOBAL excursion project and the ViSH scenario. Section 4 explains our proposed model. In Section 5, we discuss the advantages of applying this model to ViSH. Finally, the last section provides some concluding remarks and outlook on future work.

II. RELATED WORK

A great variety of research and practical applications exist in the area of recommender systems and context-awareness (see e.g. [1], [2] or [3]), especially in the mobile guides field [4] or the shopping domain [5].

However, proactivity has not gained much attention in personalization and recommender system research. Most systems require the user to perform some kind of action to trigger the generation or retrieval of recommended items. As an example of proactivity in an existing system, Hong et al. [6] proposed an agent-based framework for proactive personalization services. This approach proposes a model according to which a user profile is deduced from a user's context history. The model enables proactive recommendations in the future. However, training time is very important in the proposed model.

Ricci discusses proactivity and its role in recommender systems to transform them from topic oriented information seeking and decision making tools, to information discovery and entertaining companions [7].

Regarding to proactivity models, Woerndl et al. [8] recently proposed a model in mobile context-aware recommender systems. And Gallego et al. [9] carried out a study on proactive delivery of restaurant recommendations for Android smartphones based on that model, with good results regarding usefulness and effectiveness.

Although recommender systems have been traditionally applied in different domains such as shopping, TV programs, books, etc. [10], the use of recommender systems provides useful applications in the educational field [11], [12]. It has potential to assist students in finding the best possible courses into enrolment applications [13], [14].

On the other hand, recommendation approaches for learning objects repositories have been proposed. For example, Ruiz-Iniesta et al. [15] proposed a proactive recommendation approach adapted to the student profile. Cheng [16] presented a type of recommendation agent based on cognition inference. The semantic web also offers new possibilities for recommender systems, and ontology-based learning object recommendations have been presented [17], [18], [19].

Some authors aim to integrate multi-agent recommendation systems into a mobile learning platforms [20]. Others findings [21] presents research on personal recommender systems for lifelong learning. User profiles, learning contents and preferences are usually relevant in a recommender system. However, Bobadilla et al. [22] take into account the student's opinion as input for further recommendation of the learning object.

III. SCENARIO: RECOMMENDING IN THE VIRTUAL SCIENCE HUB PLATFORM

The GLOBAL excursion project [23] will develop a common understanding, teaching use cases, as well as pedagogical and technical artifacts. The main purpose of the GLOBAL excursion project is to enable students and teachers access to the experimental laboratories and resources of

selected e-Infrastructures in order to improve science curricula by enriching school's existing teaching and learning materials. GLOBAL excursion will develop a platform called Virtual Science Hub (ViSH) to host all the activities carried out by the teachers and researchers in the project and to foster collaboration between them. With the intention of continuing after the project ends, being a meeting point between science and schools, researchers and teachers, and teachers themselves. That is why ViSH will be a social network, where every user will be able to follow another user and to be followed by other users interested in their activity. Users will also have a profile with their activity (e.g. learning objects uploaded, users followed and following, etc.) and a wall compiling the activity of their contacts network.

On the other hand, some science fields can be very difficult for young students. The initial fields covered in the project are nanoscience, biotechnology, volunteer computing and grid computing. To enhance the students interests and make this topics enjoyable and amusing for them, a new kind of complex learning objects called virtual excursions have been defined. These virtual excursions are created by the teachers and consumed by their students. A virtual excursion can be one of the following:

- a virtual meeting via videoconference between the classroom and the researcher, where the researcher explains a specific topic with the contents available in the platform.
- the use of a remote lab or microscope with the supervision of a researcher.
- a compilation of simple resources, like texts, images or videos together with interactive objects such as quizzes and flash objects into a slides presentation.
- interactive resources or applications based on specific topics developed by the project partners like virtual experiments or flashcards.

To create a virtual excursion the teacher will have to select among contents hosted in the ViSH. The number of resources available in the ViSH platform can be very high, and higher with time, because when new researchers and teachers join ViSH they can upload new resources from their institution. Recommendation will be very important here to make this task as easy as possible. Besides, as the teachers and researchers community grows, ViSH should recommend interesting users to follow. They could be other teachers or researchers with common interests or that have uploaded content that can be interesting. Finally, a virtual excursion can be directly recommended to the teacher to use it with his/her students if it is related, for example, to the teacher's subjects.

IV. INTRODUCING PROACTIVE CONTEXT-AWARE RECOMMENDATIONS IN E-LEARNING SYSTEMS

Our model for generating proactive recommendations in e-Learning systems incorporates contextual information to assess whether a recommendation is suitable in a given situation. It also evaluates which learning objects from ViSH are interesting for the user that is being recommended. We

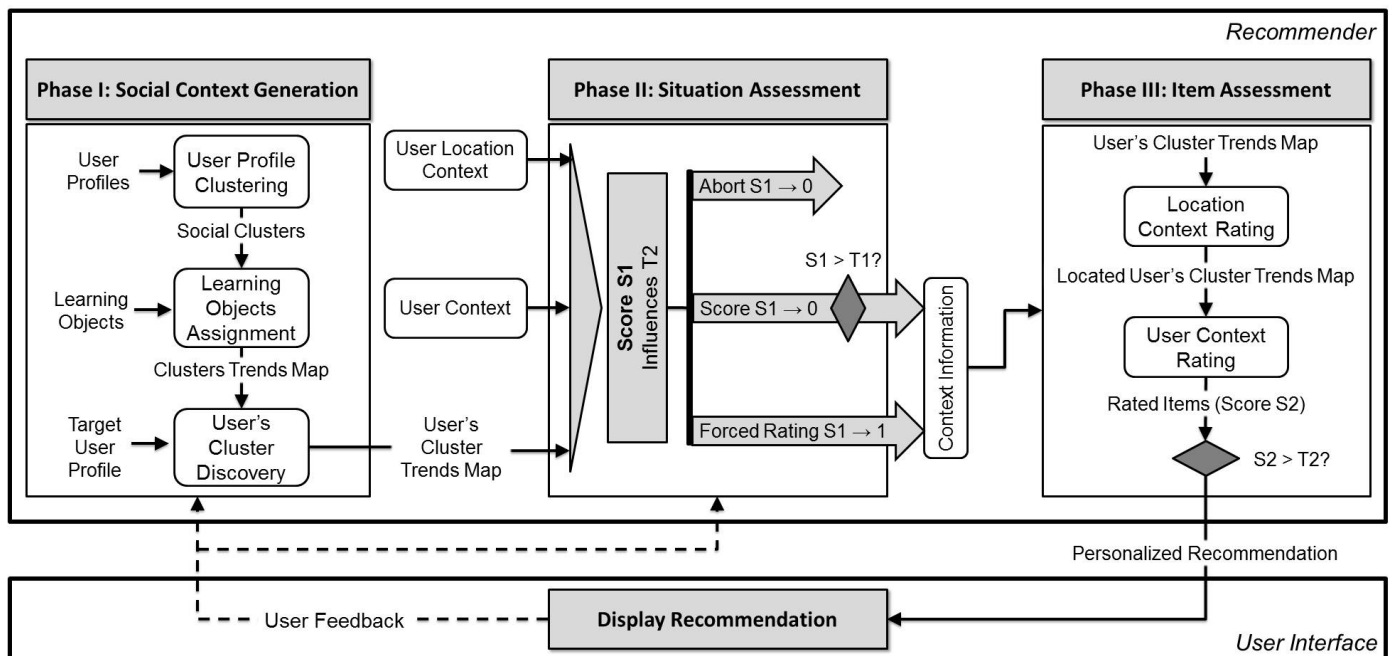


Fig. 1. Model for generating Proactive Context-aware Recommendations in e-Learning Systems.

first define what we mean by context and then we develop our model.

A. Context

As we have seen in Section 2, using context-awareness information is now a common feature to improve recommender systems on the basis that the more information you have from a user, the more personalized and accurate will be the results provided.

There has been much research on the area of generating context-awareness and different definitions of the term *context* exist (e.g. [24], [25]). We follow the definition proposed by Dey [26], in which context can be defined as characterizing the situation of entities that are relevant to the interaction between a user and an application. To generate proactive recommendations we are utilizing the following context categories:

- 1) Social context: the links (e.g. common interests, related profiles, etc.) among users in the ViSH platform that allow us to gather them into clusters by similarity.
- 2) Location context: temporal (e.g. current time) and geographical information (e.g. nationality or language).
- 3) User context: the current activity of the user (e.g. if he/she is consulting the ViSH platform through a mobile device or a desktop computer).

B. Model: process overview

Fig. 1 summarizes our three-phase model to handle proactive context-aware recommendations in e-Learning systems. The model analyzes the current context and generates a personalized recommendation that determines not only the best item(s) in a given situation, but also whether the situation

warrants a recommendation at all. It combines previous work in the area of proactivity proposed by Woerndl et al. [8] and in the area of context-aware recommender systems proposed by Gallego et al. [27].

In the first phase, the system generates the social context related to a user by analyzing all the users and learning objects present in the e-Learning platform in order to gather them in clusters by similarity. This phase is executed from time to time (e.g. once a day), as the social context does not change quickly.

In the second phase, the system determines whether or not the current situation warrants a recommendation considering social, location and user context information. This phase is executed periodically in the background when the user is active in the e-Learning platform.

The third phase deals with evaluating the candidate items to be recommended. If one or more items are considered good enough in the current context, the recommender system would communicate it to the user. This phase is only executed when the second phase indicates a promising situation and the corresponding score exceeds a threshold.

Finally, the user has the possibility of giving feedback about the recommendation provided in order to allow the system to take that information into account for future recommendations.

C. Phase I: Social Context Generation

It begins with the system taking the user profiles provided by the e-Learning platform so as to apply a clustering segmentation to them. In the ViSH case, two users are similar when their profiles are alike in terms of educational interest (e.g. nano- and biotechnologies), role in the platform (e.g. teacher or researcher), students' age, curricula, etc. Once the

social clusters have been generated, the system calculates the clusters trends map by considering which learning objects have been created or consulted by every user belonging to the clusters. We assume that in the platform there is an unequivocal relationship between a learning object and its creator, and also between a learning object and the users that have consulted or used it.

Hence, in this second process, we create a map of learning objects where the relationships among them and the clusters are shown, noticing this way the educational trends of every cluster. In other words, we know what learning objects are consumed in every cluster.

When the target user enters the first time to the e-Learning platform, his/her user profile is retrieved and the user's cluster discovery process is activated. The system checks the information profile extracted from the user ViSH account and calculates the similarity between it and the social clusters available in order to assign him/her to any of the existing clusters. After these steps the system knows the social context of the user because he/she has been assigned to one of the social clusters previously generated. Every cluster has a set of learning objects assigned that are interesting for the users belonging to the cluster. Therefore, the system knows which learning objects (that have not been generated or previously consulted by the user) are candidates to be recommended (represented by the user's cluster trends map). This set of candidates learning objects is rated taking into account how many times a pedagogical material has been queried and by whom, so as to recommend first the items that are trendier in the user's social cluster.

Finally, bearing in mind that this kind of information does not change continuously (e.g. the user profile usually is a constant information), this phase is not restricted to a real-time execution. For that reason, despite the fact that the data mining procedure could be heavy if we have a lot of users and/or learning objects, it is not necessary to calculate these clusters in every recommendation process.

D. Phase II: Situation Assessment

In the second phase, the system calculates a score $S1$ which is a number between 0 and 1. If $S1$ exceeds a threshold $T1$, the third phase will be initiated. If $S1 = 1$, the highest possible value, then a recommendation will be triggered in any case. If the current situation does not warrant a recommendation, no matter how high a particular item would score, $S1$ is set to 0 and the recommendation process is aborted without considering items for recommendation. Note that this phase does not take properties of single items into account. However it considers general properties of the set of candidate items in a current context (e.g. availability of learning objects in English that can be consulted in a mobile device).

Each contextual attribute is weighed depending on the relative importance of the parameter to the recommendation process. The higher the score for a context attribute, the higher the indication that a proactive recommendation could be useful. That contextual information related to the user is

needed as a prerequisite to calculate $S1$. In our model, the social context information is provided by the user's cluster trends map generated in the previous phase. The location context (i.e. temporal and geographical information about the user) is extracted from the platform or in the worst case, from the browser or from the mobile device (if the application is being consulted from a smartphone or a tablet). The user context is provided by the platform. In the ViSH case, as it can be consulted through desktop and mobile devices, the platform is in charge of providing this information as well as other context parameters like what is the current activity of the user (e.g. completing a virtual excursion, having a videoconference session, etc.) in order to avoid disturbing him/her if the user is focused on other important task.

Furthermore, the score $S1$ has an impact on the threshold $T2$ of the third phase, i.e. the higher $S1$ is, the lower $T2$ is set. Therefore, the threshold $T2$ is a function of $S1$ in the simplest form:

$$T2 = |1 - S1| \quad (1)$$

This means that when the situation is considered appropriate for a recommendation, $S1$ is high and it is more likely that at least one item score $S2$ in the third phase reaches the required threshold $T2$ and an item will be recommended to the user. On the other hand, if the situation assessment leads to a mediocre score $S1$, phase III might still be initiated but only an extraordinary high rated item might score good enough to be recommended.

E. Phase III: Item Assessment

If the current situation is considered suitable for the user, then the third phase is started by passing it the context information previously used to calculate $S1$.

In this phase, the suitability of particular items is evaluated. To do so, the rated learning objects provided by the user's cluster trends map are now rated taking into account the location context. Consequently the learning objects that are in the same user's language or have to be consulted at a specific time (e.g. synchronous learning objects such as remote experiments under the supervision of a researcher), will have a higher rating compared to other educational contents that do not fit the location context properly.

After that, the system applies a new rating process to the located user's cluster trends map considering the user context. Again, a learning object that fits better the current user context will have a higher rating. For instance, if the user is consulting the application in his/her smartphone, the educational content has to be adapted to be consumed in a mobile device.

Therefore, the result of phase III is a score $S2$ for each item in the candidate set. To determine this score, a combination of the previous contextual ratings (i.e. *socialCtxScore*, *locationCtxScore* and *userCtxScore*) is done as a linear weighted combination:

$$S2 = w_s \times socialCtxScore + w_l \times locationCtxScore + w_u \times userCtxScore \quad (2)$$

Where *socialCtxScore*, *locationCtxScore* and *userCtxScore* are numbers normalized to [0, 1] and $w_s + w_l + w_u = 1$.

Consequently, S2 is again a number normalized to [0, 1], with S2=1 being the best possible score. An item can be immediately eliminated from the recommendation process (then S2 is set to 0), for example if a learning object is not available right now.

The candidate items will be ranked according to S2 and tested against the threshold T2. If $S2 > T2$ for an item, then this item is finally considered for recommendation and the user is notified. Depending on the application scenario, the best k items above the threshold will be displayed. If no item score S2 exceeds the threshold T2, then no item is recommended. The process is aborted and restarted with phase II at the next configured interval. If the score S1 from the first phase is 1, the best-ranked item will be proposed in any case, since the threshold T2 is 0.

F. User Feedback

Once the recommender engine has generated a personalized recommendation composed by the best-ranked learning objects, the user interface is in charge of displaying the recommendation. The model is not restricted to how the visualization is carried out, as it will depend on the device used, as well as the design and layout available in the application.

After the recommended items are communicated to the user, he/she can optionally give feedback on the recommendation. The feedback is a rating for an item that can be utilized when assessing the relevance of the item, so as to be taken into account as social context information for his/her social cluster in phase I.

In addition, the user can give feedback on the point in time of the recommendation by rejecting or ignoring the whole recommendation. In this case, the feedback influences the thresholds T1 and T2: a negative feedback on the point in time results in higher thresholds, and thus decreases the chance of a proactive recommendation in the future in a similar situation.

V. DISCUSSION: APPLICATION IN ViSH

The application of the model described above to the ViSH platform brings several advantages against traditional recommender systems methods. First of all, users do not need to set up the system with initial information as it learns from their activity in the platform. The recommender engine works in a transparent way to end users since it retrieves the required data from ViSH to generate the recommendations, without being necessary an explicit training process.

In addition, by using this model the system can recommend not only learning objects, but also users from the same cluster as interesting people to follow in the ViSH platform. This can

be done by using the social clusters generated in the phase I of the model. All the users belonging to the same target user's social cluster are by definition similar in terms of educational interest, profile, type of students, etc. Hence, although the system is focused on recommending learning objects, it is also possible to recommend people so as to increase the collaboration and social relationships among ViSH users, achieving in this way one of the main purposes of the project.

On the other hand, the model allows different ways of accessing the application as it is not restricted in how the recommendations are displayed and how the location and user context information is retrieved. In ViSH, desktop and mobile user interfaces are available. For that reason, different visualizations and context parameters will exist providing richer information to enhance the context-aware recommendations and the proactivity features.

Finally, despite this model is focused on generating proactive recommendations, it is also possible to activate the recommendation process by a user request. One of the features that are supposed to be available in ViSH is a recommender tool in which users can set a personalized request to generate a recommendation about learning objects whenever they want. This can be done in our model by skipping the phase II (Situation Assessment). As the user is requesting a recommendation, that means that the situation is completely suitable, and for that reason by setting $S1 = 1$ we can skip the analysis of proactivity, passing directly to the phase III in which the items are evaluated considering the context information and the user request parameters.

VI. CONCLUSION AND FUTURE WORK

In this paper we have presented a new model for proactivity in context-aware recommender systems focused on the e-Learning domain. We have described an innovative way of recommending learning objects to users belonging to an e-Learning platform. It takes into account their current social, location and user context to select the most suitable situation to consume that objects, without being needed a training process as the system learns from the users' activity.

As we have seen, the application of this model in ViSH (a real scenario related to the GLOBAL excursion European project), provides several advantages compared to traditional recommender systems. It allows not only the possibility of recommending learning objects, but also users belonging to the platform that share the same interests considering a target user. The model additionally provides the possibility of recommending in two ways: proactively and following a user request, achieving the uses cases required in ViSH.

Future work includes the implementation of this model in ViSH to test it in the user evaluation phase. It is going to be carried out inside the GLOBAL excursion project in the present year. This will allow us to evaluate the usefulness, effectiveness, accuracy or reliability in the recommendations provided.

In regard to enhance the social context generation, the application of network science techniques to analyze

relationships and links among users and learning objects in the ViSH social network could be also an interesting point to investigate. The appearance of power law distributions, small-world [28] or scale-free network properties [29], or users acting as social hubs, would provide us important information to improve the social context information.

An additional open issue related to the application of this model in an e-Learning scenario is the possibility of recommending a personalized composition of related learning objects. This will allow to create complex learning objects (or virtual excursion like are called in ViSH) focused on one specific topic to provide extra value to end users interested on it. For instance, several learning objects (e.g. videos, slides or images) related to the biology of the cell could be joined in order to offer a complete pedagogical material that could be used by teachers giving a lesson on that subject.

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Aural Instruction with Visualization in E-Learning

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Abstract—This research investigates the effectiveness of using aural instructions together with visualisation in teaching some concepts of data structures to novice computer science students. A prototype learning system, known as the Data Structure Learning (DSL) tool, was developed and used first in a short mini study that showed that, used together with visualisations of algorithms, aural instructions produced faster student response times than did textual instructions. This result suggested that the additional use of the auditory sensory channel did indeed reduce the cognitive load. The tool was then used in a second, longitudinal, study over two academic terms in which students studying the Data Structures module were offered the opportunity to use the DSL approach with either aural or textual instructions. Both the quantitative data provided by the automatic recording of DSL use and an end-of-study questionnaire showed appreciation by students of the help the tool had provided and enthusiasm for its future use and development. These findings were supported by qualitative data provided by student written feedback at the end of each task, by interviews at the end of the experiment and by interest from the lecturer in integrating use of the tool with the teaching of the module.

Keywords—component; Aural Instructions; Visualization; Cognitive Load; Computer Science Learning; Data Structure Learning Tool

I. INTRODUCTION

One of the first challenges that faces novice computer science (CS) students when they start their course is to acquire the skills required to write or compile computer programs. Consequently, the Introduction to Programming and the Data Structures (PDS) modules are compulsory for first year CS students at Durham University, UK. Within these modules, object-oriented programming (OOP) is a widely used paradigm for software development.

OOP is defined by [1] as “a practical methodology that encourages modular design and software reuse.” data structures, on the other hand, offer memory based organization of information for better algorithm efficiency [2]. Understanding the concepts of OOP and data structures is crucial because they enable students to reuse existing code and to create objects that form the building blocks of their programming projects.

The starting point towards students acquiring professional programmer skills is to make sure that they participate in high quality learning. Students need to interact with their learning environment by talking, listening, reading, writing and reflecting on their own knowledge as they approach the course content [3]. Active learning theories [4] support teachers and students to be actively engaged in their learning environment if they are exploring, experiencing, experimenting with, testing

and applying the knowledge they gain in class to solve real life problems.

A. Use of Visualisation in E-Learning

Visualisation is one of many attempts to use technology to improve learning by creating a mental image of how things work. It is also a common learning style that many students prefer as a way to increase their comprehension of concepts, bearing out the proverb “a picture is worth a thousand words.” As an active learning approach [5], interactive visualisation tools increase the interaction between the learner and the subject being studied. However, there are problems with many of the existing visualizations [8]. These include loss of focus if the level of abstract representation focuses concentration on low-level steps rather than on high-level properties like invariants.

B. Use of Audio in E-Learning

The use of audio, either musical or spoken sound, was presented by researchers [7,8,9,10] as a means of aiding visualisation in learning environments. Its usage in CS learning and in algorithm animation started as a way to describe what visualisations are currently showing. It can also help students to focus on their learning task. This means that the use of both aural instructions and visual components can improve students’ awareness of their learning environment.

C. Cognitive Load in E-Learning

Cognitive approaches to human methods of learning, on the other hand, have highlighted the transformation that occurs on different mental representations of situations and tasks. The concept of mental load was based on the concept of a communication between two channels with limited capacity [11]. The Dual Channel Assumption [12] posit that humans process information in two separate channels, visually or aurally. Research shows that the use of animation and an associated aural narration were most effective when presented simultaneously rather than successively. In short, to provide students with an effective and active learning environment, the cognitive load should be reduced to the minimum.

II. OBJECTIVE OF THE RESEARCH

Previous research [12,14,15,16] in this field examined the use of visualisation tools to assist students’ learning experience. This research investigated the reduction of cognitive load by providing an intensive visualisation environment. However, not all visualisation environments reduce the cognitive load, and [17] argues that a “visualization environment that requires users to handle additional information and tasks, which increases cognitive load, offers similar performance advantages to that of a user who has no visualization at all.” Other research [9, 10, 18] investigated the use of sounds or audio feedback to improve the interaction

between users and their systems. However, their investigation did not exploit the dual channels of working memory to speed the learning process.

The main goal of this research is to investigate the effectiveness of using aural instruction together with visualisation in teaching the concepts of data structures to novice CS students. The research tries to provide enough evidence to support three main hypotheses:

- Reducing cognitive load improves student engagement and outcomes when learning data structures.
- The use of aural instructions in teaching data structures to CS students has a positive effect on student perception of data structure concepts.
- Students perceive a positive benefit to their learning by using the DSL tool.

III. IMPLEMENTATION

The design of the DSL tool is based onto three main components namely: Basic Objects, Nodes, and Integration of Audio with Visualisation. Figure 1 shows a snapshot of the DSL tool, it shows both basic object and node structures.

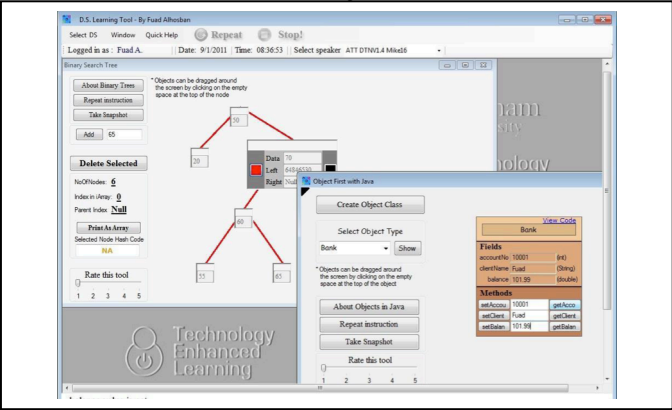


Figure 1. A Snapshot of DSL tool

A. Basic Objects:

This component is designed to help students in understanding what is meant by objects in Java, and how they are created. The design of this object simulates BlueJ’s presentation of Java classes in order to build a relation with the programming environment that students will be working with during the academic year.

Created object is made in a way that it is dynamically changed according to the student’s specification of its attributes. When creating an object, a student can name the object class. Based on that, an object is created that simulates the run-time state of the Java class. Student can then interact with the object by setting and getting its values.

B. Nodes:

In object oriented programming, nodes are referred to as the data record in the computer memory that forms the basic form of data structures such as Linked Lists, Binary Trees. Nodes are used to simulate how DS actually work and are stored in the memory.

Figure 2 illustrates two types of nodes used in the DSL tool in their run-time state. Figure 2-A shows the full size and the reduced size of the Linked List node that contains both the value stored in the node and a single Hash Code (address location in memory) of the next node connected to it. The red square box shows that the node is linked to another node, but a black box is shown if the node is not connected to any other node (leaf node). Figure 2-B illustrates a Binary Tree node that works as a Linked List node; however, it holds the left and right memory location of its children.

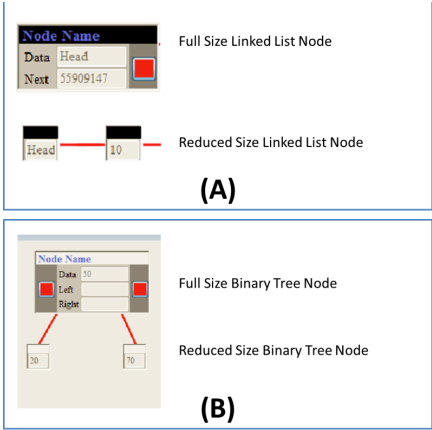


Figure 2. (A) Linked List Node (B) Binary Tree Node

C. Integration of Audio with Visualisation:

As aural instruction is a key factor in the DSL approach, it is important to present how the audio component is used as an instructional method. The use of speech technology allows the integration of aural instructions and the rendering of any text as spoken audio. The voice used in this research was chosen because it sounds the most natural of the voices available and it was the favorite voice of both staff and students.

D. Use Case:

When students opt in to use the DSL tool, first, they logs in to the tool to supply and verify his or her user information. Then, they choose their desired format for the instruction. The tool is then set to deliver textual or aural instructions while the student is learning any of the visualized data structures approaches available in the tool. When students finish working on a visualization task, a snapshot of their screen can be taken and saved for later reference.

IV. METHODOLOGIES

Several research methods were used in this research. Studying the effectiveness of aural instructions with visualization in the DSL environment depends mainly on collecting quantitative data, but some qualitative data also needs to be collected to support the findings based on the quantitative data based on triangulation methods. Two experiments were conducted to find enough evidence to support the research hypothesis, a preliminary study and a longitudinal experimental method.

A. The Pilot Study

The main objective of the pilot study was to investigate relationship between response time and cognitive load, and how can the DSL tool keeps learners cognitive load to the minimum. Based on [12] model of information processing in multimedia learning, the Cognitive Theory of Multimedia Learning and its three assumptions, the research looked at prior studies in the field that concluded that higher levels of cognitive load resulted in increased response times to instructions.

The experiment was conducted during the first practical session of the Introduction to programming module when most CS students had little or no previous contact with computer programming. A total number of 30 students were involved in this experiment (out of 40 students who were enrolled in this module). The experimental procedure applied was based on dividing the students into three conditions in a between-subjects design. In the first and second conditions, at the beginning of the practical session, each student in the two groups was given a laptop and a headset. In the third condition, the remaining group used the non-audio version of the DSL tool, so they were given only laptops. The aim was to investigate how students' responses can be affected by the type of instructional method used (Aural Only, Textual Only, and combination between Aural and Textual instructions), and how can the DSL tool achieve the lowest cognitive load while maintaining successful task completion.

B. Longitudinal Research

The DSL tool was later used in a second, longitudinal, study over two academic terms in which students studying the Data Structures module were offered the opportunity to use the DSL approach with either aural or textual instructions. Their use of the approach was recorded by the DSL system and feedback was invited at the end of every visualisation task.

As the experiment ran over two academic terms, the DSL tool was made available through a network connection to a CS Department local server (SMART), which is run by the Technology Enhanced Learning (TEL) group. The Information Technology Service (ITS) at Durham University limited access to the DSL tool so that only students using the network computers in the PDS labs had access to it. This provided all the students taking the PDS module unlimited access to the tool. Students were also provided with instructions on how to start the DSL tool. Two types of data collection methods used in the second experiment:

Quantitative data collection (The DSL usage data):

The research observed student behavior by automatically gathering information about their usage (Automated collection of usage data). This helped to provide general feedback from students about their overall learning experience. In addition, at the end of every data structures task, they were asked to provide comments on the tool's usefulness and rate the task based on the usefulness of the tool. At the end of the experiment, a questionnaire with students was conducted, to check the conclusions based on the collected usage data and to gain a deeper understanding of their views and experiences in engaging with the DSL approach.

Qualitative data collection:

It was hoped that the qualitative data collected would enable an understanding of the benefits of the DSL environment which integrates aural instructions into a visualized learning setting, how students use the DSL tool, and whether it helps them to achieve what they were trying to do. Three main types of usage data were scheduled: each student's usage of each visualisation task, written feedback within the tasks, and interviews with users.

This part of the research was conducted over the second and third terms of the academic year, that is, from 15 January to 25 June 2010. The students had access to the prototype tool whenever they wished to use it. The total number of participants decreased from 30, who took part in the pilot study, to 27 who actively used the tool in this experiment. The term "actively" means that they used the tool more than once. After reviewing the students' usage data at the end of the experiment, it was seen that a small group of students had used the tool only once. This indicated a lack of interaction with the tool and these students were excluded from the results and their analysis.

Conducting follow up interviews:

A sample size of interviews was limited to three students. Although this is a small sample of the participants, the interviewees provided valuable feedback about student engagement with the DSL approach. However, because of the small sample size, generalizations cannot be made about the student population at large.

The students were carefully selected from among those who volunteered to be interviewed about their experience of using the DSL environment and after reviewing all the students' usage data. Before the interview, a profile of each student's usage was sent out to them to remind them of what they had done. Each profile also contained snapshots of the DSL tool screens that the student had generated or they were replicas based on the student's action list. In addition, the profile contained all the written feedback the student had generated throughout the experiment.

V. ANALYSIS OF RESULTS

A. Discussion of the Pilot Study Results

Table I shows the post-hoc multiple comparisons among the three instructional methods used. As shown in the table; there was a statistically significant difference between the audio only and text only instructional methods. However, was no statistically significant difference between the text only and text with audio instructional methods. These results indicate that students who used the DSL environment responded significantly more quickly with a successful outcome to audio instructions than to other types of instruction. This leads to a conclusion that aural instructions do benefit students in a visual interactive learning environment.

TABLE I. POST-HOC MULTIPLE COMPARISONS TABLE

| Multiple Comparisons Dependent Variable: Response Time in Seconds | | | | | | |
|--|----------------|----------------|-----------------------|------------|------|-------------------------|
| | (I) Group | (J) Group | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval |
| | | | | | | Lower Bound Upper Bound |
| Tukey HSD | Audio Only | Text and Audio | -1.52000 | 1.17772 | .413 | -4.4401 1.4001 |
| | | Text Only | -3.36000(*) | 1.17772 | .022 | -6.2801 -.4399 |
| | Text and Audio | Audio Only | 1.52000 | 1.17772 | .413 | -1.4001 4.4401 |
| | | Text Only | -1.84000 | 1.17772 | .279 | -4.7601 1.0801 |
| | Text Only | Audio Only | 3.36000(*) | 1.17772 | .022 | .4399 6.2801 |
| | | Text and Audio | 1.84000 | 1.17772 | .279 | -1.0801 4.7601 |

* The mean difference is significant at the .05 level.

Based on this result, the research continued into its second part, using audio only instructions with visualisation and abandoning the use of text with audio instructions. It is expected that using audio only instructions will produce an improvement in students' interaction with the DSL approach.

B. Discussion of the Longitudinal Study

Having established, through the pilot study, the effectiveness of aural instruction for computer science students in a visual learning environment, this research moved on to investigate the effectiveness of the main feature of the DSL environment, which is visualizing the concepts of data structures in conjunction with aural instructions.

Usage Time: The first type of data collected was information about the usage time and the number of times each student used the system. The experiment recorded the time and date of each student's session. It also recorded which data structures visualisation was accessed and whether any audio assistance was used to accompany the visualisation.

Figure 3 summarizes the overall usage data. The mean average time spent on engaging with the DSL tool was about 40 minutes, which equates to one third of a practical session. The results show that, during ten practical sessions over two terms, students spent an average of 3.3% of practical session time using the DSL tool. However, usage by different students varied greatly. The longest time a student spent using the tool was 127.92 minutes (about 2 hours and 8 minutes) and the least time was about 4 minutes. This implies that students do choose to use the DSL tool while studying data structures.

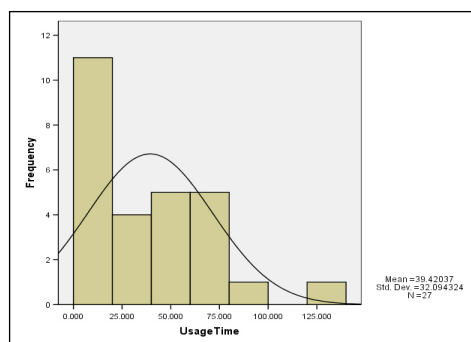


Figure 3. Students' usage time

Task Choice: Although the previous data provides an overview of the tool's usage, more investigation was needed to assess what sort of visualisations were more likely to be used by students and what was their effect. To answer this, the DSL environment was designed so that the prototype tool records each student action while working on the three available tasks, Binary Tree Traversal (BTT), Binary Search Trees (BST), and Linked Lists (LL). The results shows that the students engaged with the BTT visualisation task the most and with the LL visualisation the least, but the DSL tool was well used in all three tasks.

Table II provides further details of the collected data and shows the number of actions performed on each visualisation during the course of the task. In order to avoid discrepancies in the system's usage data, all the tasks where less than 5 actions were performed were eliminated from the results. This was because, after checking these instances, it became clear that they were not genuine interactions with the tool and the students did not perform valuable actions with it. Thus, it was unrepresentative data.

TABLE II. EFFECTIVE USAGE OF DSL APPROACH

| Task Type | Task Total Runs | Total number of actions |
|------------------------------|-----------------|-------------------------|
| Binary Search Trees | 46 | 367 |
| Linked Lists | 42 | 404 |
| Binary Trees Traversal | 54 | 710 |
| Total Effective Usage | 142 | 1481 |

The data in Table II shows that students made substantial use of the DSL tool to help them study all the three types of data structures. They ran a total number of 142 tasks and, within these, they performed nearly 1,500 actions while interacting with the tool. However, the BTT visualisations attracted the largest number of both runs and actions and these accounted for 38% and 48% of their respective totals.

Task Rating: The DSL environment also allowed students to rate each task they engaged with and to produce feedback that was specific to the task. For this, a rating scale was offered with each visualisation task. The scale allowed the student to rate each task with 1 to 5 stars, with 1 being poor and 5 being excellent. Out of the total of 142 effective tasks undertaken, the students used the rating scale on 60 occasions (23 BTT task, 19 BST task, and 18 LL task). The overall rating for the three visualisation tasks was as follows (BBT:3.8, BST:3.2, and LL:2.8). The BTT task achieved a higher rating than the other two tasks, which correlates with the previous data about the greater interaction with that task. In addition to the rating, written feedback showed appreciation from students of the contribution of the DSL approach to an active learning environment.

Audio Usage: Students were given the choice to use the tool with or without aural instructions. At the login screen, students could choose either to have aural or written instructions, but they could not have both. However, there is a known risk of a student choosing to use aural instructions without having headphones on, or taking the headphone off

when switching between visualisation tasks. The only way used to avoid the risk, was by continuous monitoring of students usage of the DSL tool during the practical session by the main researcher conducting this research. However, there was no case found where students have reported that they are using audio without actually using it.

Table III shows the percentage of audio usage with visualisation versus using visualisation alone. Again, these results were based on the number of students who engaged actively with the DSL tool, as defined previously. The overall usage of audio in all the tasks performed by students was 54.11%. Looking back at the data generated by the students' engagement with the DSL approach, it was noted that most of the audio usage (77.77%) was from tasks that generated less than ten actions. This means that most students used audio in short tasks, whilst students involved in longer tasks requiring a high number of actions were less likely to use audio with a visualisation.

TABLE III. PERCENTAGE OF AURAL INSTRUCTION USAGE AGAINST TEXTUAL INSTRUCTIONS

| Visualisation Type | Percentage of Audio Use |
|----------------------------|-------------------------|
| Binary Search Trees | 56.52% |
| Linked Lists | 59.52% |
| Binary Trees Traversal | 46.30% |
| The overall usage of audio | 54.11% |

A question is raised here, that is “do CS students perceive benefits from aural instructions along with visualisation when studying data structures?” The perception of benefits was measured from student responses to a questionnaire and interview questions. Students’ responses to the questionnaire at the end of the academic year showed that they perceived that the DSL environment helped them to build mental models of data structures. A majority (93%) of the students who responded to the questionnaire reported that the aural instructions were clear and easy to follow. The results of the interviews, discussed later, also confirmed this finding. However, some external factors may have resulted in reducing the choice of aural instructions over the textual instruction, such as the students’ own learning styles, students forgetting to bring their headphones to the lab, and previous unfavorable experiences with audio based learning materials.

Questionnaire Results: The questionnaire results provide evidence that the students perceived benefits from using aural instructions and visualisation by engaging with the DSL tool. 93.8% of students reported that their use of the DSL tool helped them to create a mental model of the three data structures.

In the written feedback about the DSL experience, one student reported that the DSL tool “*was a very easy to use tool that provided a good visual aid for linked lists and binary search trees.*” This comment shows a deep understanding of the approach and his positive interaction with it. However, he also added that “*the linked list program was quite buggy and sometimes left the program prone to crashing.*” It should be noted here that there are no records of how many system crashes occurred because the data was saved only upon normal and error free closure of a visualisation task.

There were mixed reviews about the usage of audio to support visualisations. Some found it good and useful, for example, “*audio instructions and descriptions were very useful, as well as the ability to add and remove nodes into an existing list.*” The students who experienced technical issues with integrating audio and visualisations tended to be deterred from using it, with one student explaining, “*Audio didn't work first time, and I haven't used it since then.*”

Students Marks vs. Engagement: The student participants in this experiment did not do a pre-test and post-test to see if the DSL environment had a direct effect on their learning. This was because there were other types of learning inputs to the PDS module so it would not have been possible to isolate the effect of the DSL environment. In any case, the DSL environment was not part of the PDS module and it was not considered a formal learning approach. Instead, the research looked at students’ results in their PDS end-of-year assignment to investigate possible correlations between these and their engagement with the DSL environment, keeping in mind that correlation does not necessary mean causation, and the researcher had no information about the students’ abilities and weaknesses.

To compare students’ assessment marks with the duration of their engagement with the DSL tool, Figure 4 shows the linear regression of the scattered marks against engagement with the DSL approach. This shows, in general, that students who spent more time using the DSL tool obtained lower marks in the end-of-year assessment.

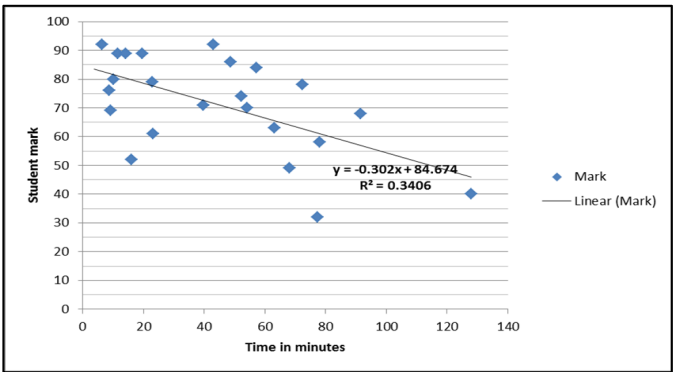


Figure 4. Student marks Vs. Time spent using DSL tool

This result may suggest that less able students used the DSL tool as an additional resource to help them to understand the concepts of data structures, rather than that their use of the tool contributed to their lower marks. If true, this finding confirms the need for learning methods like the DSL to provide students with an extra support system if and when they need it. Although there is no clear indication about whether or not using the DSL tool affected the students’ marks, it is important to note that the less able students used the tool repeatedly, and found it valuable to their study. It is also possible that these students could have gained even lower marks if they had not used the DSL tool.

Students’ Interviews: in the student interviews, the interviewees agreed that the aural instruction was clear and easy to understand. However, they had some reservation about

using aural instructions all the time. One stated a personal preference for textual instructions and the way in which this was expressed revealed that she was conscious of her own preferred learning style. Though investigation of possible relationships between students learning styles and the DSL environment was not part of the study, it is recommended, that this should be included in any future work.

VI. CONCLUSION

A. Research Summary

This paper presented a study of the effectiveness of using aural instructions with visualisation in an interactive learning environment (the DSL environment). It concentrated on the use of this approach when teaching novice computer science students the concepts of data structures. This approach aimed to reduce cognitive load on students' memory by exploiting the dual sensory channels for information processing.

A triangulation method was used to explore the relationship between the results obtained by the qualitative and quantitative research methods described in this paper. The results showed the benefits of using this research environment on students' learning experience. Data was collected by using a prototype tool created for this purpose, by testing students' perception of this approach through an end of term questionnaire and by conducting a group interview with a sample of students.

The implementation of the DSL environment provided enough evidence of the value of aural instructions to show that this is a research channel that is worth pursuing and that its development would extend its benefits. The research also demonstrated a substantial interest from the students and the lecturer in continuing to use the DSL environment as an extra resource in learning the concepts of data structures.

B. Future Work

While the DSL environment proved to be useful to students and the successful results support the use of aural instructions with interactive visualisation, there were some technical limitations that could be removed by future work. For example, adding visualisations that help students in learning AVL Trees and Graphs algorithms would improve its usefulness. These additions were recommended by the students themselves in comments they made while using the DSL approach as well as later in answers to questionnaires and in interviews.

The following suggestions would improve the scope and methodology for future research on this topic:

- This research will further be extended by including a comparative study of students who experience the environment and those who choose not to participate.
- Multiple cross-sectional studies could assess each aspect of the DSL approach individually in shorter experiments instead of conducting a longitudinal study.
- The results of this research can be supported by investigating the impact of students' learning styles on the choice of instructional method.

- The research results can also be enhanced by conducting pre and post-tests to evaluate students' level of achievement before and after using the DSL environment.

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Automating the Authoring of Learning Material in Computer Engineering Education

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Abstract— Due to the impact that Information and Communication Technologies have in the current society in general, and in academic institutions in particular, there is a growing need for effective creation and management of digital content. But content authoring is known to be an effort and time consuming task.

Digital contents used inside Technology Supported Learning Systems with learning purposes are often referred to as Didactic Resources, or Learning Objects if they are annotated with metadata. One of the main advantages of Learning Objects is that they can be reused to support learning in different platforms or environments.

Along this paper an experiment carried out with ErauzOnt, a system that automatically builds Learning Objects from electronic textbooks using Natural Language Processing techniques, ontologies and heuristic reasoning is presented. ErauzOnt was able to gather definitions, examples and exercises for the topics of the Object Oriented Programming subject –a compulsory subject studied at the first year of the Computer Engineering degree at the University of the Basque Country– using as a starting point a textbook written in English.

Keywords – *Learning Objects, Knowledge Acquisition, Content Authoring, Semi Automatic Authoring*

I. INTRODUCTION

Academic institutions, aware of the impact of information and communication technologies in nowadays lives, are adopting technology based solutions to enhance learning and to promote more active learning methodologies [1], [2]. Technology Supported Learning Systems (TSLs) enable teachers to move from the classical lecture-based approach to more active learning methodologies.

To be effective, any TSL requires the learning materials (didactic resources) that will be used during the learning process. Content authoring is known to be effort and time consuming, but the development cost might be lightened by promoting the content reuse [3]. Nowadays, there are plenty of electronic documents for any domain that can be reused to build new learning material suitable for TSLs.

Traditionally, teachers have used a set of textbooks for preparing their lectures and providing reference information to their students. Teachers usually combine fragments of different textbooks to provide information about each topic to be mastered. In a similar way, electronic textbooks can be used to generate Learning Objects (LOs), i.e., reusable didactic

resources, by identifying and extracting the meaningful (appropriate) fragments of the documents.

Object Oriented Programming is a compulsory subject studied at the first year of the *Computer Engineering* degree at the *University of The Basque Country (UPV/EHU)*. This subject tackles with the principles of Object Oriented programming including classes, objects, inheritance, etc. Although at present the subject is taught both in Basque and Spanish languages, nowadays the UPV/EHU is immersed in a multilingualism program and some subjects of the degree can be also studied in the English language. Moreover, students are expected to understand and, even write, technical reports on computer science in foreign languages such as English.

The *Principles of Object-Oriented Programming* textbook¹ [4], licensed under the Creative Commons Attribution License, covers the theoretical topics of the subject and introduces Object Oriented Programming with Java. This textbook might be used as reference book for the lessons as well as the source for generating the didactic resources employed in the *Object Oriented Programming* subject.

Along this paper an experiment carried out with ErauzOnt [5], a system that automatically builds LOs from electronic textbooks using Natural Language Processing (NLP) techniques, ontologies and heuristic reasoning, is presented. ErauzOnt was developed with the aim of being domain-independent and easily extendable to support new languages. ErauzOnt was firstly used for the Basque language and tested with textbooks about *Natural Science* [6]. This is the first experiment processing textbooks in the English language to gather definitions, examples, and exercises for the topics of the *Object Oriented Programming* subject from the above-mentioned book.

The paper is structured as follows. First, for the sake of contextualizing this work, the use of LOs and LO Repositories (LORs) as a means to support knowledge reuse is presented. Then, the motivation for using automatic or semi-automatic tools for building learning material is introduced. Next, ErauzOnt, the system used to build LOs, is briefly described. Then, the experiment is depicted and the results presented. To finish, some conclusions and future lines are pointed out.

¹ Available at <http://cnx.org/content/col10213/1.31/> and <http://www.etnassoft.com/biblioteca/principles-of-object-oriented-programming/>

II. REUSING LEARNING MATERIAL: LEARNING OBJECTS AND LEARNING OBJECT REPOSITORIES

The IEEE Learning Technology Standards Committee (LTSC) defines a Learning Object (LO) as “any entity, digital or non-digital, which can be used, re-used or referenced during technology supported learning” [7]. However, as Wiley [8] states, this definition may be too vague as almost everything matches it, i.e., the notes a teacher uses for his/her classes, may be considered a LO since it can be referenced during the learning process, even though its reusability in an application is quite limited. He instead recommends considering LOs as “any digital resource that can be reused to support learning”.

Downes provides sound argument about the need of using LOs in educational applications, especially in on-line courses [9]. He claims that we can find several courses about the same topics, e.g. “Introductory Trigonometry”. All those courses may describe the sine function, in a very similar way. If all these courses are available on-line, we will be able to find hundreds of similar resources. However, if LOs are used, there will be only a few similar resources that are shared and used in all those courses.

In order to facilitate the reuse of LOs, these digital didactic resources must be described in a common format before storing them, so that any learning system can retrieve the appropriate didactic resource for the learning process. LOM [7] is the standard used for the annotation of LOs.

For storing and sharing LOs, Learning Object Repositories (LORs) are needed. Many LORs such as ARIADNE [10], Edutella [11], or MERLOT [12] exist, and even LOR alliances such as GLOBE² are proliferating to promote the reuse of educational material.

III. SEMI AUTOMATIC CONSTRUCTION OF THE DOMAIN MODULE

TSLs require an appropriate representation of the knowledge to be mastered, i.e., the *Domain Module*. The *Domain Module* includes the topics to be mastered, the pedagogical relationships among the topics, which may be employed to guide the learning sessions, and the learning material to be used. Authoring the *Domain Module* requires some knowledge engineering expertise and it is not a task that any average teacher could face easily [13]. Hence, tools that enable the (semi-)automatic construction of the *Domain Module* to lighten the workload and engage average teachers to profit from the use of TSLs in their lectures should be provided.

Natural Language Processing (NLP) techniques can be used together with heuristic reasoning and ontologies to enable the semi-automatic construction of the *Domain Module* from textbooks. In the approach here described, the *Domain Module* entails knowledge at two different levels: the *Learning Domain Ontology (LDO)*, which contains the knowledge for planning the learning sessions, and the LOs to be used as learning resources. The development of the *Domain Module* comprises three tasks:

- **Textbook pre-processing:** Electronic documents are available in many different formats. In this task, the textbooks are prepared for the subsequent knowledge

acquisition processes and, therefore, they are transformed to the standardized internal representation that the system uses. Besides, this internal representation of the document is enhanced with the *part-of-speech* information that will be used for the knowledge gathering tasks.

- **LDO Gathering:** In this process, the domain topics to be mastered as well as the pedagogical relationships among them are identified and represented in the LDO [14]. The LDO will allow instructional TSLs, such as Intelligent Tutoring Systems, to plan the learning sessions, or the students to guide themselves during the learning process in exploratory TSLs. The LDO might allow the student to observe what has to be learnt and provide hints about the order that should be followed to prevent getting lost.
- **LOs Gathering:** At this stage, the LOs - *definitions, examples, exercises*, etc. - to be used during the learning process are identified and generated. The LO generation process here described is carried out by ErauzOnt [5]. The LDO defined in the previous process is used to conduct the acquisition of LOs. The LOs Gathering task is described in the next section.

Both the acquisition of the LDO and extraction of the LOs rely on the identification of syntactic patterns. The automatically obtained results can be supervised by the instructional designers both individually or collaboratively using Elkar-DOM [15], a concept map-based tool designed to supervise the *Domain Module* authoring process. This paper presents the experiment conducted with ErauzOnt, the subsystem responsible for the third task. Therefore, the process for extracting LOs from the electronic textbooks is described.

IV. GATHERING LOS FROM DOCUMENTS USING ERAUZONT

The generation of LOs for the domain topics is accomplished through the identification and extraction of Didactic Resources (DRs), i.e., consistent fragments of the document related to one or more topics with a particular educational purpose. The identification and extraction of these pieces is carried out combining the use of ontologies, heuristic reasoning, and NLP

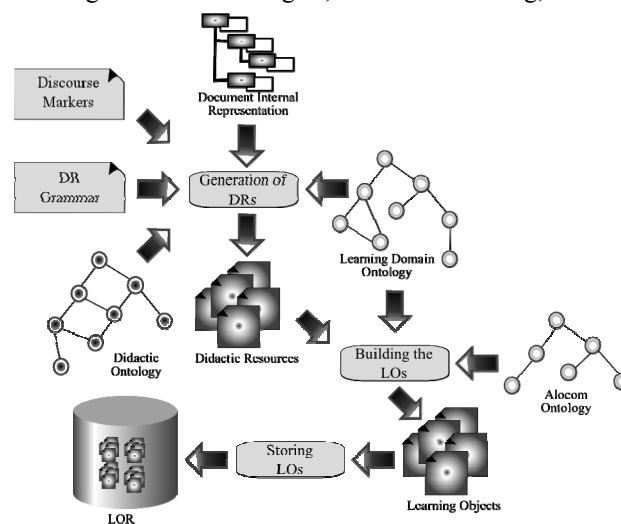


Figure 1. Generation of the LOs from Documents

² <http://globe-info.org/>

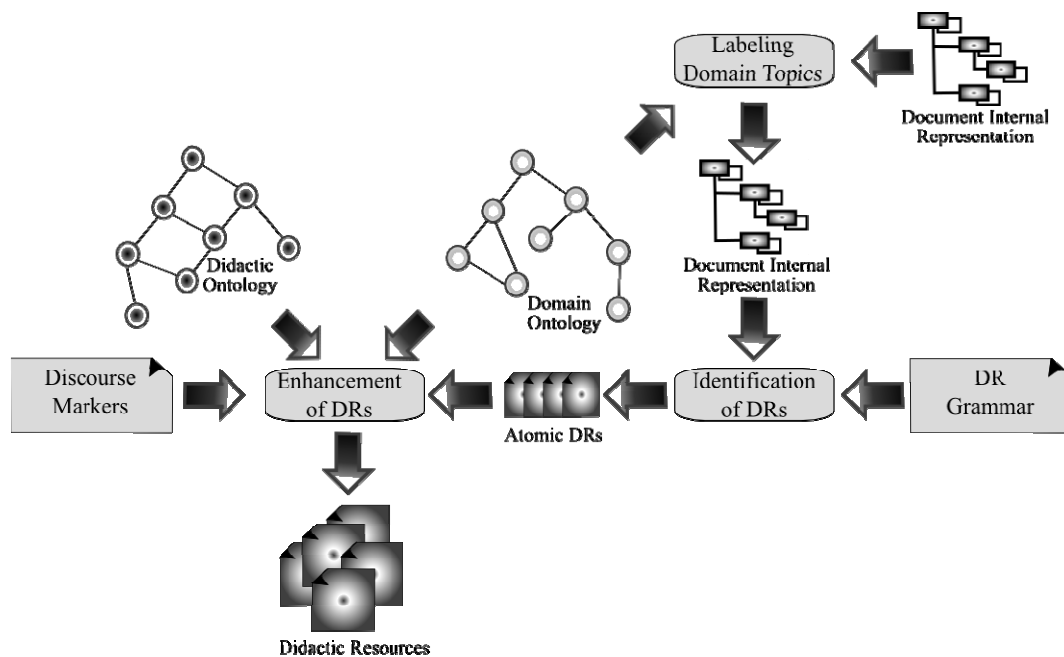


Figure 2. Generation of Didactic Resources

TABLE I. EXAMPLE OF A PATTERN FOR DEFINITIONS

| | |
|---------|---|
| Pattern | <u>@Topic</u> + is are + [determiner] |
| Example | A <u>class</u> is an abstract description of a set of objects |

techniques. From now on, a DR will refer to a piece of the document meant to be used during the learning sessions (e.g., *definition*, *exercise*,...) while a LO refers to a reusable DR enriched with metadata.

ErauzOnt aims to be applicable to any document no matter the domain it relates to. It does not rely on implicit domain-specific knowledge. The domain topics and the relationships among them, described in the LDO, are all the domain-specific knowledge used for the extraction of LOs from textbooks.

Fig. 1 describes the process for gathering the LOs from the electronic document, which entails the following tasks: generating DRs from the document, building reusable LOs from the DRs, and, finally, storing the generated LOs in a LOR for further use/reuse. The LDO, a DR grammar, discourse markers and a didactic ontology [16], [17], an ontology that defines the different kinds of DRs, are used to gather DRs from the internal representation of the electronic textbook.

The identification of the DRs is carried out by finding relevant text fragments that correspond to *definitions*, *examples facts*, *theories*, *principle statements* and *problem statements* for

TABLE II. EXAMPLE OF A PATTERN FOR EXAMPLES

| | |
|---------|--|
| Pattern | for instance e.g. for example as an example + [,] + [adverb] + @Topic |
| Example | For instance, the <u>Apple class</u> would extend the <u>class Fruit</u> . |

the topics included in the LDO, as shown in Fig. 2. First, the appearances of the LDO topics are labeled in the document internal representation with the *part-of-speech* information. Next, the set of DRs are identified using the DR grammar. The DR grammar includes a set of rules that recognize the different patterns or syntactic structures that were identified by manually analyzing a sample of documents. These patterns are the most common syntactic structures found in several topic *definitions*, *examples*, etc. TABLE I. shows a pattern that identifies a *definition* if a domain topic (@Topic) is followed by the **to be** verb and some text that describes it. Similar patterns have been also used for the identification of definitions in electronic documents written in English [18]. TABLE II. presents one of the patterns for examples. The grammar for identifying DRs from electronic documents was developed using the Constraint Grammar formalism [3].

Given that the DRs identified by the grammar, atomic DRs, are usually quite elemental, they are enhanced in two ways to make them more accurate and reusable. On the one hand, consecutive DRs are combined in a new composite DR if they are similar, to which end similarity measures have been defined [19]. These similarity measuring methods rely on the UKB algorithm [20–22] and use the LDO to obtain the resemblance of two DRs according to the referred topics and the kind of the DRs; the Didactic Ontology [16], [17] determines if two DRs are suitable to be combined based on their kind. TABLE III. shows two DRs suitable for being combined in a new composite DR. On the other hand, and in order to keep the cohesion of the DRs, previous fragments are added to each DR if it contains references to preceding DRs or sentences. The cohesion maintenance relies on the use of discourse markers, i.e., words or expressions that connect part of a text with its context.

TABLE III. EXAMPLE OF TWO ATOMIC DRs THAT MIGHT BE COMBINED

| | |
|------------|---|
| DR1 | Array variables are declared like other variables: declaration consists of the array's type followed by the array's name. |
| DR2 | For example, <pre>double[] [] matrixOfDoubles;</pre> declares a variable whose type is a two-dimensional array of double-precision floating-point numbers. |

Once the final set of DRs has been built, each DR is turned into a LO to facilitate its reuse. The ALOCOM formalism [23], [24] is used to represent the content of the LOs and to enable its flexible repurposing and reusing. The facility to find and retrieve the appropriate LO is essential for reusability issues, to which end each LO is annotated with descriptive metadata. ErauzOnt can gather LOs of different granularity. Whenever a composite LO is generated, all its finer grained LO components are also labeled. The annotation of each gathered LO is made automatically using SAMgl [25], an automatic metadata generator, except for labels such as *Keywords* or *Learning Resource Type* which are filled with the information elicited during the DR construction phase. The *Keyword* label specifies not only the domain topics referred in the LOs but also the semantically closest topics in the LDO. To label the *Learning Resource Type*, the most confident rule among the ones that fired during the identification of the DR is chosen. The *Learning Resource Type* is specified in terms of the ALOCOM ontology [26]. All the generated LOs are stored in the LOR so that they can be used for *Domain Module* authoring.

V. IMPROVING ERAUZONT TO SUPPORT ENGLISH

The ErauzOnt framework was developed to enable the automatic extraction of LOs from electronic textbooks following the approach mentioned above. The framework aims to be applicable on any document no matter the domain it relates to. None of its components relies on implicit domain-specific knowledge. All the used domain-specific knowledge are the domain topics and the relationships among those topics described on the LDO, which is semi-automatically gathered in the previous phase of the *Domain Module* authoring [14] and is the input for the LO extraction process together with the document to be analyzed. Furthermore, the LDOs might be built semi-automatically from the document [14].

Besides, although originally ErauzOnt was evaluated with textbooks written in the Basque language, it was designed to be easily extended to support new languages. In fact, the work here presented required to enhance ErauzOnt to support the English language.

ErauzOnt relies on NLP techniques to identify the relevant DRs in the textbooks, so an analyzer must be integrated for each supported language. ErauzOnt was enhanced to use FreeLing [27], an analyzer that supports several languages such as English or Spanish. In addition, it was necessary to define the DR grammar that contains the syntactic patterns used in English for the DRs and the Discourse Markers for English. ErauzOnt uses the appropriate resources, i.e., NLP analyzer,

DR grammar and Discourse markers, for each document according to the language it is written in.

The development of the DR Grammar for English took a Computer-Engineer's 4 day work, while the integration of FreeLing was carried out in 4 days and the Discourse Markers were defined in 1 day.

VI. EVALUATION

ErauzOnt was tested to assess its performance over a textbook written in English and oriented to Computer-Engineering students. The *Principles of Object-Oriented Programming* textbook, which tackles the basic concepts of *Object-Oriented Programming*, was used for this evaluation. The main goal of the experiment was the evaluation of the acquisition of text-based LOs, so an adapted version of the textbook, in which the images were removed, was processed instead of the original document. The analyzed book consists of 67 pages and 29300 words.

The experiment was carried out in the following procedure: the teachers of the subject defined the LDO that describes the topics to be learnt as well as the pedagogical relationships among the topics. The teachers manually analyzed the textbook to identify and label the set of DRs (*definitions*, *examples*, etc.) that would like to use for mastering the main topics of the subject. Then, the LDO was used to process the textbook with ErauzOnt, and a set of LOs was obtained and stored in a learning object repository. The set of automatically elicited LOs was assessed by instructional designers to determine their adequacy, to which end the set of DRs manually identified by the teachers was used.

Given that this was the first experiment with ErauzOnt over documents written in English, both the DR grammar and the gathered LOs were tested as a means to assess the performance of the system.

A. Evaluation of the DR Grammar for English

The DR grammar was evaluated by analyzing the atomic gathered LOs, i.e., the finest grained LOs. Each LO was inspected to determine which rule were used to identify it and, therefore, to obtain the accuracy of the DR grammar.

TABLE IV. shows the statistics about the evaluation of the DR grammar. The DR grammar is able to identify *definitions*, *examples*, *problem statements*, *principle statements*, *facts* and *theories*. However, not every kind of DR is always used. Neither *facts* nor *theories* were used in the analyzed textbook. The DR grammar built for identifying the syntactic patterns commonly used in DRs achieved 80.09% accuracy. The average of the rules ranges from 100.00% for the *examples* to 58.33% for the *problem statements*. The DR grammar achieved

TABLE IV. ACCURACY OF THE DR GRAMMAR

| | Definitions | Examples | Problem Stat. | Principle Stat. | Total |
|-------------------|-------------|----------|---------------|-----------------|-------|
| Found | 164 | 1 | 12 | 49 | 226 |
| Correct | 138 | 1 | 7 | 35 | 181 |
| Accur. (%) | 84.15 | 100.00 | 58.33 | 71.43 | 80.09 |

TABLE V. RECALL OF THE LO ACQUISITION PROCESS

| | Definitions | Problem Statements | Combined DRs | Total |
|-------------------|-------------|--------------------|--------------|-------|
| Real | 35 | 2 | 17 | 54 |
| Found | 22 | 2 | 17 | 41 |
| Recall (%) | 62.86 | 100.00 | 100.00 | 75.93 |

similar results to the previously conducted experiments over textbooks in Basque [6], except that the accuracy for *problem statements* was considerably lower, mainly because imperative cases, frequently used to state *problem statements*, are easier to identify in Basque, which uses an auxiliary verb for that purpose. The identification of the *problem statements* in English mainly relies on the appearance of keywords such as *exercise*.

B. Evaluation of the LO Acquisition Process

Finally, the gathered LOs were evaluated. This evaluation was carried out comparing the manually identified DRs with the automatically gathered ones. The evaluation of the gathered LOs considered both their appropriateness (*precision*) and the quantity of the manually defined DRs that were automatically identified (*recall*). An aspect to be considered to evaluate the gathered LOs is that while a LO might be the most accurate in a particular context, one of its components or a more complex LO (a composite LO that comprises it) might fit better in other situations.

In order to obtain the *recall* of the LO acquisition process, the automatically gathered LOs were compared to the manually identified ones. The teachers identified 54 DRs, 35 *definitions*, 2 *problem statements* and 17 *combined DRs*, i.e., DRs that entail two or more DRs of different kind. ErauzOnt achieved a 75.93% *recall*, i.e., 41 of 54 manually identified DRs were automatically gathered. 100% of the *combined DRs*, 62.86% of the *definitions* and 100.00% of the *problem statements* were automatically gathered. *Problem statements* proved to be easy to find, while *definitions* were more difficult. *Problem statements* are presented using verbs in imperative case or keywords such as *exercise*, while *definitions* may appear in many different forms that make them more difficult to find.

Determining the *precision* was not so straightforward, and all the gathered LOs and their components had to be analyzed. While a particular LO could be the most appropriate for a certain context, one of its component LOs or a more complex LO, a composite LO that comprises it, might fit better in other situations. Therefore, each generated LO was observed to determine whether it was valid, not only considering the subject for whom the textbook was analyzed but any other context.

TABLE VI. PRECISION OF THE LO ACQUISITION PROCESS

| | Definitions | Problem Statements | Combined DRs | Total |
|----------------------|-------------|--------------------|--------------|-------|
| Found | 140 | 2 | 229 | 371 |
| Correct | 121 | 2 | 199 | 322 |
| Precision (%) | 86.43 | 100.00 | 86.90 | 86.79 |

TABLE VI. summarizes the information of the analysis of the automatically elicited LOs. ErauzOnt gathered 371 LOs, 140 *definitions*, 2 *problem statements*, and 229 *combined LOs*, i.e., LOs that comprise LOs of different kinds. Although the DR grammar also identified fragments that may be part of *principle statements*, these were elements of other kinds of LOs, either *combined* or not.

The overall achieved *precision* was 86.79%, i.e., 322 of the 371 LOs were considered usable for this course or any course that might be developed in the future. *Problem statements* obtained 100% *precision*, while *definitions* got 86.43% and *combined LOs* 86.90%. Considering these results, the pattern-based approach used by ErauzOnt to gather LOs from electronic textbooks prove to be accurate and useful.

VII. CONCLUSIONS AND FUTURE WORK

This paper has presented ErauzOnt, a framework for the automatic extraction of Learning Objects (LOs) from electronic textbooks. ErauzOnt uses Natural Language Processing (NLP) techniques, heuristic reasoning and ontologies. It was firstly used for the extraction of LOs from textbooks in Basque, but it has been extended to support English, and has been tested over the *Principles of Object-Oriented Programming* textbook, used in the *Object-Oriented Programming* subject, to evaluate its performance.

ErauzOnt was developed with the aim of begin domain-independent and scalable, i.e., easy to enhance to support new languages. Therefore, improving ErauzOnt to enable the acquisition of LOs from textbooks in English was quite simple.

Given that this was the first attempt to use ErauzOnt for building LOs from a textbook written in English, and oriented to university level students, both the DR grammar that facilitated the identification of DR fragments and the generated LOs were evaluated.

The analysis of the results proved that the DR grammar is an appropriate means to identify the fragments of the document that may contain relevant content to achieve an instructional objective. The DR grammar achieved 80.09% accuracy, i.e., correctly identified and classified fragments of the document with educational purpose.

The gathered LOs were also analyzed both individually to determine their appropriateness and comparing them with the set of Didactic Resources manually identified by the teachers of the subject. The LO acquisition process extracted 75.93% of the manually identified Didactic Resources, and 86.79% of the gathered LOs were considered valid.

ErauzOnt had already been tested over textbooks in the Basque language, covering different areas of the *Nature Sciences*, for secondary education students. The results of the English experiment were quite similar to the previous experiments, so it might be deduced that ErauzOnt is neither tight to a particular language nor a concrete domain.

Further work on ErauzOnt comprises improving the treatment of images in the LO generation. Although ErauzOnt is currently able to process images in the electronic document, it only considers their position in the text, unaware of where the image is referenced and, therefore, useful. Hence, the treatment of the images must be improved so that they can be

combined with the fragments of the document that reference them to get more accurate LOs.

Machine Learning methods are planned to be used to infer new rules that might improve the identification of the LOs in the electronic textbooks.

The construction of multilingual *Domain Modules* is being also addressed. The Learning Domain Ontology supports the multilingual representation of the domain topics, and machine translation might be used to get approximate translations of the gathered and employed LOs that would be looked for either on the Learning Object Repository or different resources.

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Improving Collaborative Learning by Personalization in Virtual Learning Environments Using Agents and Competency-Based Ontology

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Abstract—With the spread of distance education courses or blended, an increasingly common problem is the lack of a personalized accompaniment to the student and the delay in responding by mediators and other colleagues the doubts and requests from students in Virtual Learning Environments (VLEs), usually posted on forums or manifested via e-mail. The approach taken to solving this problem presented in this paper is based on multi-agent systems and a competency-based ontology of the learner model. Through such technologies, the student's doubts are identified and these are directed to community members who have the profile with best suited skills and competencies to resolve it, decreasing the response time of doubts from students. A Petri Net has been developed in order to represent interactions among agents. The system was tested in a Numerical Analysis class that makes use of the VLE Moodle. The results of the tests were used to prove the validity of the system and the viability of the solution. Survey questionnaires were passed in the classroom in order to obtain and evaluate the students' impressions about the resource available to them in the VLE.

Keywords—*Learning Management System (LMS); competency; ontology; multi-agent systems; Petri Nets*

I. INTRODUCTION

The advancement of Information and Communication Technologies (ICTs) and the increased demand for e-learning platforms, which enable interaction between students and teachers, sharing knowledge, have transformed the Internet into an important tool for teaching purposes. However, a Learning Management System (LMS), or Virtual Learning Environment (VLE), generally provides learning resources in the same way for all students, where learning cannot become effective for all students by the several cognitive characteristics that each learner has. Therefore, this creates difficulty of knowledge acquisition for some students.

For a better understanding about the problem addressed in this paper, let's imagine this scenario: consider a group of students participating in a Distance Education course or blended, which uses in these classes a VLE. There are teachers and tutors monitoring the course and interacting with students in this environment via forums and e-mails, but there is not an automatically and effectively management with regard to the

doubts that students may have when they are performing some activity. These doubts could be detected by the incorrectness of students' answers to questions. The difficulties of the student to perform the proposed tasks can also be evident if a task is not delivered until the date specified for delivery. Nor is there an automatic service of experts indication to answer these doubts, not allowing the teacher or tutor being free to do other activities relevant to the course.

As a strategic solution, it is proposed in this paper the support of student activities in educational environments by the personalized indication of some student of the same course. Personalization in the context of this work is the search for one or more students with an adequate profile, i.e., students who have desirable skills and competencies to address questions about certain subject matters of students. The approach taken to solving this problem is based on multi-agent systems and a learner model ontology that extends the IMS Learner Information Package (LIP) [1] specification from the theory of skills and competencies developed by the Swiss sociologist Philippe Perrenoud. The proposal is based on the idea that the completion of certain activities from the collaborative learning among students in a VLE is a way to build the student's knowledge, in addition to several teaching tactics in the literature, such as recommending materials studies for the student and adaptive tutoring strategies. Furthermore, the interaction between learners is a strategy employed in order to build knowledge more significantly. This is because learners develop intra and interpersonal skills, not being independent to be interdependent [2].

Moreover, with the aid of Artificial Intelligence techniques, as agents and ontologies that constitute the pillars of the Semantic Web [3], is added to this e-learning environment a characteristic of STIs, the personalized recommendation [4] students proactively and dynamically. The recommendation feature is inserted in the context of adaptive learning systems, and modified according to the learner needs [5].

In addition to this section of Introduction, this paper is structured as follows: Section II describes related works; Section III presents the system architecture, explaining how the recommendation process of students is and also illustrates a Petri Net modeling of the system; Section IV reports on

experiments conducted in a VLE system and Section V, conclusions and future work.

II. RELATED RESEARCH

There are several studies related to adaptive learning systems that reinforce our proposal in this paper. Among them we highlight [6], where is shown a proposal for an adaptive environment in which students must achieve certain skills, but without going into detailed features how to get them, only infer them through the evaluation results. This work uses the IMS standards and in accordance with the assessments of student grades, activities and study materials (e.g., learning objects) are recommended, aiming to increase the level of learning and skills of the student, not doing use of multi-agent systems. A work that makes use of multi-agent systems in association with Semantic Web is [7], in which uses crawlers RSS feeds to generate content and learning objects to students depending on their areas of interest and their cognitive levels in the LMS Intelligent Web Teacher (IWT). LORSE [8] consist of a set of intelligent agents developed in the JADE [9] framework, whose responsibility is to deliver to users different learning objects from several learning objects repositories in response to specific searches requested by teachers and students. The LUISA project [10] consists of a semantic ontology-based architecture which is used in the LMS Moodle [11], where users enter and perform the login to the environment in a course for the first time, select the skills that they intend to develop and for those that were marked, learning objects and activities are recommended for the user study and achieve the desired competence.

We can see, with these works described above, there are several techniques for customizing VLE based on the recommendation of educational resources to students in order to make learning by students more effectively. In the case of adaptive systems, there are many works based on student information such as interests, competencies and skills, but there is no data detailing of these skills. Thus, the learner model may not be able to inform to the e-learning environment what are the deficiencies of the student more accurately. Regarding the recommendation process resources, many studies in the literature present recommendations for learning objects, which not always the student will be interested in using them. Consequently, the e-learning environment may not make decisions that cannot assist the student completely.

This work differs because we consider specific competencies and skills in courses or subjects that students take part, in order to obtain a more accurate diagnosis of the students' situation in the educational environment. Moreover, the recommendation of learners to help other students with questions turns out to be a different solution and complements the traditional techniques of content adaptation in VLEs.

III. SYSTEM ARCHITECTURE

A. Overview

The system architecture [12], composed of the agents developed in JADE [9], ontology, VLE and its MySQL database, is shown in Fig. 1. The personalized recommendation

process begins when the teacher elaborates the activities in the VLE, selecting what skills and competencies, and their levels (which are normalized in the range of 0 to 10) are needed to resolve them. The teacher can also select the level of initial skills and competencies of students, which is useful in cases where the teacher already has some knowledge of their students. The learner, in turn, interacts with the system, either by registration of his/her personal data, by posting something on the forum or resolution of proposed activities on the e-learning environment.

The agents of updating, that are responsible for changing the learner model, are:

- *Initial Skills Agent*: query the database about the students' initial levels of skills and competencies set by the teacher and sends this information to the *Update Profile Agent*;
- *Activity Assessment Agent*: responsible for the assessments of the answered questions, and sends scores of students to the *Update Profile Agent*;
- *Update Profile Agent*: responsible for updating the learner model data by the interactions with the environment, such as upgrading their levels of skills and competencies through the information obtained from the *Initial Skills Agent* and the *Activity Assessment Agent*.

The agents of recommendation, responsible for the recommendation process of students who can help their colleagues, are:

- *Doubt & Error Profile Agent*: agent that searches for students' doubts and errors based on the results of the activities answered in the e-learning environment and that maps such errors in skills and competencies needed to perform the tasks. With this information, the agent sends a message to the *Recommended Profile Agent* containing data about the existence of learners with doubts and errors;
- *Recommended Profile Agent*: agent that searches for students with levels of skills and competencies (greater than or equal to those suggested by the teacher in the registration of new activities) capable of resolving the questions proposed based on requests made by *Doubt & Error Profile Agent*. A student can be recommended only if he/she is frequent in the blended course. The recommendations' data of students selected by the *Recommended Profile Agent* are saved in the database and then are listed in the VLE for students with errors or doubts concerning the proposed activity.

Finally, the agents of tutoring that send messages to students in the e-learning environment, are:

- *Notifier Activity Agent*: agent notifier of new activities requested by the teacher to keep students informed about new activities;

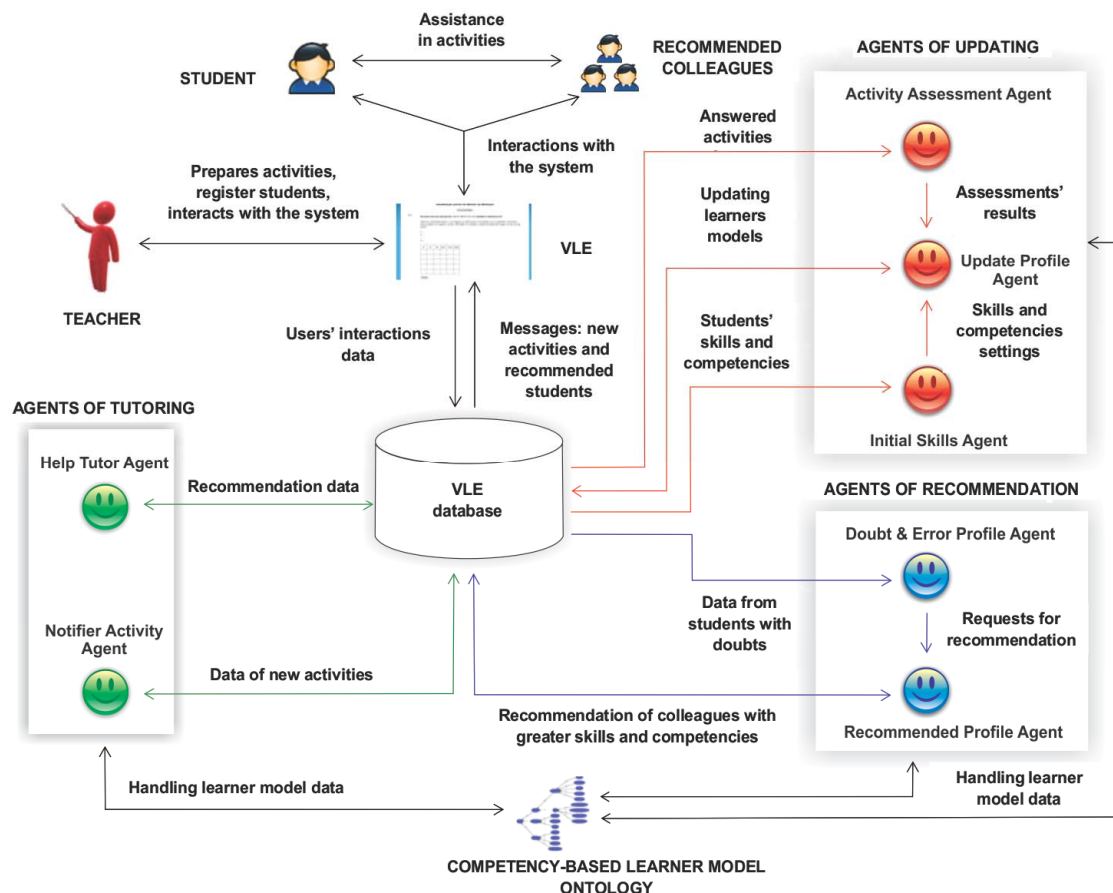


Figure 1. System architecture.

- *Help Tutor Agent*: responsible for sending two types of messages. The first type consists of messages to students with doubts by sending a link that they can access to see their recommended colleagues. The second type of message is for those learners who did not deliver the job within the deadline set by the teacher. Fig. 2 shows a message sent to a student with doubts by messaging service using the LMS Moodle.

All agents use the learner model competency-based ontology presented in [13] and created in Protégé [14]. For integration between JADE agents and the ontology we used the *BeanGenerator* plugin in Protégé. The ontology contains rules of inference that complies with the IMS LIP standard. The ontology is also useful for the correct handling of message exchanging between agents and allows reuse, but modifications are necessary according to the discipline.

For the learner model ontology was used the LIP standard, which is supported by examples and implementations of the model, besides being a standard commonly used nowadays and allows extensions. However, data such as student skills and competencies in LIP are generic, and for certain subjects or specific courses, may not reflect directly how level the student knowledge is. Thus, although using LIP, this standard has been extended to the needs of this project, emphasizing the skills and competencies of the student.

In our work, the definition of competence is consistent with the criteria cited by the Swiss sociologist Philippe Perrenoud, who says that competencies may consist of a set of skills, whose skills are in the student's ability to know and do certain tasks [15]. Thus, each student's competence is composed of a set of specific skills. For example, in the Numerical Analysis [16] subject, curricular component of Engineering and some Science courses, the competency "Finding roots of functions by the bisection method" consists on the following skills: "Handling the calculating machine", "Understanding of functions (continuity, the Intermediate Value Theorem, plotting graphs, convergence and divergence)" and "Understanding the bisection method operations (choice of the initial interval, the formula and criteria for selecting the new range)".

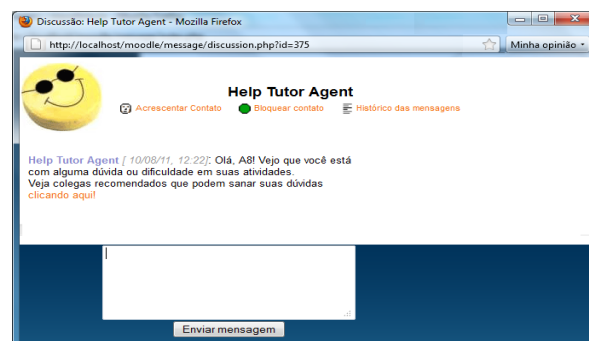


Figure 2. Message sent by *Help Tutor Agent*.

B. Modelling the System Using Petri Nets

Petri Nets (PN) is a modeling technique that allows the representation of systems, using as its foundation a strong mathematical background developed by Carl Adam Petri. This technique has the particularity to enable modeling parallel, concurrent, distributed discrete and non-deterministic systems.

The use of Petri net is justified once that it is a well-established tool for the specification of an information system of any type, specially those that need to specify concurrency and synchronism. Its graphical representation is formed by two types of nodes, places and transitions, and tokens that are used to make the system dynamic. Places are represented by circles and transitions by bars or squares. Tokens are represented by dots inside the place, when the predicate associated with the place is true [17].

To our system we developed a modeling in a non-deterministic marked Petri Net, with the aim of show the correct execution order and synchronism of the agents, as well as users' interactions within the VLE, which directly influences the agents' behavior. Fig. 3 presents a part of the non-deterministic marked PN regarding to the detection of students with doubts, the search of recommended students and the recommendation feature being shown to students in the VLE. The validation of the PN developed was done in the Snoopy [18] software. The non-determinism of PNs applies in cases such as correct activities done by students or the teacher has not yet created new activities, justifying the fact that the simulations not always have the final places (recommendations and messages to students) been achieved.

IV. SOME EXPERIMENTS

The tests were divided into two stages: a simulation in a fictional class and a second test, consisting of the use of agents and ontology in the e-learning environment in a real class of Numerical Analysis from Mathematics course at Federal University of Amazonas (UFAM). Both tests were carried out in the LMS Moodle.

A. Simulation on a Fictional Class

Simulations were done in our system to test the effectiveness of the ontology and agents within a fictitious Numerical Analysis class in Moodle containing 15 students (S1 to S15) that had different profiles. The VLE has been available on the server of Educational Robotics Laboratory (LaboREAm), Federal University of Amazonas. We prepared two activities involving matters of Bisection Method (activities 1 and 3) and an activity involving the False Position Method (activity 2).

As indicated in Table I, the skills related to the activities (1) and (3) are "Handling the calculating machine", "Understanding of functions" and "Understanding the bisection method operations". In activity (2), the skills involved are the first two mentioned for activities (1) and (3), also "Notion of absolute error" and "Understanding the false position method operations".

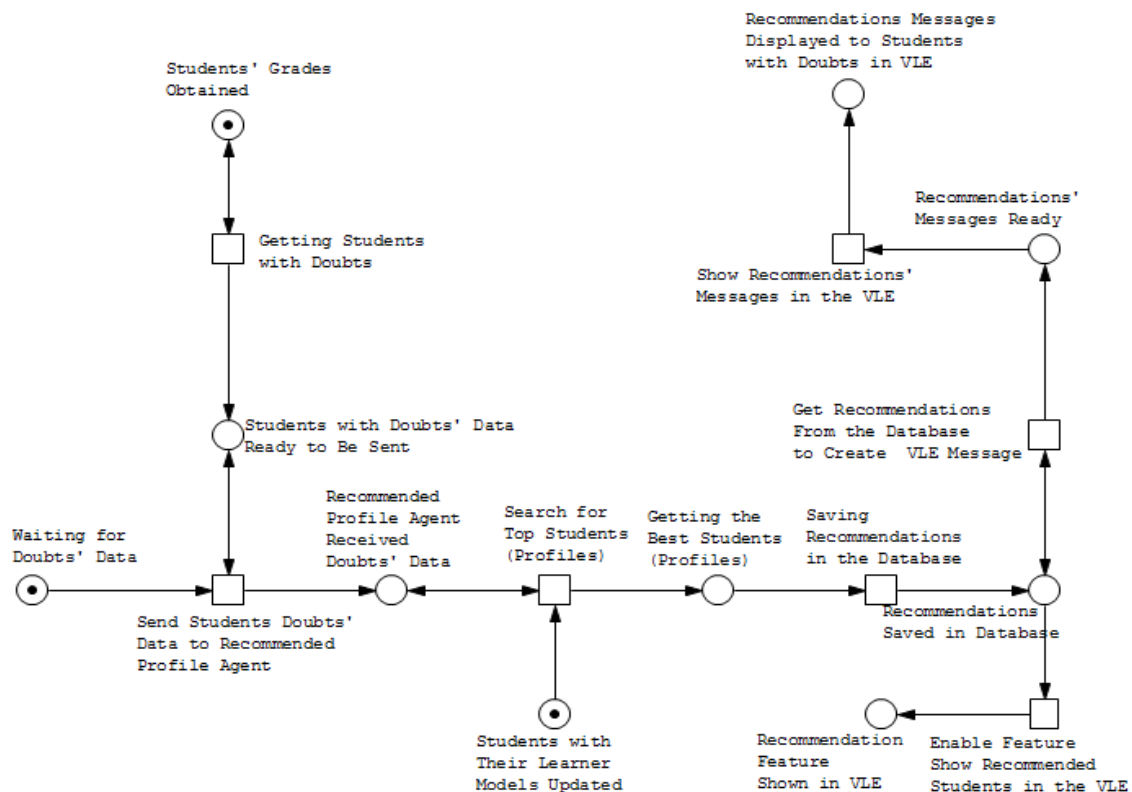


Figure 3. Agents of recommendation modeled through Petri Nets.

TABLE I. INITIAL/FINAL LEVELS OF STUDENTS' SKILLS

| Student/Activities Done | Skills Levels Initial/Final | | | | | | | | | |
|-------------------------|--|---|--|---|---|---|------------------------------|----|--|---|
| | Handling the calculating machine (1) (2) (3) | | Understanding of functions (1) (2) (3) | | Understanding the bisection method operations (1) (3) | | Notion of absolute error (2) | | Understanding the false position method operations (2) | |
| S4/1,2,3 | 1 | 4 | 1 | 4 | 1 | 3 | 1 | 2 | 1 | 2 |
| S8/ <u>1,2,3</u> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S14/ <u>1,2,3</u> | 0 | 1 | 0 | 1 | 0 | 0 | 9 | 10 | 1 | 2 |

Table I summarizes the settings of initial skills levels (before the execution of activities by students) and final (after the execution of activities and agents) for three students, S4, S8 and S14. The students' initial skills are in the first column of each required skill for the activities, while the final skills are in each second column. The identification of activities which each student did until the end date is in the first column of Table I, and the activities highlighted (and underlined) are those that the student missed.

We can observe in Table I, for comparisons between each of the two columns of the required skills for activities, that the levels of skills and competencies of students have increased one unit to each correct answer, while there was a decrease of one unit for each one of the wrong activities. Furthermore, to the activities (1) and (3), the student that is able to be recommended is S4, while in activity (2) is S14.

With the simulation results, we noticed that the system have succeeded in upgrading the skills levels according to the students' interactions in Moodle.

B. Tests in a Real Class

After the test in a fictitious class, it was time to test the system in a real class comprised of 33 students of the Numerical Analysis discipline from Mathematics course at Federal University of Amazonas, delivered in a blended learning using the LMS Moodle. Fig. 4 shows the VLE used by the class.

Two activities were passed: one involving the Bisection Method and another involving False Position Method. In the VLE were also some links, like forum postings for questions/doubts and the link of recommendation, to show who are the students who can assist in case of doubts or errors in activities.

The real test in the class was divided into two steps. The first stage was make available the LMS Moodle on LaboREAm server for students to do activities in a pre-established time, with the agents running in parallel to Moodle in order to make the environment more adaptable to students and to show the recommendation resource, useful for students with difficulties. The second step was to evaluate and verify the process of interaction with students after the recommendation of students assistants in the same class,

checking if students who missed in the first stage (after contact with colleagues who can assist them), did the exercises correctly in second time, via collaborative learning.

At the end of the tests a questionnaire survey was passed in order to students express their ideas about the system presented to them. Some responses from the questionnaire and the percentage of errors and successes of students before and after the recommendations are shown in Table II.

We can note in Table II that there was an improvement in the results of the exercises done by the students, since more students were able to make the proposed activities after the recommendation process. Although the percentage of students who scored questions even after the recommendation process is low (37%), we can see an improvement by 180% of correct answers. The low level of correct answers is also due to the fact that some students have escaped the LMS Moodle during the course of Numerical Analysis.

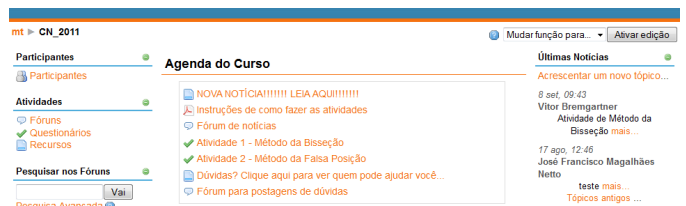


Figure 4. LMS Moodle used in a real class.

TABLE II. CLASS' ANSWERS OF THE QUESTIONNAIRE

| Question | Before Recommendation (%) | After Recommendation (%) |
|--|---------------------------|--------------------------|
| Could you do the exercise posted on the LMS Moodle? | 70 | 90 |
| Did you feel the interface "friendly" to perform the exercise? | 79 | 79 |
| Did you have any difficulty or doubt to do the exercises? | 50 | 10 |
| Percentage of correct answers (from activities) | 13 | 37 |

V. CONCLUSIONS AND FUTURE WORK

This paper shows a strategy of personalization that uses competency-based ontology integrated into a multi-agent system characterizing a learner model in the IMS LIP standard able to update, analyze, and recommend student profiles in the LMS Moodle. This proposal allows greater customization of content presented by means of personalized recommendation of students with desirable specific skills which constitute their competencies (based on the Perrenoud's concepts) to help other students with weaknesses. Simulations with the Petri Net that models the multi-agent system validated the correct order of initialization of the agents, as well as collaboration between them. The recommendation process described in this paper increases the interaction among students of the same course or

subject, thus increasing the knowledge level of learners as a whole and greater correctness in the tasks performed.

The tests with a fictitious class were performed in order to explore the efficiency of competency-based ontology with multi-agent system. The tests in a real class showed that the recommendation of students to assist others with questions through collaborative learning is a useful and effective solution to the problem of aid to students with questions in VLEs, improving student learning. This strategy can be another way to improve the teaching of students using modern Information and Communication Technologies, in addition to several techniques in the literature. The approach of the multi-agent system together with the learner model ontology can be applied to other VLEs, since the agents and the e-learning environment share the same database.

As future work, the proposal is to improve the system for adaptation in mobile devices. Also, whereas the ontology and multi-agent system work under the IMS standard, we intend to make interconnections with several e-learning systems, as virtual laboratories for telerobotics, scheduling services between students, and forums in VLEs, using this standard or compatible in order to allow data interoperability from students. Thus, personalized recommendations of students with the best profiles based on their skills and competencies will be made from reuse of student data in other LMSs to assist learners with learning difficulties.

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Flexible Virtual Environments for Teaching and Learning

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Abstract— Distance learning boosts the development of Web-based software aimed at supporting teaching and learning processes. More recently, information technology became part of pedagogies since their conception, especially for those called “pedagogical architectures” focused mainly on learning and on the processes of creation, discovery and invention. This scenario presented a new challenge: software tools need to facilitate the expression of individual idiosyncrasies and teams as well as incorporate multiple fine-tuned ways of working. It became necessary to design flexible virtual environments that meet the needs of its users, allowing runtime changes in their structures and interfaces. In this paper we present a platform designed under a novel paradigm for designing virtual environments, with flexibility to be combined and to define several virtual environments, runtime changeable without loss of data. As proof of concept, a software platform was developed and used to model and implement a total of 11 well-known virtual environments spanning from usual ones like forum, blog and wiki, to more complex examples. Finally, in order to evaluate the platform’s ability to accommodate changes, a case-study was carried out in a real-world event with a class of 10 multipliers (teachers responsible for training other teachers) that reported their use of the platform’s resources available so far.

Keywords- *Distance Learning, Flexible Virtual Environments, Tailorability*

I. INTRODUCTION

In the last ten years, the Web has changed from an ordinary medium to a complex platform, from a read-web to a read-write-web and these days Web 2.0’s ideas are in line with modern educational theories such as constructivism and connectionism, making its applications very attractive for teachers and learners [1]. This is fulfilling Berners-Lee’s original vision of the Web – ‘a system in which sharing what you knew or thought should be as easy as learning what someone else knew’ [2].

Although technical characteristics of those tools lead to specific pedagogical characteristics especially when considering Distance Learning scenarios, traditional learning management systems (LMS) tend to replicate conventional forms of teaching, especially on its focus on content organization and student activity management, both issues based on a knowledge-transfer perspective.

More recently, some pedagogical approaches take into account the technological support since its conception.

This is the case with “pedagogical architectures” [3] that are focused mainly on learning and on the processes of creation, discovery and invention, as well as encouraging subjects to perform experiments and simulations while searching for solutions to significant problems connected through different situations.

This scenario presented a new challenge: software tools need to facilitate the expression of individual idiosyncrasies and teams as well as incorporate multiple fine-tuned ways of working. In a collaborative context, software developers are not able to predict all user needs at design time [4]. That means that even if a developer is able to develop an optimal application for a group, it will eventually become inadequate due to new situations and problems that eventually will appear [5]. Thus, users should be able to adapt their applications according to their pace and work methods [4]. It became necessary to design flexible virtual environments that meet the needs of its users, allowing runtime changes in their structures and interfaces.

Developers of virtual environments tackle this problem by using approaches like component-based development, software production lines and web-services-based services. However, they do not manage to deal with the kind of dynamic modification their users are now demanding. All these approaches take an application as a finished product, without need for modifications after it is ready for use. These approaches are still not flexible enough to tackle new demands of highly dynamic domains.

In this context, a distinct approach called MORFEu (from a Portuguese acronym for Flexible Multi-Organizer of Virtual Spaces) was proposed and has been evolving [6][7]. MORFEu’s perspective is that virtual environments should be composed of simple elements that, when combined, can define tools for communication, interaction, organization of knowledge and so on. This simplicity of composition gives MORFEu-based tools, flexibility to define several virtual environments, which are runtime changeable without loss of data.

In this paper we describe a web-based software platform developed upon MORFEu’s perspective and aimed at highly dynamic collaborative scenarios. This platform is described here using a Model-View-Controller (MVC) pattern and as proof of concept we implemented a total of 11 well-known virtual environments, spanning from usual ones like

forum, blog and wiki, to more complex examples, used in pedagogical architectures for which there was no direct implementation reported. Finally, in order to evaluate this platform ability to accommodate changes in its elements, a case-study was conducted in a real-world event with a class of 10 multipliers (teachers responsible for training other teachers) that reported their use of resources available so far.

II. RELATED WORK

Software developers have been addressing suitability of virtual environments to user needs through techniques such as: modular development, component-based development, software product lines and web-services. However, the problem is still not solved.

Modular development relies upon services, libraries and frameworks that encourage reuse and focus on the goals of an application. Among virtual environments developed with this approach, Moodle¹ is one the most used. It has an atomic core of basic services and all communication and interaction tools are installed as modules, making easy to install a new module. However, these modules are available by a developer community in not so large numbers. If a group of users demands modification on any of these modules, all users of that environment would be affected.

The main idea in component-based development is to encapsulate many of the technical difficulties faced by virtual environment developers [8]. The focus of this approach is on the reuse of infrastructure aspects like protocols, synchronism, session management and others, leaving time to implement innovative solutions. Components assembled according to a group needs imply that a certain virtual environment would be developed to that specific group. Unsurprisingly this approach will have limitations when dealing with new demands resulting from different patterns of interactions and natural evolution inside the original groups. The works reported in [9], [10] and [11] are examples of component-based development.

Software product lines (SPL) present a more systematic approach than the ad-hoc criteria frequently seen in component-based [8]. SPL span over all stages of groupware development and like the component-based approach, it allows customization of applications, but also it considers a virtual environment as a finished, unchangeable product.

Virtual environments can also be developed using web-services in a distributed architecture. Examples of this approach are reported in [12] and [13], with development of applications by composition of distributed services over the Web. The work reported in [4] proposes a tailorable groupware architecture that enables the dynamics composition of services into a collaborative application. Nevertheless, as happens with the other approaches, there is no thought on how to modify one of the services, but only how the services might be composed, dynamically or not.

These approaches are still not flexible enough to tackle new demands of highly dynamic domains already into the web.

¹ <http://moodle.org>

In Table I we present a synthesis of the characteristics of current approaches and of MORFEu's, considering typical issues like when new tools can be integrated to an existing environment, how a customized environment can be made, how an existing tool can be modified, and how much time is needed to make some modification.

TABLE I. COMPARISON OF VIRTUAL ENVIRONMENT APPROACHES

| | Module based | Component based | Web services | MORFEu |
|--------------------------------|--------------|-----------------|--------------|----------|
| Deployment of new tools | run-time | project-time | run-time | run-time |
| Customized environments | no | project-time | run-time | run-time |
| Modification of existing tools | no | project-time | no | run-time |
| Modification time | – | Slow | – | fast |

III. A FLEXIBLE MULTI-ORGANIZER OF VIRTUAL SPACES

MORFEu [8] has individual production of users as its central focus, and building virtual environments will be guided by the organization of that production. Using simple elements, MORFEu can define a great variety of virtual environments that can be made flexible and able to deal with runtime changes in specification.

MORFEu has the following premises:

- Users interact with each other through virtual environments, in a knowledge construction setting;
- Interactions are materialized through user production stored in these environments;
- User production is organized in virtual environments as documents, shared according to predefined elements such as: structure, responsibility table and interaction order.

In this way, a basic item of individual production does not need to be subdued by a specific document. The same production item can be reused to form different group documents.

Conventional virtual environments organize their work spaces according to communication/interaction tools used. Tying up a production to a specific document or tool has been reason of complaining by a web pioneer that stated: “every time I write something with a computer, I have to choose whether to open the *electronic mail* application or the *net news* application or the *Web editor* application” [2].

We introduce the concept of **Intellectual Production Unit (IPU)** as the basic artifact to support authoring and registration of individual production. The IPU's can be produced in different languages, text, graphics, sound, etc., so that each IPU may be of a different type. Any production made by a user into an application can be considered an IPU. For example, forum's posts, a blog's comments, an e-mail message sent to a friend, all of them are IPU's.

In a virtual environment, interaction starts when a user shares an IPU with others. This leads to another central concepts in MORFEu: The act of sharing an IPU in a virtual

environment is called ‘publishing’, and these virtual environments defined by IPU composition are called **Communication Vehicle (ComV)**. ComV are responsible for ‘materialization’ of production generated by interaction between users following certain **interaction protocols**, and are transposed to user view according to individual **templates**.

Template is another key concept. Any visualization of data within a ComV’s document is made through a template. Instantiation of a ComV generates a hypermedia document jointly generated from publication of organized IPUs, visualized through templates.

These concepts can be used to describe conventional communication/interaction tools, as follows:

- A *chat* conversation, for example, will produce a document (ComV) generated by participants of that chat session. Posts (IPUs) are usually done one after other, with no predefined intervention order, carried out synchronously. Usually a chat has just one page, which is generated by a template.
- In a *blog*, authors create several posts (IPUs) organized by publication date. Each one of these posts is open to get comments from other users (IPUs), which in their turn will become co-authors of that document (ComV). Basically, a blog has two kinds of pages (both generated by templates): the main page with a posting list and the comments for every posting.
- In a discussion *forum*, productions (IPUs) are organized in tree organization (from graph theory). An IPU replies to other IPU or starts a new thread of publication, in a hierarchical way. The final document in this ComV is the set of all productions in the tree structure. Templates generate a page with the list of threads and one page for each thread showing its posts.

IV. PEDAGOGICAL ARCHITECTURES

Aiming at breaking away from conventional praxis around educational software – that of schools adopting artifacts (contents and program) available off-the-shelf – a novel approach was introduced in [3]. In that work, Pedagogical Architectures (PA) are described as a matching of a pedagogical approach (a group-based dynamic driven to knowledge production, devised to address a specific learning situation also considering the subjects and a specific context) with a computational support (software, communication networks, Artificial Intelligence tools, etc). Thus, is not enough to have a generic pedagogical approach (a meta-PA) and apply it to a new situation (contents, subjects and context) – it is necessary for a PA to be in consonance with its elements and that it could be modified through its use, in order to comply with new demands risen from that use.

MOrFEu [6] was proposed to tackle this challenge – production of software artifacts for cooperative learning – with the following PA requirements:

- A software artifact where is possible to describe interaction patterns combined with document generation;

- Support for supervision and intervention by a teacher;
- Support for storage and retrieval of individual and group productions;
- Resources could be modified and tuned during its use.

V. A PLATFORM FOR THE DEVELOPMENT OF FLEXIBLE VIRTUAL ENVIRONMENTS

Grounded upon MOrFEu’s principles, we propose a software platform for developing web-based virtual environments that makes it easier to build ‘tailorable’ social interaction tools, runtime changeable without loss of data. We discuss how those principles have been instantiated with current technology and used to define a platform described and prototyped using MVC development model [14].

Starting with organization of IPUs published in ComVs, behavior and data from the application domain need to be managed by a moldable element, with a data scheme that cannot be fixed since it should allow editing or adding new data types on the model. Conventional relational database are not suitable for this, once changes on its scheme are inefficient or not allowed at all. ‘NoSQL’ database are recommended, especially scheme-free ones, for example XML and document-based ones.

Each user must have its own way of accessing data, and several templates will act on a same set of data. For instance, data in a spreadsheet can be seen in several ways: a table, a row graphic, a pizza graph, a histogram, and so on.

An important element in this platform is related to management of interaction protocols and regulation of issues like: user roles, permissions, interaction rules and other constituents of formally represented workflows. Functionalities like these are requirements for current social inspired web applications [5][15][16].

Finally, MOrFEu’s principles state that IPUs exist independently of where they are published, and should be available for publishing at any ComV. Thus, there should be an IPU Database managed by the system and in ComV there are references (publications) to IPUs that constitute it. A MVC representation of these elements can be seen on Figure 1.

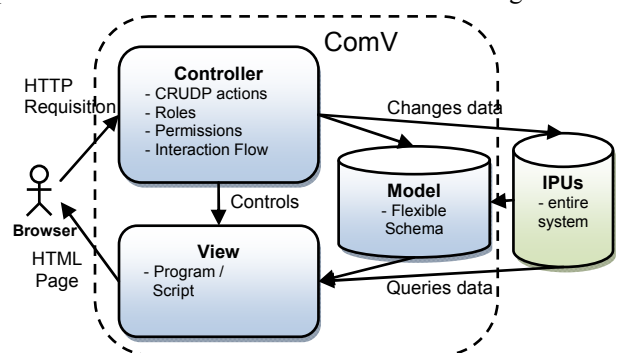


Figure 1. A MVC representation of the platform.

A Prototype of a MOrFEu-based Platform

Using MVC development model we have implemented a platform for development of ComVs. In this platform, every user can manage their IPU's and related publications. An user can access existing ComVs and create their own. Every ComV has its own MVC elements, as follows:

- **Model:** it was implemented through a XML file, stored as an IPU. This model has a flexible scheme and IPU's are published as reference to IPU's on an IPU database.
- **View:** views are IPU's in XSLT – a Turing-complete programming language for XML processing. Views process Model and display HTML pages with information in the Model.
- **Controller:** CRUDP (Create, Read, Update, Delete + Publish) actions were implemented as well as View manipulations. Permissions deal with authors and readers of a ComV.

A prototype was implemented using PHP as programming language and MySQL as DBMS. A PHP processor with modules for XML/XSLT processing is required. A software development framework called Yii² was used to speed up the prototype development. The prototype³ can be installed on any Apache-MySQL-PHP hosted either by Linux or Windows with active XML/XSLT processing on PHP.

Figure 2 shows the layer architecture of the prototype with relations between elements.

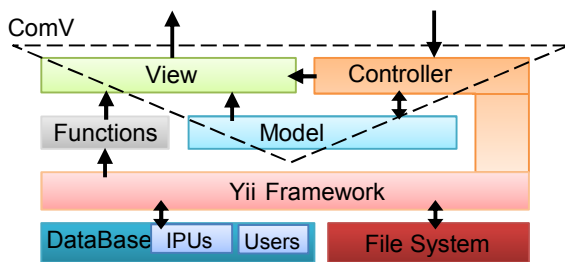


Figure 2. Layer Architecture of the Prototype.

In the prototype there are ComVs already implemented and they are used as 'models' for new ComVs. For example, if a user wants to create a discussion forum, they can copy a model from the standard forum in the system. Thus, modifications done on a ComV are valid only at each specific instance. To modify a ComV, a user may use the ComV editor and alter ComV elements: View, Model and Controller.

Interface modifications are done through View. On views also are found the links for IPU publishing and functions to obtaining system information like name of an user accessing data, IPU data, date of last modification of a ComV, etc.

Model modification includes inclusion of publishing schemata – short pieces of XML code that are included in the model at the moment of publishing.

Controller modification can refer to permissions or configurations. At the prototype, only simple permissions were implemented like who are authors and readers of a ComV.

Each ComV might have its configuration set adjusted to match an expected behavior. Simple modifications, like interface ones, can be done by the user and requires some knowledge of HTML and ComV architecture. More complex modifications, like inclusion or modification of ComV functionalities might involve several modifications on views and model, or even inclusion of new views, and should be done by developers or more specialized users.

VI. DEVELOPING FLEXIBLE TOOLS FOR INTERACTION

As concept proof, we have described and implemented 11 software tools. In this section, we illustrate the ComV development process, from design up to runtime modifications in its functionalities. To do that, we show the development process for a tool supporting a pedagogical architecture called "Thesis Debate" (TD) [17].

TD was developed as an experimental activity, in a stepwise way. After each stage, the following one was included according to what happened in that stage. As a result, a five-stage activity was devised.

In the first stage the moderator (teacher) selects theses to be debated from a survey on student previous knowledge. A chart with the thesis assigned to each student (stage 2) is prepared and each student must states whether he/she agrees or disagrees with it, along with a correspondent justification. Next (stage 3), each opinion must be evaluated by two or more members of the group and they must compose a short review. In stage 4, authors of the initial justifications can, if they want to, answer to evaluators' comments. At stage 5 users can presented a new/revised version of their positions and arguments.

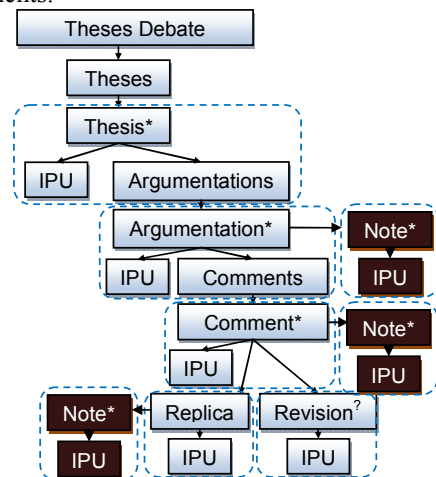


Figure 3. Data Scheme for Thesis Debate (TD)

² <http://www.yiiframework.com/>

³ <http://gsiufam.com/>

A. Project

Our ComV development platform includes a tool modeling scheme comprising data modeling and web navigation. Figure 3 presents a data model for the discussion chart of TD. Its tree-like shape makes easier to map it to a XML scheme, using for it a notation similar to ancient Jackson representation diagram [18]. On that representation, arrows mean “composed by” and a star means “one or more”. Dotted line represents publication schemes. Dark colored boxes are modifications after initial modeling, carried out during runtime. Modification process will be described later.

Figure 4 shows the navigation diagram (between webpages) for this tool. It consists of three states: the main page; a “participants list”; and “charts I have commented”. Parameters are represented along connectors.

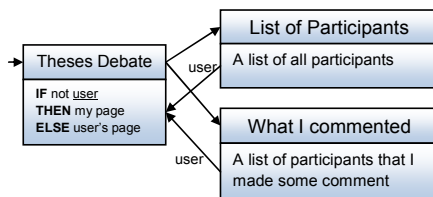


Figure 4. Navigation Diagram for a TD tool.

B. Implementation

Implementation process involves development of views, model and controller. First it is necessary to implement an initial model and publication schemes in XML. Next comes the development of a view for each of the three pages, written using XSLT. A view must “extract” data from the model and present them as a web page. The view must have links for publications specifying which publication scheme must be used, what sort of IPU and “where” in the model publication must be made. It is also possible to show system information and IPUs currently in the IPU database. Publication links and information display are done through a specific function used by the view processor.

C. Modifications

The first modification tested was the inclusion of text notes for direct interaction between moderator and participants, a situation not anticipated in the original version of TD [17]. To do this, a new Note publication scheme was added (see Figure 3). After that, a publication link was added in the chart for situation when user is a moderator. In this view an exhibition code for published notes was also added.

Other feature wanted in the tool was suggestion of charts for evaluation, since each participant should evaluate only two charts from other participants. Thus, a generation of a random list of pairs of participants was included.

A third modification was done to parameterize ComV configurations and allow informing how many charts each participant should comment upon.

These three modifications have been carried out as a straightforward task – a simple programmer working two hours at each modification. These modifications could be done

by most of the users and are supported by a versioning tool. As result, Figure 5 shows a chart of one user of this ComV, generated at the Case Study described in the next section.

D. Using ComV to develop other virtual cooperative tools

As concept proof, we have described and implemented other 10 software tools. Description for some of these tools can be easily found on the web: forum, blog, wiki, questionnaires, glossary and whiteboard. For others, there is no specific description: simulated jury [19], problem-solving virtual diary [20], soccer world-cup betting tool and a simple LMS-like course manager. The later spans over various application contexts and functionalities and are aimed to represent real world situations. These ComV have from 1 to 4 views and were implemented by one programmer working up to two days in each view. The resulting code is about 260 lines for each view.

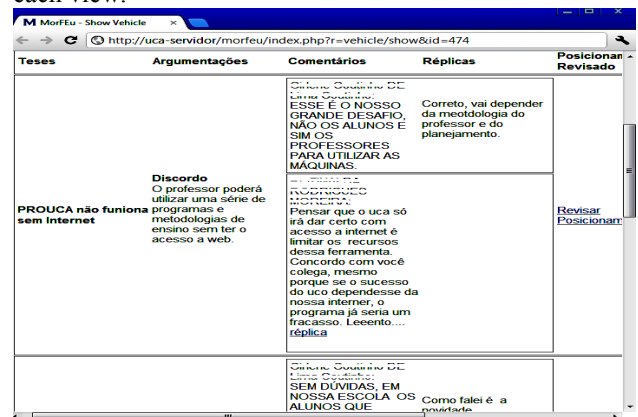


Figure 5. A TD runtime modified chart.

VII. FORMATIVE EVALUATION

An exploratory Case Study has been carried out in order to determine how the platform would tackle real-world demands for modification. The main goal was to develop hypothesis and related propositions for a following study on what sort of virtual environments can be build using the platform.

The scenario for the Case Study was a course with 10 multipliers (teachers responsible for training other teachers) on using of Information and Communication Technology on elementary school. Those participants had to reach proper skills level before to go back to their own schools and replicate the strategies and materials there. All participants agreed to be observed and to use our prototype.

Among several activities planned for that course, some time was allocated for exploring pedagogical architectures described here, built using our prototype. Two tasks were observed: using of Thesis Debate and evaluation of learning objects using forums to discussion and wiki for reporting. Participants had little knowledge on using internet-based tools, so the first task had a preliminary step: after discussing how Thesis Debate works, a structured debate was done using only 3 participants (the others stayed as observers) with conventional materials (pen and paper). By the end of the process, all participants (3 operators and 7 observers) have

said that it was too complicated to apply that pedagogical architecture with no computing support.

Next, we presented a Thesis Debate supporting tool built using our prototype and all 10 participants started the activity. We assisted the participants with technical support and questions about that pedagogical architecture, taking notes on all problems reported or functionalities the participants would like to have on that tool. The same assistance was given in the second task.

By the end of those activities we have identified a total of 31 modifications. From those, 10 were simple bugs and 11 were variations on the ComV to better accommodate personal preferences. All these 21 modifications were easily done (about 6 working hours) and checked upon by users in the following day.

All remaining modifications were concerned with variations on the pedagogical architecture, especially interaction rules, that participants thought would better suit their application scenarios (students and teachers at their own school) and not implemented because they require modifications over the controller, a component not yet incorporating formal definitions allowing runtime alterations in current prototype.

In addition to these variations on Thesis Debate, some participants suggested other ComV that they thought would be used in related contexts like a synchronous, cooperative and multi-operated text editor; or an educational-oriented social net.

VIII. CONCLUSION

In this paper we described a web-based software platform developed upon a novel software development perspective called MORFEU and aimed at highly dynamic collaborative scenarios.

Results of a concept proof implementing a total of 11 software tools gave evidence of: (1) feasibility of the proposal – there is a running prototype; (2) flexibility of the proposal – several tools, in various contexts, were implemented and used in a real-world situation; (3) ease of use – considering the amount of code, time and personnel involved in the development task.

A Case Study developed as formative evaluation gave evidence that even non-experts can present a challenging demand for modification in virtual environments (a need for flexible approaches), which support our initial assumption that even if a developer is able to develop an optimal application for a group, it will eventually become inadequate due to new situations and problems that eventually will appear.

Traditional approaches for development of this kind of tools are not flexible enough, and as we checked in a prototype stage, our platform already allows developers to implement several runtime modifications.

Our Case Study also brought out some issues related to the interaction protocols of the activities that are supported by those tools. Therefore, deeper formalization of user templates and interaction patterns, as well as other real-world case studies are the next steps on this investigation.

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