Collaborative Project-Based Training and Learning Through Multidisciplinary Undergraduate Research

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***Abstract*— This Innovate Practice Work In Progress paper presents an integrated approach into a course-based STEM undergraduate research experience. The objective of the course is to provide students with proven hands-on experience that teaches integration of discipline-specific knowledge with engineering practice on challenging multidisciplinary projects. The course design, instruction delivery, project preparation, team formation, system, and sub-system construction, as well as student and course assessment will be discussed and faced challenges emphasized. Initial feedback from students and faculty shows that the benefits include increasing interaction with the faculty and increasing intellectual maturity, knowledge, and confidence for the students. As for the faculty, this includes furthering of research projects and achieving some of program objectives as required by accreditation boards.**

Keywords—Multidisciplinary Undergraduate Research Course, STEM, Subsystems, Assembly, Design, Peer Evaluation

I. Introduction

This paper presents a STEM Multidisciplinary Undergraduate Research Course for Collaborative Design and Learning. The course is an elective, aiming to offer upper division undergraduate students with outstanding academic potential exposure to research challenges and the opportunity to work closely with faculty mentors on research projects.

One primary objective of the course is to enhance the multidisciplinary component of the students, infuse STEM skills and, prepare them for their professional careers, which may not necessarily be in research [1, 2]. The projects can range from several engineering as well as science fields [3-5]. Several surveys have revealed that, the alumni overwhelmingly state that their education would have been far more effective if they had had access to independent studies and research courses through which they could solve real-world problems and practical applications [6]. Furthermore, several industrial companies, and accreditation boards e.g., ABET, (Accreditation Board for Engineering and Technology) recommends enforcement of problem-solving abilities and mandated minimum credits of design content in all the four-year undergraduate engineering programs [7, 8]. An integrated sequence composed of five courses was proposed in [9], one each in the spring of the freshman, sophomore, and junior years, followed by the two-semester capstone in the fall and spring of majors' senior year. This vertical integration of topical themes and multi-year teams in engineering design provides scaffolding for the development of skills needed to be effective and productive. In a study reported in [10], undergraduates from 41 institutions participated in an online survey on the benefits of their undergraduate research experience. Participants indicated gains on 20 potential benefits and reported on career plans. Over 83% of 1,135 participants began or continued to plan for postgraduate education in the sciences [11].

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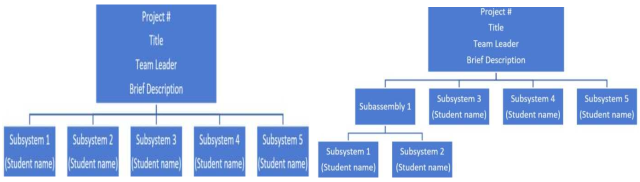
II. DESIGN PROCESS AND IMPLEMENTATION

The course introduces undergraduate students to basic skills about conducting an independent research project. It builds upon the papers [2, 3] through two main components: project/students selection and subsystems development. Students use appropriate research tools and search engines, define research topics and devise research questions. They will write computer code, model, and simulate computational phenomena and conduct and analyze experiments. They will run the design process iterations and work within a team with specific steps. Each student interacts with his project-mates and with other project teams. He also interacts with a faculty instructor and a faculty supervisor.

The idea consists of an elective 3-credit hour special topics course for senior standing and junior under instructor approval. The course runs on a two-side basis; the first consists of regular lectures given by a faculty instructor who also is the coordinator and manager of the whole process. The second part is group-based, where a team of students work on a research project under the close supervision of a faculty member. Such projects are carefully worked out so that it can be achieved during a period of 9 to 11 weeks. Interested faculty participators will supervise at most two projects each. The projects could be part of their current research. All faculty participators will meet before the course offering to finalize the required material, projects, and course delivery.

The course delivery starts with regular lectures during the first three weeks, which involve an introduction to research, and library and computer lab sessions. Blackboard contains the course reading material, lessons, handouts and corresponding video presentations and students are required to access course material and submit assignments through LMS, which is the main communication tool. Faculty coordinator and faculty supervisors are to talk to and work with all the teams to understand their initial project direction and to offer suggestions, corrections and other guidance as needed. By the end of the second week, the team should have a documented list of their subsystems and each member has his assigned subsystem. There are two typical subsystem diagrams – the "Horizontal" and the "Hierarchical".

Figures 1 shows diagrams of the two representations. If a task is bigger than to make a subsystem, it is then suggested not to assign a single subsystem to multiple students, but instead such a subsystem will be set as a subassembly of two or three students, which in turn will be broken down further, so that each member will own a subsystem. Doing so will build individual accountability and allow each student to have a clearly defined subsystem with specific responsibility and tangible output. This applies to the design/build/test of their subsystem somewhat independently of their teammates. Moreover, as the students are defining the subsystems it is critical that they consider what the interfaces are to and from that subsystem, how it interacts with the rest of the system and how they will test that subsystem. From the fourth week onwards, students will work on project tasks using appropriate methodology with respect to the timeline. Table 1 shows weekly activities of the course. During this period until week 14, one of the two weekly lectures will be devoted to a regular meeting of each project team with their faculty supervisor. Furthermore, during this period, two teams will present material at each class. In preparing for their presentation, the students will have the material well organized and connected in their own minds to effectively communicate their ideas to others. The presentations will help the students prepare for



(a) Horizontal Diagram (b) Hierarchical Diagram

Fig. 1. Subsystem Diagrams

TABLE I. WEEKLY ACTIVITIES

STEM-URC Syllabus

WEEK	UNIT DETAILS	GROUP ACTIVITIES	M/STONES
1	**1. Introduction** 1.1 Introduction to the course 1.2 Why undergraduate research? 1.3 UR worldwide, case studies 1.4 Ethics Issues in Research 1.5 Industrial vs. Academia Research 1.6 Patents vs. Publications	Team formation, Online safety training	**HW 1**
2	**2. Literature Review & Research Methods** 2.1 Research Engines (e.g., IEEEXplore, Scopus) 2.2 Literature review, Survey methods in data collection and analysis, reasoning and model building 2.3 Available library & research tools 2.4. Library lab session on EndNote 2.5 Case study of the selected project	Project Scoping & Planning, Meet Supervisor/Sponsor Preparing, Collecting Data, Equipment Tools Install Software, ...	**HW2**
3	**3. Research Proposal Preparation & Writing** 3.1 Hypotheses & problem statement, research questions 3.2 Formulate research objectives and specific objectives 3.3. Budgeting and Deliverables 3.4 Project timeline; Task scheduling, 3.5. Initial Gantt Chart	Defining the research question Finalizing subsystem and subassemblies	**HW3**
4	**4. Research Proposal** 4.1 Research Proposal Submission 4.2 Research Proposal Presentation	Preliminary Feedback & Peer evaluation	**(HW4) Research Proposal**
5-13	**5. Project Execution and Completion Phase**	Individual & Group Documented Technical Contributions	
14-15	**6. Research Reporting** Project final report and poster/conference paper writing and submission	Final Feedback Self-reflection & Peer Evaluation	**Final Report & Poster/ Conf. Paper**
16	**7. Final Presentation**	**Group Final Presentation**	**Award Distribution**

TABLE II. GRADE DISTRIBUTION THROUGHOUT THE SEMESTER

	Instructor	Supervisor	Total
Homework	10	0	10
In-Class Participation/ Meetings with Supervisor	5	5	10
Teamwork Effectiveness/ Peer Evaluation	5	5	10
Proposal Report	5	5	10
Proposal Presentation	5	5	10
Final Report (Assess Technical Skill & Project Achievements)	10	20	30
Final Presentation	5	5	10
Paper Writing	5	5	10
Total	50	50	100

speaking at conferences or giving a seminar. During the final step (weeks 14-16), students will organize their results into a finished product, communicate their results by writing a final report and a four-to-six-page paper and prepare a conference presentation. Table 2 shows grade distribution along the course components and instructor/supervisor. Rubrics were also devised to assess each component of the grading policy.

III. SAMPLE PROJECTS

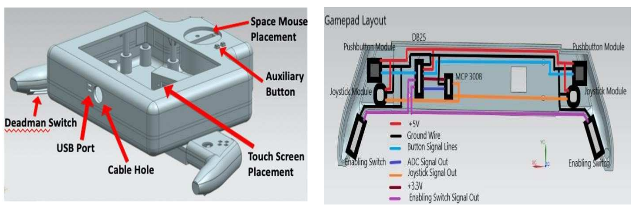
A. Project 1 Open-Source Smart Teach Pendant

The objective of this project is to develop the physical implementation of a smart teach pendant. This project serves as a platform in robotic control instruction developed at the Design Lab at Rensselaer. Unlike conventional teach pendants, the smart teach pendent in this project combines ease to operate with good ergonomic casing. Therefore, user with no or less experience in teach pendant can operate easily and comfortably. In addition, this project support both touchscreen input and physical button input (Gamepad styled with physical shortcut buttons). The space mouse can be used in both input styles. The safety components, such as enabling switches and e-stop buttons, are implemented in accordance to RIA safety standards [12].

A teach pendent prototype will consist of the following subassemblies and subsystems:

Raspberry Pi (to run Android, Linux, &/or Windows IoT)
Touchscreen user interface
Six degree-of-freedom space mouse
Removable Gamepad style inputs
E-stop button and enabling interlock
Physical shortcut buttons
Wired connection to robot

Students went through the design process and performed substantial research as well as code writing. They did the FEA to simulate drop test, a full CAD draft, a conceptual model, Casing assembly and the electrical layout of the Gamepad, and full circuit schematics and electronics layouts. Figure 2 shows Casing assembly. Figure 3 shows RPi circuit schematic.



(a) Casing Assembly (b) Electrical layout of the Gamepad

Fig. 2. Mechanical and Electrical Design

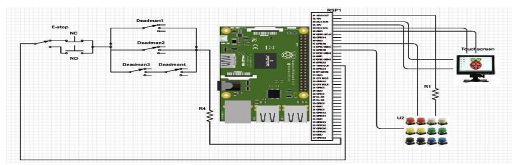


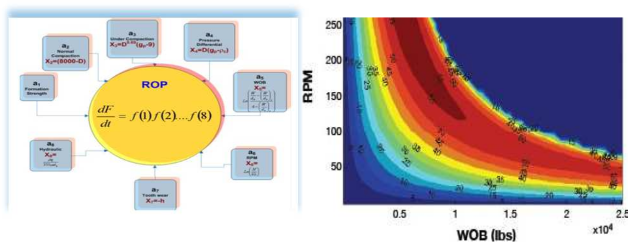
Fig. 3. RPi Circuit Schematic

However, due to the COVID-19 outbreak, the campus was closed and moved to remote learning and the physical implementation of a prototype was converted into the completion of full CAD modules for the casings. Students had been delving into code writing using various software. Each group of students wrote specific code e.g., MultiSim, Adams, ANSYS, SolidWorks, Python and MATLAB/Simscape.

B. *Project 2: Machine Learning for ROP Optimization*

Rate of penetration (ROP) prediction is a crucial phase in oil and gas industry as it allows cost reduction of drilling projects. In this project, student went through a comparison of the traditional multiple regression method with artificial neural network (ANN) methods. ANNs are cellular systems which can acquire, store, and utilize experiential knowledge. They used a dataset composed of seven input parameters. These are depth, bit weight, rotary speed, tooth wear, Reynolds number function, equivalent circulating density (ECD), and pore gradient. Extreme Learning Machines (ELM) were used with varied activation functions, number of hidden neurons, and number of data points in the training data set to find the best combination. The comparison is made based on field data of two different wells with no correction, then with weight on bit (WOB) vertical correction, and finally with interpolated WOB and rotary speed (RPM) motor correction. The techniques are compared in terms of training time and accuracy, and testing time and accuracy. Different input parameters of ELM and RBF (Radial Basis Function networks) gives different results.

A comparison made between ELM and RBF, shows that they are very close to each other. Since ELM is faster, we can say that ELM is the best predictor for ROP, followed by RBF and then the regression model. Figure 6 shows ELM Testing Accuracy, a) RMSE, b) SD c) APRE. Figure 7 shows a comparison among ELM, RBF and Regression methods. The professionals and decision makers are advised, according to the results of this study, to choose ELM with Sigmoidal activation function, training data = 80% and number of hidden neurons = 10 for ROP prediction (Figure 7). Additional ANN techniques and type-2 fuzzy logic can be used to further this study.



(a) Regression model schematic (b) Sample regression (Average ROP ft/hr)

Fig. 4. Example of regression-based schematic drilling operation

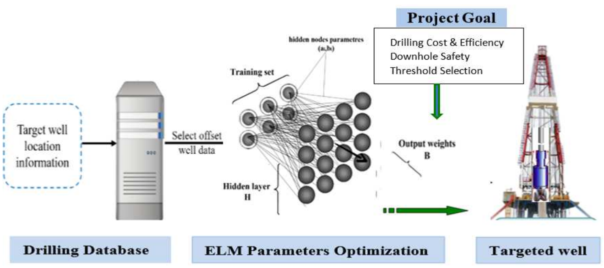


Fig. 5. Extrem Learning Machine using offset well data to optimize the drilling process of a target well

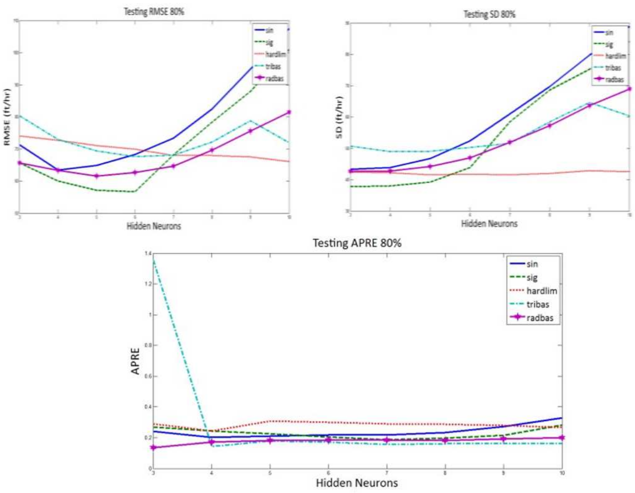


Fig. 6. ELM Testing Accuracy, a) RMSE, b) SD c) APRE

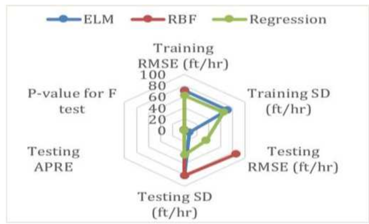


Fig. 7. Comparison: ELM, RBF, & a Multiple Regression Model

C. *Project 3 Gantry Pick/Place Robot for Repairing Pot Linings*

The purpose of this research is to design an automatic machine that can easily lift and transfer materials from a place to another without need human intervention. It is required that this transfer should be fast, safe, while transferring higher quantity of material. For this purpose, a new robotic structure is proposed (Figure 8). This is four degrees of freedom suspended mechanism designed to pick bricks within a constrained and limited space. The robot features three prismatic joints with a fourth revolute. Students went through the design of experiment, budget and parts cost, and reported on providing expected outcomes and deliverables. Early in the semester the pots were collected, and students started preparing for parts purchase and set up.

Then, because of the special circumstances, they had to go online, and mostly did a lot of modelling and simulation. They wrote a lot of code using Matlab/Simulink/SimScape and Robotics Toolbox. They simulated a couples of paths planning (e.g. A* method) and control algorithms for pick/place tasks.

(a) Robot Structure (b) Pot Lining Example

Fig. 8. Gantry Robot for Pick/Place & Repairing Pot Linings

IV. ASSESSMENT AND FEEDBACK

A. Midterm Assessment

A first assessment and feedback were obtained on the midterm by an independent instructor. The students were unanimous about the importance of the course, we quote: "*I believe that what I am being asked to learn in this course is important*". "*Initiate us to work on research project, teaches us how to define a research question, gives us opportunity to publish a conference paper and to contribute to knowledge, enhance our motivation for post-graduation studies*". On the other hand, they raised some issues to improve the course offering. These include "*Have more projects ahead of time*" and "*Enlarge course duration and enrollment, by offering it in two semesters to cover deeply and extensively the material*".

B. End of Semester Qualitative Feedback; Open-Ended Q/A

At the end of semester, student learning was fairly assessed through different activities. Rubrics have been produced upgrading those in Ref [2, 3], and using [14] to objectively grade each student. More than 75% of the students agreed on the usefulness of the newly designed assessment system. Only 8 % considered these new rubrics not useful. A main ABET student outcome considered in this course is the outcome "c"[5] that says: "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". Henceforth, two performance indicators are set for student outcome "c": (*i*) Identify constraints and requirements of the design of a system, component, or process. (*ii*) Design a system, component, or process that meets the design requirements and is within the constraints imposed. Figure 9 displays students' answers to 11 questions on how successful their experience was in relation to their current work and studies. The students were asked to rank their confidence on a scale of (Very helpful) to (Not helpful). The answers clearly show the significant benefits the students gained upon completing the course.

C. Students Grading and Assessment

Grade components include homework, research proposal, teamwork, attendance of meeting with faculty coordinator and faculty supervisor, and other graded work). Students did a great job and a couple of them ended up with an A grade. Furthermore, a questionnaire was provided to assess the course outcomes achievement and help to better prepare the next offerings.

V. FACED CHALLENGES

Upon discussion with faculty supervisors, they mentioned two important faced challenges; First is how to gear students quickly towards the research work and get them more active at the early stage, and allow them work more than 8 to 10 weeks to perform the actual research. The second is the COVID-19 Outbreak and the lessons learnt from the experience of moving to remote learning mode. These include: Usage of WebEx and WebEx Teams, along with LMS and other platforms, How the experience transformed students to deepen their coding and software development skills as well remote teamwork and communication abilities.

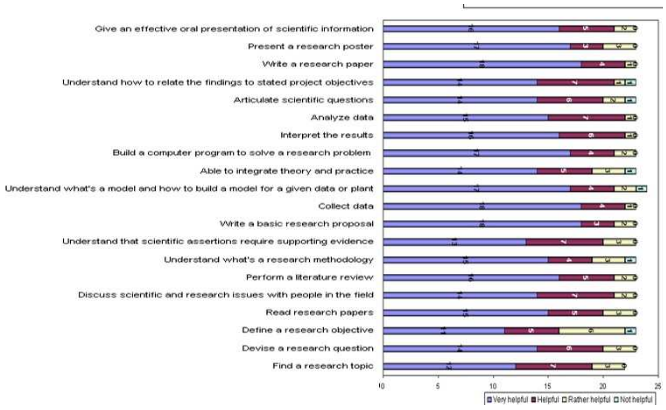


Fig. 9. Students' feedback on how successful their experience was for their current work and studies

VI. FUTURE WORKS

More efforts had been undertaken to come with more practical and effective rubrics based on [2, 14] for student assessment and grading policy. These rubrics along with new assessment surveys and analytics reporting on both students and faculty supervisors feedback are not added here because of the space. As well, significant work is undertaken to evaluate the course using several surveys and tools. This is done through regular university course and instructor evaluation to fill by the students. It is also through course outcomes achievement by e.g., giving a pre-survey to the students when the class begins aligned with the learning objectives, and/or a survey to measure the student's confidence in conducting research, and at the end of the semester, the same two surveys are given to students and then examine the improvement [15]. In that way, one could show the improvement gained in terms of student's knowledge and confidence in undertaking research activities supported by data. This undertaken work as well as the analysis and results will be published soon.

VII. CONCLUSION

In conclusion, we believe the Multidisciplinary Undergraduate Research Course will be an exciting opportunity. Upon project realization and offering research opportunities through proper modes of participation, we expect this will not only enhance students learning and understanding of many challenging issues related to their majors and having hand-on practice into real life engineering problems, but at the same time this will bring and keep them up through exposure to research challenges and open doors towards career in research and academia. Furthermore, the course can serve as a model easily adapted for use across the disciplines of science, technology, engineering, and mathematics by taking into account context, environment, and project specifics.

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