Developing Engineering Education Products via Project Ownership Oriented Learning in an Undergraduate Mechanics of Materials Course

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Abstract

Engineering students can experience hands-on learning in laboratory courses. However, running experiments and analyzing data often demand significant student time. Sinking time into these activities is a challenge because while they may induce learning, data collection and processing produce no tangible external benefit. Students value and engage with activities that carry external impacts complimentary to their own learning. Such learning environments are achieved when multi-semester engineering Capstone Design projects are sponsored by industry and students produce working prototype solutions for companies. However, it remains uncertain whether similar learning environments can be created in a single-semester laboratory course.

This paper introduces a new pedagogical technique called "Developing Engineering Education Products via Project Ownership Oriented Learning" (DEEP POOL). This approach is predicated on the hypothesis that student engagement, enthusiasm, and interest in laboratory work will increase if the lab is structured so student activities support the development, construction, testing, and commercialization of real products for an engineering education company. Increased student excitement and participation should produce student achievement of Learning Outcomes on par with or better than conventional lab courses.

Jacksonville University's 2017 Fall Mechanics of Materials course pioneered the DEEP POOL pedagogy. This paper describes how the course's laboratory component was structured to focus student time toward creating, fabricating, testing, and analyzing new and novel sample coupons for the PASCO EX-5515A Materials Stress-Strain Experiment in collaboration with Engineer Inc, an engineering education technology company.

Keywords

Entrepreneur, University-Industry Partners, Product Development, Mechanics Of Materials, DEEP POOL

Introduction

In engineering laboratory courses, students experience hands-on, open-ended, inquiry-based learning. This type of learning is pedagogically favorable to the passive learning sometimes occurring during lecture-based content delivery. The problem with labs, however, is that they demand significant busywork. Students must often invest much time in data collection, reduction, and analysis for the sake of learning with no tangible outcome, artifact, or external benefit. Contemporary student populations value and engage better with learning activities that have some impact complimentary but external to their own learning [1]. We hypothesize that a project-based educational laboratory course structured so that regular student lab activities support the development, construction, testing, and commercialization of real products for an engineering education company will increase student engagement and interest. The result will be achievement of Learning Outcomes on par with or better than conventional lab courses. We call the technique being evaluated “Developing Engineering Education Products via Project Ownership Oriented Learning” (DEEP POOL).

To test the hypothesis, students in the Jacksonville University (JU) 2017 Fall Mechanics of Materials course applied their laboratory time toward creating, building, and testing new and novel sample coupons for the PASCO EX-5515A Materials Stress-Strain Experiment [2] (Figure 1) in collaboration with Engineer Inc, an engineering education technology company. The course’s impact on student achievement of Learning Outcomes will be interpreted and assessed based on pre/post differences between Indirect and the Direct assessments.

Figure 1: Students learn how to use the PASCO EX-5515A stress-strain apparatus in preparation to designing and fabricate new test samples for the educational lab device.

Background

The pedagogical literature indicates that engineering students become strongly engaged when their courses include projects with “real world” relevance and external partners. For example, Jorgensen et al found that involving industry in course projects raises student interest and performance because the “real-life” experience gained through interactions with industrial clients bespeaks future career activities [3]. Jorgensen et al surveyed students and companies collaborating on industry-sponsored projects and found that a physical prototype is the desirable endpoint of this type of collaboration. However, they found it “impossible” for students to embrace a design problem, generate concepts, and carry one to a prototype stage in the time frame of a single class. Students can only complete a “paper study” in a single class, according to Jorgensen et al, and they require a two-course sequence to succeed in the prototyping stage.

Perhaps the most successful U.S.-based university-industry collaboration to support student projects is the Learning Factory at Pennsylvania State University – College Park. The Learning

Factory annually engages over 750 students from 12 engineering majors on more than 150 Capstone design projects for 80 industry sponsors. In the 2011-2012 academic year, more than 40 projects were sponsored by entrepreneurs or start-up companies [4]. The Learning Factory was established in 1995 with a $2.75 Million NSF grant ($4.12 Million in 2017 dollars).

Shen reports outcomes from a sophomore-level Materials Science course that culminates in an experiment where students complete every process stage on their own: material selection, sample preparation, procedural design, test setup, data collection, and result analysis [5]. The authors report this self-designed experiment increases student interest, improves problem solving skills, and encourages independent thinking. This project was supported by the Center for Layered Polymeric Systems, which received over $37 Million from the NSF between August 2006 and 2017 [6].

Luryi et al describe an entrepreneurial program claimed to be unique because it is not part of their college's formal curriculum. The program, is funded by a $599,785 NSF grant [7]. Maintaining students' balance between technical and entrepreneurial activities is challenging, according to Luryi et al. Anecdotally, technical students dismiss the entrepreneurial side of projects while business students ignore projects' technical aspects. To combat this tendency, the program required all members participate in both technical and entrepreneurial activities [8].

Theory

Pedagogical Motivations
There is no literature consensus on how to structure, organize, and bankroll engineering learning environments that feature product development, entrepreneurship, and university-industry collaboration. Three major structure types are typically described: 1) year-long Capstone design-and-build projects [3,4], 2) externally-funded entrepreneurship centers [8], and extra-curricular project clubs [9]. Single courses are not typically mentioned. Moreover, a common aspect of projects described in the literature where students work with companies to develop products is external funding.

The current study is important because it tests three questions unanswered in the literature.
1. Can meaningful university-industry collaborations that involve students and yield commercialize-able product prototypes be achieved within the timeframe of a single semester?
2. Can students participate in "real" product development as part of a college course if their university has not been awarded external grant to support this activity?
3. Does it even matter? Are students more engaged and do they achieve more when placed in entrepreneurial environments and challenged to develop products in partnership with companies?

In short, this study explores whether learning environments forged by collaborative university-industry partnerships producing real product prototypes are both <u>effective for teaching</u> and <u>accessible to everyone</u>.

Technical and Commercial Challenge
PASCO's EX-5515A is a tabletop experiment allowing students to manually perform tensile tests and develop experimental stress-strain curves with real engineering materials. The

apparatus comes with only nine different sample coupon types. Once those nine types are exhausted, the experiment provides little added utility. PASCO does not offer any other coupon types, and new and novel samples cannot be easily fabricated by end users. Engineer Inc identified lack of more exotic sample coupons from PASCO as a market opportunity to expand educational uses and value of the EX-5515A. A collaboration between JU and Engineer Inc was established to create an aftermarket selection of new coupons made from more diverse materials and using different fabrication methods than PASCO's available samples. Of interest are samples possessing one aspect or feature discernable from one of the nine sample types available from PASCO. Changing one attribute of a sample to see how that modification impacts the resulting stress-strain curve dramatically enriches the utility of EX-5515A as a laboratory teaching tool.

Experiment

Pedagogical Data Collection

Data for the study are collected via Indirect and Direct instruments as well as by observation. The following data collection instruments are being used. 1) *Pre-Project Survey:* a paper survey, replicated in the appendix provides indirect assessment asking students to evaluate their skills and knowledge. 2) *Post-Project Survey:* identical to the Pre-Project Survey but administered at the end of class after projects are complete. 3) *Pre-Project Exam Question:* an open-ended quantitative direct assessment of students' skills and knowledge is being embedded in a quiz administered before the course project. 4) *Post-Project Exam Question:* an exam question identical to the Pre-Project Exam Question administered after the projects are complete. 5) *Observation:* course instructors are observing the classroom activities of students looking for behaviors of interest to the study. Notable behaviors could include creative student problem solving; unusual or unanticipated collaborations; or unexpected levels of excitement, frustration, or enthusiasm.

Student Designed Sample Coupons

In response to the charge by Engineer Inc to produce novel sample coupons compatible with PASCO's EX-5515A, students developed and are pursuing the following three product ideas:

1) Router-Cut Extruded Nylon: PASCO provides injection-molded Nylon coupons infused with 15% carbon fibers. The complementary student-developed product uses a tabletop router to cut Nylon 6/6 coupons from an extruded sheet to facilitate stress-strain curve comparison between different Nylons made via the two disparate fabrication techniques.

2) 3D Printed ABS: PASCO provides injection-molded Acrylonitrile butadiene styrene (ABS) coupons. The complementary student-developed product uses a MakerBot® Replicator™ 2X 3D Printer to create ABS coupons via additive manufacturing to facilitate stress-strain curve comparison between the two fabrication techniques.

3) 3D Printed PLA: Polylactide (PLA) is a popular construction material for 3D printers along with ABS. PASCO does not provide PLA samples, but PLA's material properties are of interest to 3D printer users, especially in comparison to ABS. The student-developed product uses a MakerBot® Replicator™ 2 3D Printer to create identical PLA and ABS coupons to facilitate stress-strain curve comparisons.

Results & Discussion

This study evaluates whether students can develop products in a one-semester engineering course working in collaboration with the external company. Provided students meet this challenge, the study then aims to determine whether the resulting learning environment facilitates student achievement of Learning Outcomes on par with or better than a conventional laboratory course. As of this writing, the study is still a work in progress. Pre-Project Direct and Indirect data collection has occurred as has collection of Post-Project Data. However, analysis of these data is still pending. Thus, the only reportable results to-date are observations from the course instructors, which are summarized here.

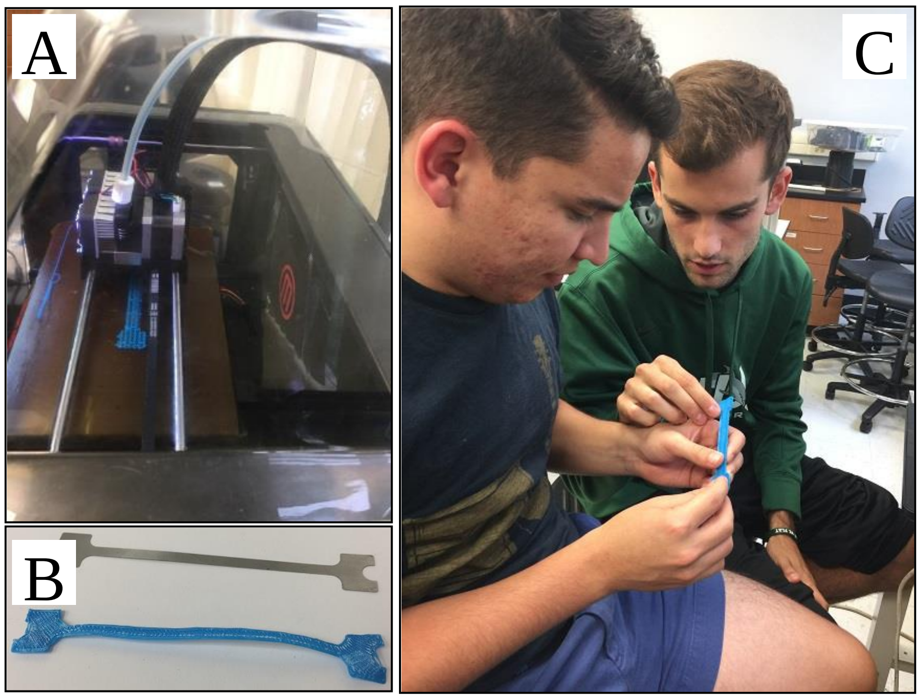

Figure 2: (A) A prototype sample coupon being 3D printed in PLA. (B) A Finished 3D printed coupon compared against an aluminum original upon which it is based. (C) Students evaluate the print quality and tool path of the coupon as they iterate to improve its design.

Students have resonated strongly with the product development focus of the laboratory. As shown in Figures 2 and 3, they quickly converged to product ideas and began fabricating prototypes for testing. Rapid and creative student response and ability to fabricate prototypes contradicts previous literature suggesting the one semester timeframe is too short for a product development project. Multi-semester course sequences are not necessary to implement successful university-industry product development collaborations. In addition, this project is being implemented without external grant support using only modest department funds earmarked for the lab. In other words, this study demonstrates that *industry-university product development collaborations are accessible to everyone.* One motivated faculty member can successfully undertake such a partnership without need for complex institutional curriculum modification or a large external grant.

Certainly, the scale of the product to be developed must be modest, and the fabrication capabilities of the university and industry partners must be considered when assigning this type of project. In this case, selection of an aftermarket add-on to an existing product with simple geometry easily-fabricated with benchtop hobbyist tools facilitated the project's viability with modest budget and one-semester time constraint. Another enabling feature is small laboratory section size. The lab's initial enrollment of eight students allowed the instructor and laboratory technician supporting the class to work one-on-one with each project team on a weekly basis.

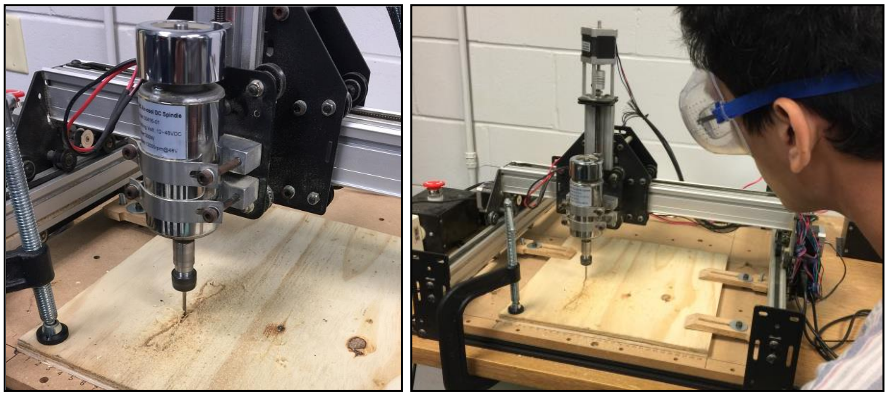

Figure 3 (Left) Testing router tool paths in wood in preparation to cut a coupon from plastic sheet. (Right) A student watches the router path to ensure no tool crashes during sample fabrication.

Whether this approach is valuable and effective for successful student achievement of learning outcomes remains an open question to be answered once the collected data are evaluated.

Conclusion

The DEEP POOL pedagogical approach was introduced. DEEP POOL hypothesizes that student engagement, enthusiasm, and interest in laboratory work will increase if labs are structured so student activities support the development, construction, testing, and commercialization of real products in collaboration with external industry partners. At Jacksonville University, the Mechanics of Materials laboratory was structured using DEEP POOL. In collaboration with engineering education technology company Engineer Inc, students created, fabricated, tested, and analyzed new and novel aftermarket sample coupons for the PASCO EX-5515A Materials Stress-Strain apparatus.

While quantitative data analyses is still ongoing, observation of student engagement in product development has already countermanded two assertions found in the pedagogical literature about how to organize and fund this type of learning environment. First, provided the product to be developed is of modest complexity, product development for an external company can occur successfully within a single semester course. Second, provided product designs can be created within the fabrication capabilities of the university-industry partnership, product development can be successfully implemented without need for external funding. In short, preliminary results demonstrate that *industry-university product development collaborations are accessible to everyone.* One motivated faculty member can successfully undertake such a partnership without need for complex institutional curriculum modification or a large external grant.

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Matthew J. Traum

Dr. Traum is CEO at Engineer Inc, an engineering education start-up. Before founding Engineer Inc, Dr. Traum was a well-known higher education administrator, fund raiser, educator, and researcher most recently appointed as Associate Professor and Director of Engineering Programs at Philadelphia University. His previous full-time faculty appointments include the Milwaukee School of Engineering and the University of North Texas – Denton. Traum received his Ph.D. and M.S. degrees in mechanical engineering from the Massachusetts Institute of Technology and two bachelor's degrees from the University of California – Irvine: one in mechanical engineering and the second in aerospace engineering.

Emre Selvi

Emre Selvi is an Assistant Professor of Mechanical Engineering at Jacksonville University. He received his B.S. and M.S. from Middle East Technical University and Ph.D. from Texas Tech University. He worked as a Design and Production Engineer for Aselsan Inc. for four years and as a Faculty at Muskingum University for six years. His research interests are high pressure material science and engineering design, especially as they relate to educational environments.

Sergio A. Aponte
Sergio Aponte is a sophomore mechanical engineering major at Jacksonville University. Born in Bogota, Colombia, he has experienced different cultures and has gained a deep understanding of what it means to be an immigrant. He moved to the United States at age 10 and entered directly into 5th grade without knowing any English. He quickly learned the language and went on to receive countless academic recognitions. His passion to serve the U.S. led him to being part of Jacksonville University's NROTC program with a full scholarship. Upon graduation he will commission as an Ensign in the Navy and will pursue a naval career in engineering.

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Mr. Bayran graduated from Nile C. Kinnick High School in 2015. Mr. Bayran is currently a 3rd year student at Jacksonville University and is studying to attain a Mechanical Engineering Bachelor's Degree.

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Diego Diaz Sanchez is an International Student from Madrid, Spain attending Jacksonville University. He is a Junior studying mechanical engineering. Before transferring to Jacksonville University, he earned his Associate of Arts degree from Treasure Valley Community College in Ontario, Oregon. Diego joined an honor society before coming to Jacksonville due to his exceptional grade point average. He holds an academic scholarship that allows him to study at Jacksonville University, and he plans to secure first mechanical engineering internship during the summer.

Kristopher J. Lyles
Kristopher Lyles enlisted into the military out of high school; he obtained Global War on Terrorism Expeditionary Medal along with a Letter of Commendation for his dedicated service. Mr. Lyles was known for his persistence and knowledge of the F/A-18 Legacy Hornet aircraft platform. He was one of the youngest to operate all systems pertaining to the F/A-18 Legacy Hornet, and he became a trouble-shooter in three tours with his squadron. He helped transition his squadron to the F/A-18 Super Hornet, obtaining his licenses again. After his service, Mr. Lyles enrolled into college, obtained an Associate in Arts degree, and was recognized on the Dean's list. Currently he is finishing the last semester of his Bachelor of Science degree in Mechanical Engineering. Mr. Lyles resides with his wife, Caroline T. Lyles and their four kids.

Daryl D. Norwood
Daryl Norwood is currently a junior at Jacksonville University. He is a graduate of John Carroll Catholic High School. After graduating college, he plans to join the engineering work force. He has been on the Dean's List multiple semesters of his college journey thus far. He played college football and is a member of Kappa Alpha Psi Fraternity Incorporated.

Joshua R. Pruitt
Joshua Pruitt is in his junior year as a mechanical engineering major at Jacksonville University. He graduated from his high school in the top 10% of his class and is in the Honors Program at JU. He is also a part of the Math, Engineering, and Physics Scholars scholarship on campus. He

held a summer internship with WW Gay in Jacksonville, Florida where he worked with a young engineer and gained significant industrial experience.

Larenz J. Scroggins
Larenz Scroggins is currently a Junior at Jacksonville University, and he is a graduate from Land O' Lakes High School. Scroggins plays college football and is a member of Kappa Alpha Psi Fraternity Incorporated all while maintaining a 3.0 GPA. Following graduation, he plans to enter the engineering field to pursue his career.

Appendix: Pre/Post-Project Self-Assessment

Thinking about your experience in ME-313 Mechanics of Materials, please select your level of agreement with these statements using the following scale:

a. Strongly Agree b. Agree c. Neutral d. Disagree e. Strongly Disagree

1. I can identify a material’s yield strength from a Stress-Strain curve. [ABET (a)]
2. I can identify a material’s ultimate tensile strength from a Stress-Strain curve. [ABET (a)]
3. I can design and fabricate a series of sample coupons to show how heat-treating impacts a material’s experimental Stress-Strain curve. [ABET (b)]
4. I can set up and collect data from the PASCO Stress-Strain Apparatus by myself without supervision. [ABET (b)]
5. I can differentiate between real experimental data and empirical models presented in graph form. [ABET (b)]
6. Given a material’s Stress-Strain curve, I can calculate the cross-sectional area needed for a cylindrical bar to sustain a given load in tension without permanent deformation. [ABET (c)]
7. When working in my ME 313 team, I can resolve conflicts that arise. [ABET (d)]
8. I am a good teammate within my ME 313 team. [ABET (d)]
9. Given a material’s Stress-Strain curve, I can determine whether a square member of known dimensions undergoes necking at a given tension level. [ABET (e)]
10. I am skilled at writing technical content about Mechanics of Materials. [ABET (g)]
11. I am skilled at oral presentation of technical material about Mechanics of Materials. [ABET (g)]
12. I can design for an education technology company an educational laboratory experiment to teach a Mechanics of Materials principle to other engineering students. [ABET (h)]
13. I can use a Tension Tester to experimentally determine a sample’s material properties. [ABET (k)]
14. I can use ANSYS to model the mechanical behavior of materials. [ABET (k)]