Evaluation of DEEP POOL on Student Learning Outcomes Attainment

Dr. Matthew J. Traum, Engineer Inc.

Dr. Matthew J. Traum is founding CEO at Engineer Inc., a Florida-based STEM education social enterprise start-up. Traum invented @HOLM™ lab kits to enable students in on-line courses to build and run engineering experiments remotely at home.

Before founding Engineer Inc., Dr. Traum was a well-known higher education administrator, fund raiser, educator, and researcher with co-authorship of 12 peer-reviewed research journal articles, 18 refereed research conference articles, and 20 refereed pedagogical conference articles. As a PI or Co-PI, Traum has attracted over $841 K in funding for research, education, and entrepreneurial ventures from multiple sources including NSF, NASA, ASHRAE, AIAA, Sigma Xi, the Texas State Energy Conservation Office, and several industry sponsors including Toshiba and Oshkosh.

Most recently as Associate Professor and Director of Engineering Programs at Philadelphia University, Dr. Traum led the Mechanical Engineering Program through a successful ABET interim visit resulting in no deficiencies, weaknesses, or concerns.

Previously, Dr. Traum was an assistant professor at the Milwaukee School of Engineering (MSOE), one of the top-ten undergraduate-serving engineering universities in the U.S. Dr. Traum coordinated MSOE's first crowd-funded senior design project. He also co-founded with students EASENET, a start-up renewable energy company to commercialize waste-to-energy biomass processors.

Dr. Traum began his academic career as a founding faculty member in the Mechanical & Energy Engineering Department at the University of North Texas - Denton where he established a successful, externally-funded researcher incubator that trained undergraduates to perform experimental research and encouraged matriculation to graduate school.

Traum received a Ph.D. in mechanical engineering from the Massachusetts Institute of Technology where he held a research assistantship at MIT's Institute for Soldier Nanotechnologies. At MIT he invented a new nano-enabled garment to provide simultaneous ballistic and thermal protection to infantry soldiers. Dr. Traum also holds a master's degree in mechanical engineering from MIT with a focus on cryogenics and two bachelor's degrees from the University of California, Irvine: one in mechanical engineering and the second in aerospace engineering. In addition, he attended the University of Bristol, UK as a non-matriculating visiting scholar where he completed an M.Eng thesis in the Department of Aerospace Engineering on low-speed rotorcraft control.

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Evaluation of DEEP POOL on Student Learning Outcomes Attainment

Abstract

This paper evaluates a new pedagogical approach: "Developing Engineering Education Products via Project Ownership Oriented Learning" (DEEP POOL). We hypothesize that student engagement, enthusiasm, and interest in laboratory work increases when labs are structured so student activities support the entrepreneurial development, construction, testing, and commercialization of real products for an engineering 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 was DEEP POOL structured to focus student laboratory time toward creating, fabricating, testing, and analyzing new and novel test sample coupons for the PASCO EX-5515A Materials Stress-Strain Experiment in collaboration with Engineer Inc., an engineering education technology social enterprise state-up. The lab exposed students to topics typically taught in conventional Mechanics of Materials laboratories. However, weekly exercises were also intentionally structured to map students' efforts directly to development of new commercial products for Engineer Inc.

Student attainment of Learning Outcomes was evaluated to measure DEEP POOL effectiveness. Enrolled students who agreed to participate after informed consent notification ($n = 7$) were the study population. No additional participant recruiting was done. Participants self-assessed their own Learning Outcome achievement via pre/post surveys. Complementary direct assessment occurred using different exam problems covering similar concepts embedded within assessments given at the beginning and end of class. Course impact was interpreted based on pre/post differences between assessments both indirect and direct. To mitigate small sample size, one-tailed Wilcoxon Signed Rank Testing was applied to both data sets. To provide data visualization, descriptive statistics were also evaluated by comparing pre/post averages of students' self-reported results.

Indirect assessment showed that exposure to DEEP POOL moved students' averaged self-reported Learning Outcome achievement up across all outcomes assessed. The largest improvements (with averages increasing 1.71 points on a 4-point scale) were in skills related to ABET (k) and ABET (h). The next largest gain (the average increased 1.29 points on a 4-point scale) was in ABET (b). One-tailed Wilcoxon Signed Rank Test of indirect assessment data corroborate these results. Questions related to ABET (k) ($Z = -2.366$, $p < 0.05$), (h) ($Z = -2.023$, $p < 0.05$), and (b) ($Z = -2.366$, $p < 0.05$) revealed statistical improvement (≥ 95% confidence) in the median values. Questions related to ABET (c) ($Z = -2.155$, $p < 0.05$) and (g) ($Z = -1.955$, $p < 0.05$) showed no statistical improvement (≥ 95% confidence) in the median values; and questions related to ABET (a), (d), and (e) did not meet the hypothesis testing threshold because the sample size, n, was too small.

One-Tailed Wilcoxon Signed Rank Tests of direct assessment data revealed that one question related to ABET (e) ($Z = -1.787$, $p < 0.05$) showed no statistical improvement (≥ 95%

confidence) in the medians. Other questions linked to ABET (a), (b), (c), (e), (h), and (k) did not meet the hypothesis testing threshold because n was too small. Critically however, direct assessment of ABET (c) ($Z = -2.023$, $p < 0.05$) "an ability to design a system, component, or process to meet desired needs within realistic constraints" did reveal statistical improvement ($\geq$ 95% confidence) in the medians for student Learning Outcome achievement. This skill set is strongly associated with entrepreneurial new product development central to DEEP POOL.

In summary, this study revealed indirect/direct assessment evidence of improvement in three/one ABET-linked Learning Outcomes respectively. This result, along with the preponderance of metrics that did not meet the threshold for evaluation, motivate need for a follow-on study comparing the learning effectiveness of DEEP POOL versus a control, a conventionally-taught laboratory course. Should DEEP POOL's effectiveness prove equal to or better than its conventional analog, this novel laboratory pedagogy can emerge as a powerful way to conduct entrepreneurial new product development activities in engineering laboratories in partnership with industry.

Introduction

Capstone projects usually produce working prototypes for external customers addressing needs in industry, faculty research labs, and/or entrepreneurial ventures. In fact, we so highly value learning environments where student labor produces tangible outcomes that many ABET accredited schools intentionally build multi-semester immersive Capstone Design projects into their curricula. If these experiences are so valuable, why must they come at the end of a degree program? Is it possible to create this sought-after learning environment in the context of a single-semester laboratory course?

Students in engineering laboratory courses experience hands-on, open-ended, inquiry-based learning. This type of learning is pedagogically favorable to the passive learning that sometimes occurs during lecture-based content delivery. The problem with labs, however, is that 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].

Project-based educational laboratory courses can be structured so regular student lab activities support the entrepreneurial development, construction, testing, and commercialization of real products for engineering education companies. We hypothesize that this course structure 1) creates valuable learning environments where student labor yields tangible outcomes and 2) produces results external and in addition to learning thereby increasing students' engagement and interest. If the underpinning hypothesis is true, resulting student achievement of Learning Outcomes will be on par with or better than conventional lab courses. We call this pedagogical laboratory teaching technique "Developing Engineering Education Products via Project Ownership Oriented Learning" (DEEP POOL).

To test DEEP POOL, the 2017 Fall Mechanics of Materials course at Jacksonville University (JU) was structured to devote student laboratory time to 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 social enterprise start-up. The company plans to commercialize viable products resulting from the student's work. The course's resulting impact on student achievement of Learning Outcomes was interpreted and assessed using pre/post differences within indirect and the direct assessments.

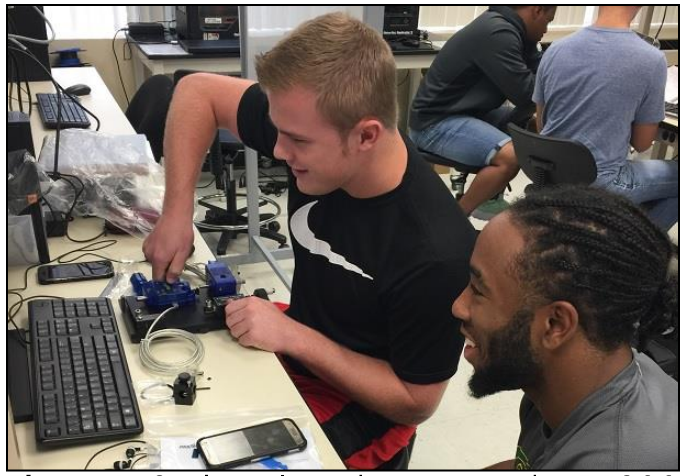


Figure 1: Students learn how to use the PASCO EX-5515A stress-strain apparatus in preparation to design and fabricate new test samples for the educational lab device.

Background

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 test 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 essentially identical to one of the nine sample types available from PASCO but possessing one differentiating aspect or feature. Changing one sample attribute allows apparatus users to explore and compare how modifications impact the stress-strain curve. This added feature dramatically enriches the utility of EX-5515A as a laboratory teaching tool. It allows students to explore stress-strain sample properties beyond material composition into areas such as shape factors, stress concentrators, fabrication methods, anisotropic properties, and sample area under tension.

Student Designed Sample Coupons

In response to the entrepreneurial opportunity presented by Engineer Inc. to produce novel sample coupons compatible with PASCO's EX-5515A, students worked in groups of 2 or 3 to develop and pursue 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 [Figure 2] 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.

Preliminary Results

In a previously published preliminary study, two key research questions related to the practicality of running a university DEEP POOL program were posed:

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?

The answer to both questions is YES [3]. Moreover, these results contradict widely-held beliefs about viable outcomes and costs of product development done in engineering lab courses.

From the perspective of industry employers, Black stated that engineering student participation in industry-sponsored design and build projects is critical, and engineering schools must infuse these experiences into their curricula to graduate students that are competitive and relevant in industry practice [4].

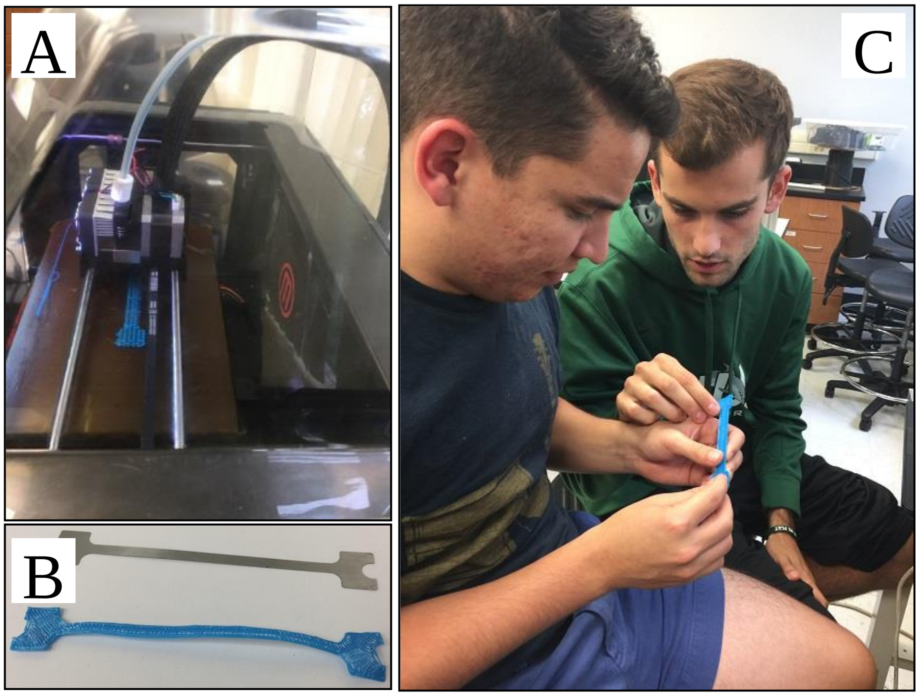


Figure 2: (A) A prototype sample coupon being 3D printed in PLA. (B) A Finished 3D printed coupon compared against an aluminum original upon which it is based. (C) Students evaluate the print quality and tool path of the coupon as they iterate to improve its design.

Jorgensen et al found that involving industry in course projects is desirable because it raises student interest and performance since the "real-life" experience gained through interactions with industrial clients previews future career activities [5]. However, Jorgensen et al asserted that physical prototypes are the desirable endpoint of this type of collaboration, and it is “impossible” for students to embrace a design problem, generate concepts, and carry one to a prototype stage in the time frame of a single semester class.

While collaborative university/industry engineering product development has been successfully demonstrated on short timescales in extracurricular engineering club projects [6], we found no examples in the engineering education literature where one-semester-long class-based design projects produced prototypes for industry partners without raising work quality concerns. For example, a Swedish Computer Science program reported for its one-semester collaborative university/industry capstone design course that student teams often failed to achieve industry-supplied project deliverables and industry sponsors agreed in advance that no projects would be commercialized [7]. Yost and Lane, report a four-credit one-semester-long civil engineering Capstone program at the University of Kentucky where student teams develop written technical reports for industry partners instead of creating physical prototypes as recommended by Jorgensen et al. Even though students are not building prototypes, these authors still report that lack of time for students to complete all tasks is the program’s biggest challenge. The scope of assigned projects had to be limited by instructors to enable completion, and engineers from industry partners express concern that not enough time was available for students to satisfactorily complete design tasks [8]. Qatu and Jones describe challenges faced in a one-semester industry-sponsored capstone senior design course run in the Mechanical Engineering Department at Mississippi State University in which students do build prototypes [9]. While these authors claim the accelerated design experience produces engineers ready to meet the time demands of industry, they also describe implementing draconian measures to keep projects on track: sending students written warning letters, removing underperforming students from teams, and withholding graduation from teams who fail to complete projects one time.

The engineering education literature also revealed that reported U.S.-based university-industry collaborations where students produced prototypes for industry partners were often seeded by significant external grants that either directly or indirectly supported the program [10-12]. These programs and others like them erroneously lead engineering educators to believe an external grant must first be secured to conduct successful classroom-based product development initiatives.

Our previously published preliminary results contradict the prevailing conceptions that 1) university-industry collaborations generating products from courses must be externally funded and 2) product development cannot happen in the timeframe of a one-semester course without problems. Instead, our previous work demonstrated that *industry-university product development collaborations are accessible to everyone.* One motivated faculty member can successfully undertake such an industry-university partnership without need for complex institutional curriculum modification or a large external grant.

These findings are necessary but not sufficient to justify continued study of DEEP POOL pedagogy. Having positively answered the question of whether DEEP POOL is possible to carry out, attention focuses in this paper on whether the approach conveys pedagogical benefit to students. Do students in DEEP POOL curricula achieve improvement in course Learning Outcomes due to course exposure?

Experimental Methods

The DEEP POOL Mechanics of Materials course in which this study occurred was offered in Fall 2017 under the 2017-2018 ABET Criteria for Accrediting Engineering Programs [13]. So, JU Internal Review Board (IRB) evaluation and approval, informed consent notification, and collection of indirect and direct assessment data were performed under the ABET Criterion 3 (a)-(k) nomenclature current at the time of the study. While we recognize that Criterion 3 of the 2019-2020 ABET Criteria for Accrediting Engineering Programs has moved to a numbered system [14], we purposefully maintained the original (a)-(k) nomenclature here for self-consistency within all parts of the study.

Students enrolled in the DEEP POOL Mechanics of Materials course and lab section at JU who agreed to participate after informed consent notification were the study sample size (n = 7). No additional participant recruiting was done.

Pedagogical Data Collection
Study data were collected via the following indirect and direct instruments.
1) *Pre-Project Survey:* a paper survey [replicated in Appendix A] provided indirect assessment asking students to evaluate their skills and knowledge using a Likert-like scale.
2) *Post-Project Survey:* identical to the Pre-Project Survey but administered at the end of class after projects were complete.
3) *Pre-Project Exam Question:* this open-ended quantitative direct assessment of students' skills and knowledge [replicated in Appendix B] was embedded in a quiz administered after relevant theoretical content was taught but before the course project began.
4) *Post-Project Exam Question:* an exam question [replicated in Appendix C] similar to the Pre-Project Exam Question was administered as part of the course final exam after the projects were complete.

Indirect Assessment Data Analysis
Collected indirect assessment data were analyzed in two ways. First student responses to pre-project and post-project survey questions were categorized by their associated ABET (a)-(k) categories. Averages of responses within each ABET category were calculated for the pre-project data and the post-project data. These pre/post averages were then compared. We appreciate given the small sample size (n = 7) that differences in these pre/post averages carry no quantitative statistical value -- we did not bother to calculate or report standard deviations of the averages. However, they are qualitatively valuable for data visualization.

Second, since each individual's unique pre/post survey responses were tracked, data for each ABET (a)-(k) category was processed using one-tailed Wilcoxon Signed Rank Tests carried out by-hand using Microsoft Excel. Data were evaluated at a 95% confidence interval or higher using Critical Value lookup tables from the University of Florida [15]. Data pairs showing no pre/post change were removed from the set, reducing n and influencing the Critical Value. The minimum population needed to evaluate data via the one-tailed Wilcoxon Signed Rank Test is n

= 5. So, questions where 3 or more students reported no change across the pre/post surveys could not be evaluated because n < 5.

Direct Assessment Data Analysis
Collected direct assessment data were analyzed in one way. Since each individual's unique pre/post exam responses were tracked, data for each ABET (a)-(k) category was processed using one-tailed Wilcoxon Signed Rank Tests. To generate quantitative data, one of us (E. Selvi, who was not the DEEP POOL laboratory instructor) evaluated both the pre- and post-assessments by scoring student responses on the following Likert-like scale from 0 to 3:

0: Response Empty or Irrelevant
1: Response Relevant But Missing Solution
2: Response Nearly Correct
3: Response Correct

This assessment evaluation was conducted independently from the grading done for class, and the instructor who wrote the questions and taught the DEEP POOL lab section (M. J. Traum) was not involved in marking the assessments. Students were asked a total of 13 questions that covered similar course topics across the pre-/post-assessments, and questions were linked to specific ABET (a)-(k) outcomes. Data were evaluated at a 95% or higher confidence interval. Data pairs showing no pre/post change were removed from the set, reducing n and influencing the Critical Value. Questions with a resulting n < 5 could not be evaluated. To further ensure the study's data integrity, students did not know which questions on which quizzes were tied to the study. We also took measures to prevent students from being cued by the pre-assessment questions on the quiz and focusing their final exam studies on those questions (thereby erroneously positively influencing the results). While students were allowed to view their quiz performance in an instructor's office under supervision, they were not allowed to remove the quizzes nor were they given posted solutions to quiz questions.

Results

Indirect Assessment Data
Indirect survey results show exposure to DEEP POOL methods in the Mechanics of Materials course qualitatively moved students' averaged self-reported Learning Outcome achievement upward across all outcomes assessed; see Figure 3.

For this metric, the largest improvements were in skills related to ABET (k) [ability to use techniques, skills, and tools necessary for modern engineering practice] where all students reported improvement between pre- and post-assessment and ABET (h) [understanding impact of engineering solutions in a global, economic, environmental, and societal contexts] where five students self-reported pre/post improvement with two remaining neutral. In these two areas, the self-reported class-wide averages improved 1.71 points on a 4-point scale. The next largest gain, 1.29 points on a 4-point scale, was observed in ABET (b) [ability to design and conduct experiments, as well as to analyze and interpret data].

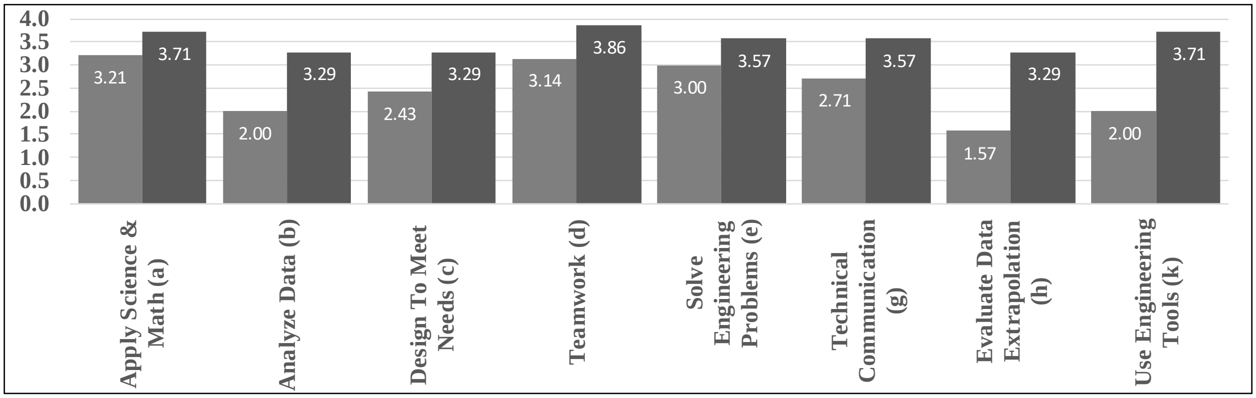


Figure 3: Indirect assessment pre-/post-project survey results display an improvement in students' self-reported Learning Outcome attainment across all ABET evaluation categories assigned to the DEEP Pool Mechanics or Materials class.

These results are corroborated by the quantitative one-tailed Wilcoxon Signed Rank Test performed on self-reported student data. Survey questions linked to ABET (k) ($Z = -2.366$, $p < 0.05$), (h) ($Z = -2.023$, $p < 0.05$), and (b) ($Z = -2.366$, $p < 0.05$) skills revealed a statistical improvement (≥ 95% confidence) in student self-reported Learning Outcome achievement. Questions related to ABET (c) ($Z = -2.155$, $p < 0.05$) and (g) ($Z = -1.955$, $p < 0.05$) showed no statistical improvement (≥ 95% confidence), and ABET (a), (d), and (e) did not meet the threshold for statistical hypothesis testing because $n < 5$.

Direct Assessment Data

Of the 13 direct assessment questions asked on pre-/post-project exams, only 2 resulted in $n \geq 5$, facilitating evaluation using the Wilcoxon Signed Rank Test. Questions linked to ABET (a), (b), (c), (e), (h), and (k) did not meet the hypothesis testing threshold. Evaluation of one question linked to ABET (e) ($Z = -1.787$, $p < 0.05$) showed no statistical improvement (≥ 95% confidence). Critically however, direct assessment of ABET (c) ($Z = -2.023$, $p < 0.05$) "an ability to design a system, component, or process to meet desired needs within realistic constraints" revealed statistical improvement (≥ 95% confidence) in student Learning Outcome achievement. This skill set is strongly associated with entrepreneurial new product development central to DEEP POOL.

Discussion

This study revealed indirect/direct assessment evidence of improvement in three/one ABET-linked Learning Outcomes respectively resulting from student exposure to DEEP POOL. Moreover, the population studied was too small to reveal effects, if any were present, in most of the other assessed categories. The overall positive outcome of this study adds a further necessary criterion to the already known merits of DEEP POOL. We have shown that *placing students in entrepreneurial laboratory environments where their labor is funneled toward developing new products in partnership with companies improves student achievement of learning outcomes.*

This result buttresses two other necessary criteria demonstrated in our previous published paper [3]: 1) university-industry collaborations generating products from courses need not be externally funded and 2) successful product development can happen in the timeframe of a one-semester course. Thus, *industry-university product development collaborations are accessible to all faculty, and* <u>*they can produce a learning environment helpful and beneficial for student learning*</u>*.*

This finding motivates a critical follow-on future step: comparing the learning effectiveness of DEEP POOL versus a control, a conventionally-taught laboratory course. Should DEEP POOL's effectiveness prove equal to or better than its conventional analog, this novel laboratory pedagogy can emerge in the future as a powerful way to conduct entrepreneurial new product development activities in engineering laboratories in partnership with industry.

Conclusions

This paper re-introduces DEEP POOL, a pedagogical approach hypothesizing that student engagement, enthusiasm, and interest in laboratory work increases if labs are structured to focus student activities and labor on activities supporting the development, construction, testing, and commercialization of real products in collaboration with external industry partners.

Indirect and direct pre/post assessments of student Learning Outcome achievement was conducted on a student population enrolled in a Mechanics of Materials course at Jacksonville University. Qualitatively, students self-reported that exposure to the course improved their skills in all eight assessment categories assigned to the course [ABET (a), (b), (c), (d), (e), (g), (h), and (k)]. Quantitative evaluation of indirect assessment data revealed statistical improvement (≥ 95% confidence) in self-reported Learning Outcome attainment across three assessment categories [ABET (k) ($Z = -2.366$, $p < 0.05$), (h) ($Z = -2.023$, $p < 0.05$), and (b) ($Z = -2.366$, $p < 0.05$)]. Quantitative evaluation of direct assessment data revealed further statistical improvement (≥ 95% confidence) in Learning Outcome attainment for one assessment categories [ABET (c) ($Z = -2.023$, $p < 0.05$)]. Critically, ABET (c) "an ability to design a system, component, or process to meet desired needs within realistic constraints" is a skill set strongly associated with entrepreneurial new product development central to DEEP POOL. Plus, the other criteria where improvement was observed (analyze data, critically evaluate data's validity, and use engineering tools) are also important components to new product development.

When combined with previous DEEP POOL research results, necessary criteria have been established to warrant further investigation of this pedagogical approach: industry-university product development collaborations are accessible to everyone, and they can produce environments helpful and beneficial for student learning. A critical follow-on study is needed to compare the learning effectiveness achieved by DEEP POOL versus a control, a conventionally-taught laboratory course.

Acknowledgements

The authors would like to thank Brian Stadelmaier, Jacksonville University's Engineering Technician, and Kamin Miller of the Gainesville, FL Hackerspace for assisting students to fabricate some of the test samples for the projects described in this paper.

Appendix A: Pre/Post-Project Self-Assessment

Thinking about your experience in 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)]

Appendix B: Pre-Project Direct Assessment Questions

Real experimental data from the PASCO Stress-Strain experiment is given below.
(Show your work on the graph below when you use a value from the graph)

a) You don't know the material but you know that it is either a brass alloy or a ceramic. Which one do you think is the material? Explain your reasoning. **(4 points)** [ABET (b) analyze data]

b) Due to limitations in the PASCO apparatus, a portion of the presented data had to be extrapolated from an empirical model.

   i. Identify the part of the graph that is extrapolated model data. **(3 points)** [ABET (h) identify fake data]

   ii. Explain what PASCO apparatus limitation prevents direct data collection in this regime **(3 points)** [ABET (k) use engineering tools]

c) Find the yield strength in SI units. **(3 points)** [ABET (a) use science]

d) Find the fracture stress in SI units. **(3 points)** [ABET (a) use science]

e) Calculate the modulus of elasticity in SI units. **(4 points)** [ABET (e) solve engineering problem]

f) Calculate the modulus of resilience in SI units. **(4 points)** [ABET (e) solve engineering problem]

g) Find the maximum axial load that can be sustained without any permanent deformation by a cylindrical specimen having a cross sectional area of 50 mm^2. **(5 points)** [ABET (c) design system to meet need]

h) If an axial load of 325 kN is applied to a specimen with a cross sectional area of 10 cm^2, would it neck? Explain. **(5 points)** [ABET (e) solve engineering problem]

i) If a specimen has a cross sectional area of 20 cm^2 and a length of 400 mm;

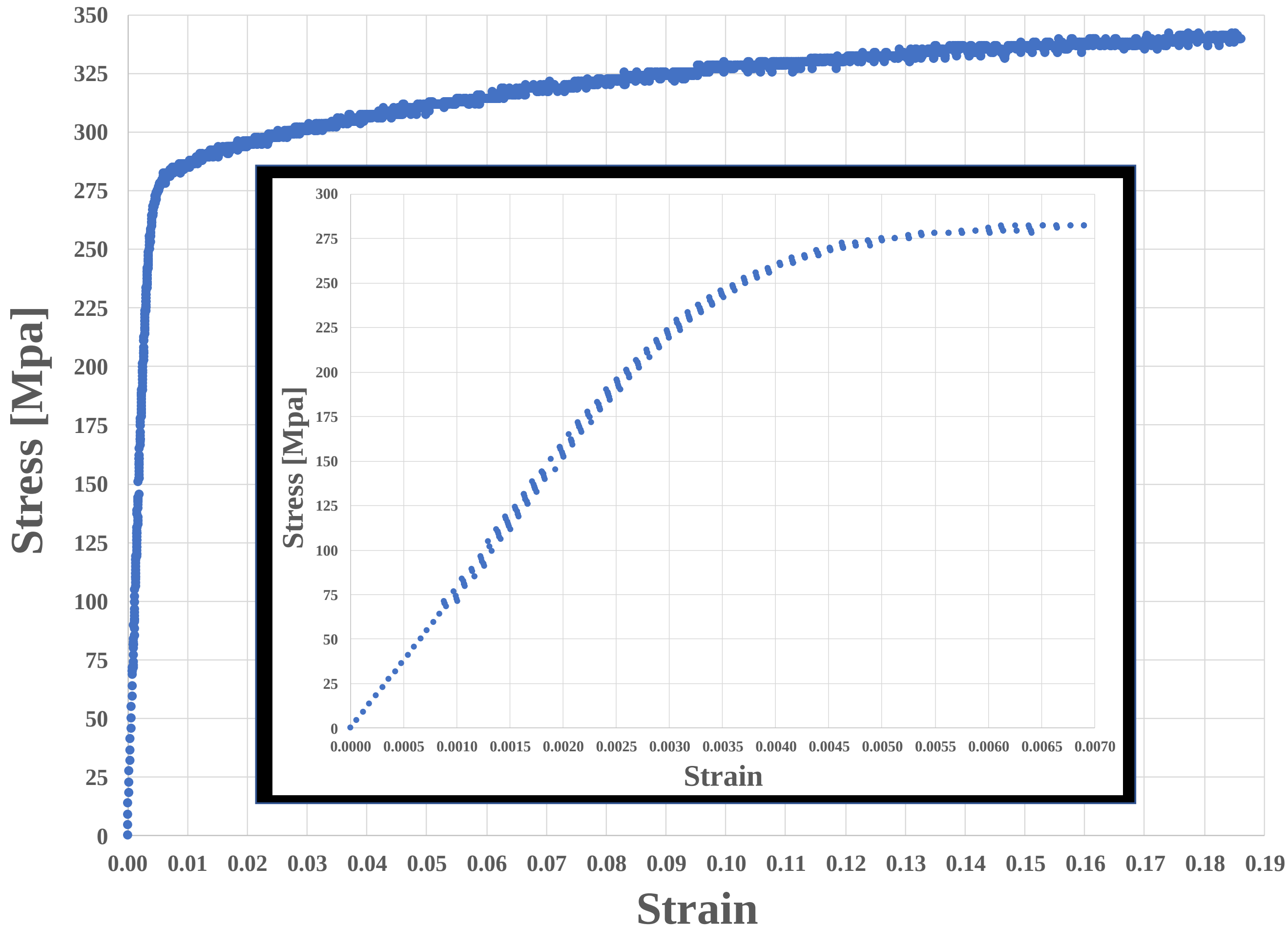
   i. What is the final length just before it fractures? **(2 points)** [ABET (e) solve engineering problem]

   ii. What is the final length after it fractures? **(2 points)** [ABET (e) solve engineering problem]

j) If a load that causes a stress of 20 MPa is applied to a 300-mm-long specimen, what would be its final length;

   i. While the load is applied. **(2 points)** [ABET (e) solve engineering problem]

   ii. After the load is removed. **(2 points)** [ABET (e) solve engineering problem]



Stress [Mpa]
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
0.00 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10 0.11 0.12 0.13 0.14 0.15 0.16 0.17 0.18 0.19
Strain
Stress [Mpa]
300
275
250
225
200
175
150
125
100
75
50
25
0
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030 0.0035 0.0040 0.0045 0.0050 0.0055 0.0060 0.0065 0.0070
Strain

Appendix C: Post-Project Direct Assessment Questions

Real experimental data from the PASCO Stress-Strain experiment is given below.
(Show your work on the graph below when you use a value from the graph)

a) Should this material be classified as ductile or brittle? Explain your reasoning. **(4 points)** [ABET (b) analyze data]

b) Due to limitations in the PASCO apparatus, data near the origin had to be extrapolated from an empirical model.

   i. Which fundamental engineering axiom ensures this extrapolation is accurate? **(3 points)** [ABET (h) identify fake data]
      (a) Hooke's Law
      (b) Moore's Failure Criterion
      (c) Poisson's Ratio
      (d) Castigliano's Theorem
      (e) Clausius Theorem

   ii. Explain what PASCO apparatus limitation prevents direct data collection in this regime **(3 points)** [ABET (k) use engineering tools]

c) Find the yield stress in SI units. **(3 points)** [ABET (a) use science]

d) Find the ultimate tensile strength in SI units. **(3 points)** [ABET (a) use science]

e) Calculate the modulus of elasticity in SI units. **(4 points)** [ABET (e) solve engineering problem]

f) Calculate the modulus of resilience in SI units. **(4 points)** [ABET (e) solve engineering problem]

g) Find the maximum axial load that can be sustained without any permanent deformation by a cylindrical specimen having a cross sectional area of 25 mm^2. **(5 points)** [ABET (c) design system to meet need]

h) If an axial load of 325 kN is applied to a specimen with a cross sectional area of 5 cm^2, would it neck? Explain. **(5 points)** [ABET (e) solve engineering problem]

i) If a specimen has a cross sectional area of 20 cm^2 and a length of 400 mm;

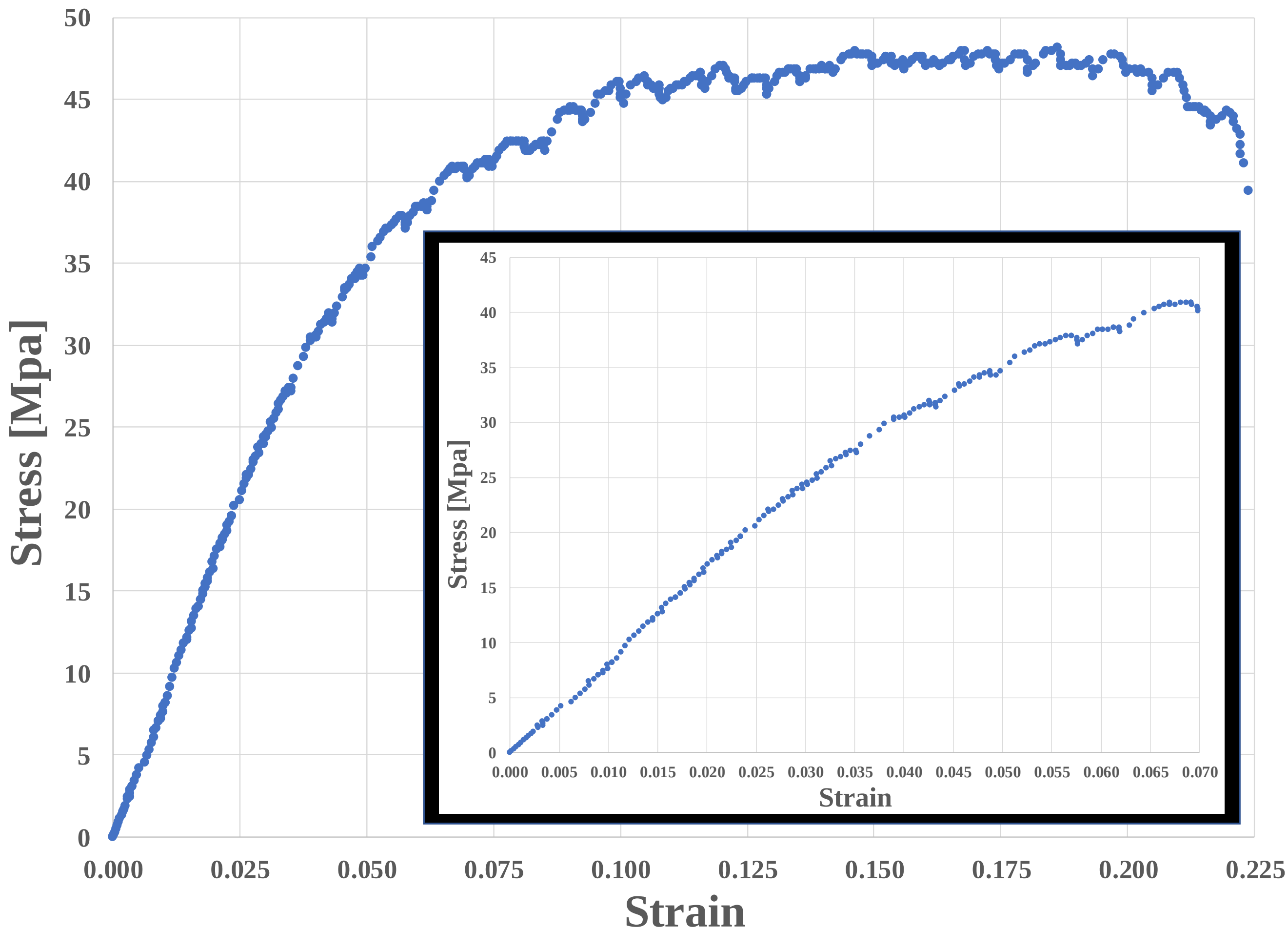
   i. What is the final length just before it fractures? **(2 points)** [ABET (e) solve engineering problem]

   ii. What is the final length after it fractures? **(2 points)** [ABET (e) solve engineering problem]

j) If a load that causes a stress of 20 MPa is applied to a 300-mm-long specimen, what would be its final length;

   iii. While the load is applied. **(2 points)** [ABET (e) solve engineering problem]

   iv. After the load is removed. **(2 points)** [ABET (e) solve engineering problem]



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