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Evaluating the Effects of Project-based Learning on a Sophomore Mechanics Course

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Abstract

The primary goal of the undergraduate engineering curriculum is to lay the groundwork for the remainder of the students' educational training, as well as prepare them for work in the engineering industry. Traditionally, the curriculum primarily consists of lecture-based courses, with some hands-on work, mostly through demonstration. In recent years, the curriculum has started using more project-based courses. In these updated courses, the theory covered via lecture is merged with hands-on project work. This integrated approach is designed to not only give the students a foundation of the course theory, but to expand on that and give them practical, hands-on applications of that theory. Additionally, it gives the opportunity to learn skills in design, manufacturing, electronics, controls, and prototyping.

This study looks at a mechanics of materials course project that has the students build a tensile-testing device from course-supplied kit to evaluate mechanical properties of a chosen material. Traditionally, this course was mainly taught using a problem-based pedagogy with the addition of a few basic labs and one project in the last few weeks of the course. The project detailed in this paper is an updated version of projects used in previous iterations of this experimental course. Despite the changes, all of these projects share a commonality of requiring the students to combine knowledge from multiple engineering disciplines, including circuits, controls, and mechanics of materials.

The effect of this experimental course on the students was analyzed a pre- and post-course self-efficacy survey that looks at how the students' self-perception of their engineering abilities and skills were affected by the application of the project-based course. To study the change in students' self-efficacy, the following hypothesis has been derived:

Hypothesis: Students who participate in the experimental project will demonstrate an increased engineering self-efficacy when compared to the onset of the course.

Introduction and Background

Since our base of engineering knowledge continues to grow, the amount and breadth of what the undergraduate engineering students need to learn grows with it. Traditionally, the method of instruction used was a direct, teacher-center, approach where the courses are centered around the instructor lecturing to the students for the length of the class. Some demonstration may be used, but the students were essentially passively involved in the course. Using a more student-centered teaching method can have a more positive response from the students and lead to a more effective learning environment [1].

To understand how this teaching method can be more effective, one must look at a comparison between the alternatives. Educational instruction can be separated into two main categories: direct instruction and constructivism. Direct instruction is a teacher-centered approach that presents or demonstrates a concept, or set of concepts, through lecture and asks questions to test mastery, where constructivism is a student-centered approach that allows students to explore answers to problems in a more open-ended education environment [2]. McLeod [3] discusses how Kolb's description of experiential learning is separated into a four-stage cycle. First is concrete experience, where the learner is introduced to a new experience or a reinterpretation of a previous experience. Next is observation and reflection on that new experience. This leads to the third stage of abstract conceptualization where the learner's reflection of their gives rise to new ideas. The final stage is where the learner then actively experiments on those new ideas. Using Kolb's learning cycle as a framework, these two methods can be combined into one teaching system wherein both inductive and deductive approaches are used: the inductive side using concrete experience and the deductive side using abstract conceptualization [4]. While both methods are deficient on their own, when these methods are merged, they can be used effectively [4]. By combining the two methods, a more complete learning experience can be achieved, effectively creating the Kolb cycle. STEM education has evolved over the last several decades to include this more combined active approach, especially in the fields of engineering education. One of the more recent pedagogies to be used in the engineering curriculum is the project-based learning approach. Project-based learning is a student-centered approach that uses a constructivist method of teaching where the students are actively involved in the learning process [5].

The study detailed in this paper is part of a larger, ongoing study. The goal of this larger study is to determine if project-based learning influences a student's engineering self-efficacy. Self-efficacy is defined as a person's perceived ability to perform a task [6]. The researcher's expectation is that a more hands-on experience through project-based learning will lead to an improved self-efficacy among the students which will better prepare them for a career after graduation. Studies have shown that improved self-efficacy can influence a person's performance, intrinsic interest, and career pursuits [6], [7]. Beier [8] showed that project-based learning can influence STEM (Science, Technology, Engineering, and Math) career aspirations.

Course Using Tensile-tester Project

The Static and Mechanics of Materials course is a core requirement for all undergraduate engineering students. The class uses a lecture-lab course design to introduce basic concepts of statics and mechanics of materials, as well as demonstrate real-world applications of some of these concepts. Table 1 shows the topics covered in this course. The class typically meets in one hour and fifty-minute classes three times a week, over the course of a 12-week term. The classes are typically structured with a one-hour lecture, coupled with a fifty-minute lab. For this experimental section of this course, the lab portion of the course is used to work on (or troubleshoot) the building of their devices.

Table 1. Course Topics

Course Topics	**Course Topics**
Resultant Forces	Truss Analysis: Method of Joints
2D Concurrent Forces	Truss Analysis: Method of Sections
3D Concurrent Forces	Frames and Machines
Normal Stress and Strain	Centroids
Shear Stress and Strain	Moment of Inertia
Axial Loading and Deformation	Shear and Bending Moment Diagrams
Torsional Loading and Deformation	Beam Deflection and Flexural Stress
Torque Transmission through Gears	Column Buckling
Rigid-Body Analysis	Pressure Vessels
Free-Body Diagrams	Stress Concentrations
	Finite Element Analysis

The project described in this paper is designed to replace the typical project from the comparison section of the course and give the students a hands-on experience by building their own testing device from a provided kit. In the traditional, lecture-based course, the students are required to build and test a truss design. To test their design, the students use a university-owned commercial tensile tester. For the experimental course, in lieu of the truss project, the students are performing material testing using this student-built device.

Tensile-tester Project Description

The goal of the engineering program is to give the students the tools and knowledge they need to be effective and productive upon entering the workforce. Through doing an in-class project, the students gain a better understanding of the concepts, as well as gain a set of skills through hands-on experience. By building their own testing device, instead of using a commercial version, the students geta deeper understanding of how the device itself works and allows them to understand and apply more of the course concepts to their class project.

The design and implementation of this project has evolved over the last few terms based on differing needs. Originally, this project was designed to be a larger, more robust tensile test device to but built in groups of two or three students. A version of this device can be seen in Figure 1.

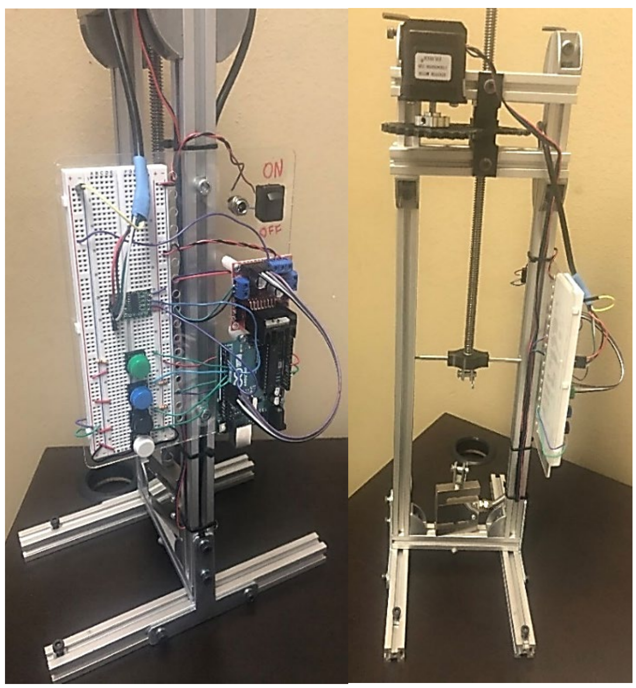

Figure 1. Tensile Testing Device (Original Design)

When the COVID-19 pandemic lead to a campus shutdown, the course had to be adjusted so that the students could attend remotely. The course project had to be redesigned to fit this new course structure. The remote nature of the course meant the students had to build the project individually. The project had to be redesigned from the ground up to make it simpler and less expensive to create the student kit. Several changes were made, including changing the drive system from a lead screw to a pulley system, the larger load cell was swapped for a smaller, less expensive version, and the overall size of the device was reduced. This design can be seen in Figure 2.

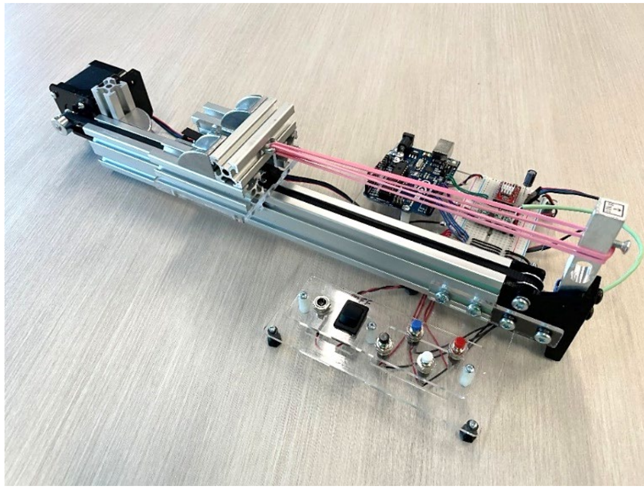

Figure 2. Tensile Testing Device (COVID Design)

Once the course was able to be taught in-person, the project was redesigned to reflect this change. Instead of going back to the original design, this opportunity was taken to update the design to make the project easier for the students to assemble and test. The overall layout of the testing device was changed to a fulcrum-centered design. This can be seen in Figure 3.

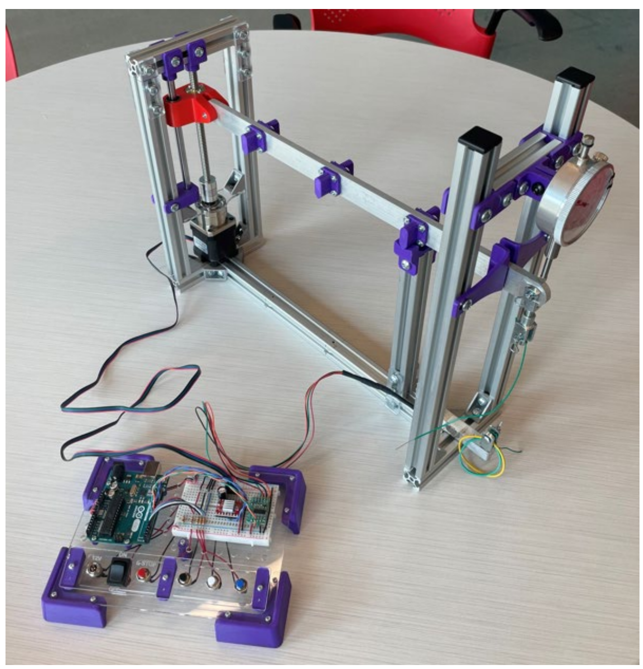

Figure 3. Tensile Testing Device (New Design)

The other major change to this project was to provide the students with a partially assembled electronics platform, as seen in Figure 4. Since at this point in their curriculum the students have already had experience with wiring buttons and switches, we gave them the partially built electronics platform to cut down on assembly time and therefor affording them more time for testing by allowing them to have the device built earlier in the course.

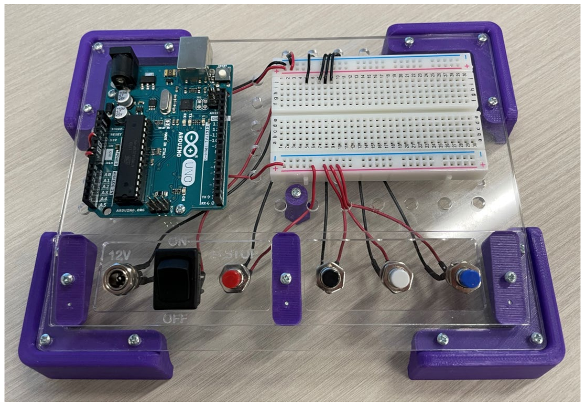

Figure 4. Electronics Platform (unpopulated)

The students are still required to do some wiring of the electronics, including the motor driver, the load cell amplifier, and all of the connections between these and the microcontroller. The microcontroller used for the project, the Arduino Uno, is not included in the kit for this course. The students are given an Arduino microcontroller during their first-year engineering course series. It is given to them with the expectation of it to be used in future projects. Through the freshman engineering series, the students learn the basics of programming using the Arduino microcontroller; a knowledge base that is expanded on in this course.

The project is broken into three main parts: the electronics assembly, the frame assembly, and material testing and reporting. Those parts are described in more detail in the following sections.

Electronics Assembly

The first stage of this build is the electronics platform for the assembly, as seen in Figure 5. The goal of this stage is to have the students complete and test the electronics platform, and use the platform to get their stepper motor functional. At this stage they install the microcontroller to the platform and wire into it the stepper motor driver. While the load cell and load cell amplifier are considered part of the electronics assembly, those are installed during the frame assembly. It is easier to test and calibrate the load cell once it is intalled in the frame.

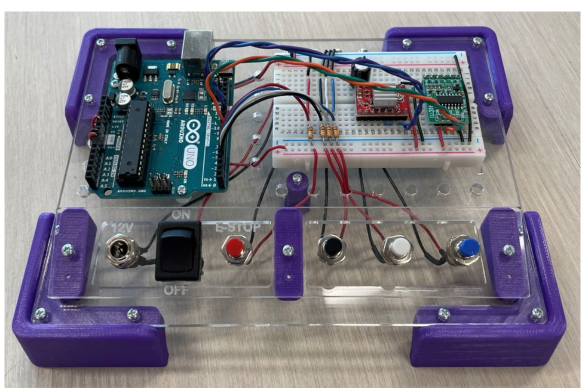

Figure 5. Electronics Platform Assembly

For the coding of the microcontroller, the students are shown and explained the code for each individual component. It is then up to the students to take each “chunk” of code and assemble them together for a complete set of working code for the tensile testing device.

The first “checkpoint” for their project is to demonstrate to the instructor that their motor is properly wired to the platform and fully functional. To show this, they are asked to demonstrate two tasks: one button to move the stepper motor clockwise, and another to move it counterclockwise.

This completes the electronics platform assembly, and the students move directly into the frame assembly.

Frame Assembly

Once the electronics platform is completed, and the stepper motor is shown to be functioning properly, the students move on to the next stage of the build: the frame assembly. The frame is mostly comprised of commercially available extruded aluminum pieces. This material is used throughout the engineering courses, so the students are very familiar with its design. Additionally, the versatility of the extruded aluminum allows the students to reconfigure their tester to design their own device later in the quarter. The purpose of that exercise is discussed later in this paper. As stated previously, the overall design of this device is centered on a fulcrum arm. This arm is driven on one end by a geared stepper motor and lead screw. On the other end of the arm, the students can attach various materials for testing. Included in the design is a dial indicator which allows the students to get a more direct feedback of the movement of the test piece. This can also be correlated with the feedback from the stepper motor. The complete frame assembly can be seen in Figure 6.

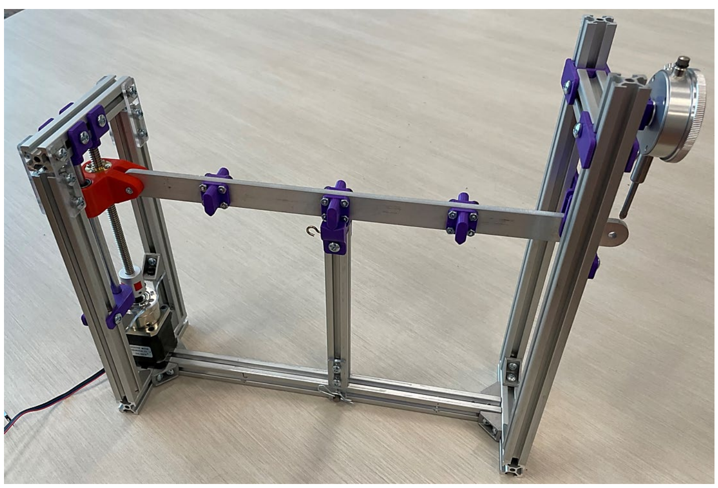

Figure 6 – Frame Assembly

The students are guided through the assembly over multiple courses, aided by assembly instructions that are available through the course website. This allows them to work on the assembly outside of class as well.

Some of the bracketry used in the design is created using in-house 3D printers. This includes the lead screw carriage, the dial indicator bracket, and various other brackets and guides. The 3D printing process allows for more intricate part design while still being relatively easy to fabricate. Since they are fabricated in-house, they are able to be created in larger quantities in a relatively short amount of time. This allows the program to prepare kits quickly and inexpensively.

During the frame assembly, the students install the stepper motor into the tensile tester frame. At this point, the students are able to install the load cell to the frame, and wire the load cell amplifier onto their electronics platform. Next the students calibrate the load cell. This effectively completes all of the electronics for the tensile tester

For the microcontroller code, the students are to ultimately produce a code that accomplishes the following:

- Two buttons that move the tensile tester moment arm: one up and one down (jog mode).
- A "test" button causes the tester to move slowly upwards a set distance? (the distance should be set beforehand)
- A button that causes the motor to stop immediately. (Typically used as bonus points)
- As the specimen is stretched, the monitor should give a read-out of the change.
- Can the read-out be properly interpreted to a meaningful force?
  - Does the monitor read out the actual force instead of a number needing interpretation? (bonus of 2 points)

Again, in the class lecture the students are show examples of the "chunks" of code for each separate component of the system. It is up to the students to take those pieces of code and combine them into a fully operating system. The students are encouraged to annotate their code for clarity (a good practice to learn for any coding), as well as elaborate on the code to do more actions with the assembly, if they desire.

Material Testing and Report

With their project assembly and functionally tested, the students are now required to perform material testing using their own device. The students are allowed to test a material of their choice; they just need to be able to compare test results to know material properties. The ultimate goal of the testing is for the students to obtain a material modulus of elasticity (E) for their chosen material, and compare that to a known value.

The students are required to collect a minimum of 10 data points from a set of at least 10 unique specimen deformations. They are then required to take the raw data and calculate the stress and strain of their material, and then plot that data showing the stress/strain relationship. Finally, they calculate the modulus of elasticity of their chosen test material. Again, the goal is for them to see how their calculated E compares to the expected value of E.

The final requirement for this portion of the project is to submit a written test report. In this report they're asked to describe the testing device, the microcontroller code (they're encouraged to include a "flow chart"), and the material testing and associated results. For the description of their system, they are asked to include a detailed description of how the system works, including a properly labeled image of the assembly showing all the major components. The focus of their description should be how the rotational motion of the stepper motor translates into linear motion on the lead screw, and then how that force is multiplied by the moment arm of the assembly. They are also encouraged to include a circuit diagram of the electrical system (showing the main components: the microcontroller, stepper motor, motor driver, load cell, and load cell amplifier). For the code description, the students are asked to describe the overall "flow" of the code, including microcontroller input and output from all major components. The material section of the report is to include a description of their chosen testing material, evidence of research of that material's expected elastic modulus, and the collected test data and associated calculations and analysis. Finally, they are to discuss their comparison of the calculate elastic modulus to the researched know value. If there is a difference between those values, the students are to discuss what might be the possible cause for that difference.

Data Collection

At this early stage of implementing the project into the course, we are interested in seeing how the changes to the course impact student performance; namely their engineering self-efficacy. To study the students' self-efficacy, an engineering self-efficacy survey [9] was administered at two points in the term: one at the onset of the course and the other at the conclusion of the course. At the end of the term, the results were collected for analysis. Before performing the analysis, the bad data was removed from the data set. This included incomplete surveys, students that declined to take the survey, and students that took the pre-course survey but dropped the class. Once complied, the total number of students included in the study was 16. Other data was collected from this class, including journal reflections and a concept inventory test, but those results are not discussed in this paper. That data will be used in future analyses and is further discussed in a latter section of this paper. The following hypothesis was made for the study:

Hypothesis: Students who participate in the experimental project will demonstrate an increased engineering self-efficacy when compare to the onset of the course.

Data Analysis

Student survey results were gathered from the pre- and post-course surveys and analyzed using t-tests. The survey is comprised of several groups of statements, each group containing multiple statements. The statements responses are listed using a 5-point Likert scale. The answer range for the General Engineering, Experiments, Tinkering, and Design sections was: 1-Definitely Not to 5-Definitely Yes. The answer range for Teamwork section was: 1-Extremely Comfortable to 5-Extremely Uncomfortable. The complete list of survey statements can be found in Appendix A. The data was analyzed in two ways: first by comparing individual statements, and then by comparing the average scores within each statement group. Table 2 shows the results of the t-tests for the grouped statement comparisons as well as the results for the individual statement comparisons.

Table 2. Survey Question Comparisons

Category		Pre-Course Mean	Post-Course Mean	t-value	df	p-value
General Engineering	**Gen-1**	4.438	4.668	-1.73	15	0.104
	Gen-2	4.188	4.500	-1.78	15	**0.096‡**
	Gen-3	4.563	4.625	-0.56	15	0.580
	Gen-4	4.438	4.563	-1.00	15	0.333
	Gen-5	4.688	4.750	-0.44	15	0.669
	Gen-6	4.375	4.563	-1.14	15	0.270
	Average	4.448	4.615	-1.56	15	0.138
Experiments	**Exp-1**	4.688	4.563	0.70	15	0.497
	Exp-2	4.625	4.750	-0.81	15	0.432
	Exp-3	4.625	4.875	-1.73	15	0.104
	Exp-4	4.563	4.875	-2.08	15	**0.055‡**
	Exp-5	4.563	4.500	0.32	15	0.751
	Average	4.613	4.713	-0.77	15	0.455
Tinkering	**Tink-1**	4.813	4.938	-1.46	15	0.164
	Tink-2	4.813	4.938	-1.46	15	0.164
	Tink-3	4.750	4.875	-1.46	15	0.164
	Tink-4	4.313	4.813	-2.74	15	**0.015†**
	Tink-5	4.250	4.625	-2.09	15	**0.054‡**
	Tink-6	4.250	4.750	-3.16	15	**0.006†**
	Tink-7	4.813	4.938	-1.46	15	0.164
	Tink-8	4.813	4.938	-1.46	15	0.164
	Tink-9	4.625	4.938	-2.61	15	**0.020†**
	Average	4.604	4.861	-2.77	15	**0.014†**
Design	**Des-1**	4.313	4.688	-2.42	15	**0.029†**
	Des-2	4.188	4.625	-2.41	15	**0.029†**
	Des-3	4.375	4.688	-1.78	15	**0.096‡**
	Des-4	4.563	4.750	-0.72	15	0.485
	Des-5	4.563	4.750	-1.14	15	0.270
	Average	4.400	4.700	-1.95	15	**0.070‡**
Teamwork	**Team-1**	2.250	2.188	0.13	15	0.896
	Team-2	2.813	2.688	0.30	15	0.796
	Team-3	2.625	2.375	0.70	15	0.497
	Average	2.563	2.417	0.37	15	0.715
Key: †significant at $\alpha = 0.05$ ‡significant at $\alpha = 0.1$						

For the majority of the questions, no significant difference was seen between the pre- and post-course surveys. There were, however; a few significant differences found that correlate well to the structure of the course. Those results are discussed in the next section.

Discussion of Data Results

Overall, the data collected does not support the stated hypothesis. This can be attributed to various causes. First could be the "Ceiling Effect", wherein the students give responses on the high end of the scale, thus giving no room for improvement through the course. This could either be because the students already feel comfortable with the topic, or are overestimating their abilities. This can directly be seen in several of the statement responses, namely Tink-1 through Tink-3, Tink-7, and Tink-8. The results from the comparison show that, across the board, the students gave the same response from pre- to post-survey. Based on their experiences in previous courses, these most likely are accurate responses. These statements are associated with using tools and machines (Tink-1 through Tink-3) and assembling and disassembling things (Tink-7 and Tink-8). Part of the freshmen series of engineering courses, the students are required to assemble and use several small kits for the course. In doing so they get experience with assembling and disassembling these kits, as well as using the associated tools and machines to fabricate and assemble. Additionally, some of the statements in this survey may not be directly addressed in the current version of this course. This is an area of improvement for this experimental course design, where future iterations can apply to a broader range of engineering skills. The last section of the survey, the Teamwork section, asks the students how comfortable they are working in teams. While they do work in teams for this course project, that is not new to the students as this point. They have been working in teams throughout their freshmen engineering series. This is most likely the reason this course didn't have a significant effect on their feelings towards teamwork.

The statement responses that showed significance in the comparison can be directly attributed to the design of this experimental section of this course. Those statements are Tink-4, Tink-5, Tink-6, and Tink-9 from the Tinkering group of statements, as well as Des-1, Des-2, and Des-3 from the Design group of statements. The statements from the Tinkering group are: *I can build machines* (Tink-4), *I can fix machines* (Tink-5), *I can manipulate components and devices* (Tink-6), and *I can apply technical concepts in engineering*. While the students have assembled and used projects in previous courses, this is their first experience with building a kit on this scale, as well as using it to apply course concepts and use the device for testing. Through this course they get to build and troubleshoot this testing device, and then use their own device for material testing.

Finally, with the Design section of statements, the following statements showed significance: *I can design new things* (Des-1), *I can identify a design need* (Des-2), and *I can develop design solutions* (Des-3). Part of this course is designed to give the students a chance to come up with their own design through an open-ended assignment. The students are instructed to create a device, using the parts provided in the kit, to achieve the maximum force output possible. Through this assignment they get to develop their own design, only guided by the desired outcome and only limited by the provided parts. This kind of open-ended project is key in helping the students improve their design skills.

Limitations and Future Work

Due to the nature of the educational structure at the university, and availability of instructors, there were some limitations that could not be avoided. The students are allowed to choose the section in which they enroll. This decision could be affected by several factors, including the perceived difficulty of the listed professor or the time of day the class is offered. This removes the ability to completely randomize the study. Ideally, both the experimental section and the comparison section would be taught by the same instructor. Doing so would remove any difference in teaching styles between the sections. While this does not affect the self-efficacy survey data, it could have effect on other data collected for future study analyses.

With each successive iteration of this project, the course structure will be updated to correlate as many topics as possible to the project, as well as ensure that coverage of the content is equal to that of the control group. Additionally, the goal is to eventually have the same instructor teach both the experiment and control sections of the course. That would help eliminate the previously mention limitation. This, of course, will depend on the limitations of staff availability at the university.

This study will continue to look at the effects of project-based learning on the students' self-efficacy in the engineering program. Using the additional data collected, as mentioned earlier in the paper, the research team will widen the study to incorporate a mixed-methods approach. Qualitative data will be combined with the quantitative data from this, and other sources, to reinforce the findings in the overall study. Since the Statics and Mechanics of Materials course is a general requirement for all engineering students, there will be ample opportunity to continue the study using this course. As mentioned previously, the qualitative portion of the study will use reflection journals written by the students periodically throughout the course. These journal entries will be coded and analyzed to gain a better understanding of whether the project will give students a broader understanding of the material taught in class.

Acknowledgements

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Appendix A

General Engineering Self-Efficacy

Gen-1	I can master the content in the engineering-related courses I am taking this quarter.
Gen-2	I can master the content in even the most challenging engineering course.
Gen-3	I can do a good job on almost all my engineering coursework.
Gen-4	I can do an excellent job on engineering-related problems and tasks assigned this quarter.
Gen-5	I can learn the content taught in my engineering-related courses.
Gen-6	I can earn a good grade in my engineering-related courses.

Engineering Skill Self-Efficacy (Experiments)

Exp-1	I can perform experiments independently.
Exp-2	I can analyze data resulting from experiments.
Exp-3	I can orally communicate results of experiments.
Exp-4	I can communicate results of experiments in written form.
Exp-5	I can solve problems using a computer.

Engineering Skill Self-Efficacy (Tinkering)

Tink-1	I can work with tools and use them to build things.
Tink-2	I can work with tools and use them to fix things.
Tink-3	I can work with machines.
Tink-4	I can build machines.
Tink-5	I can fix machines.
Tink-6	I can manipulate components and devices.
Tink-7	I can assemble things.
Tink-8	I can disassemble things.
Tink-9	I can apply technical concepts in engineering.

Engineering Skill Self-Efficacy (Design)

Des-1	I can design new things.
Des-2	I can identify a design need.
Des-3	I can develop design solutions.
Des-4	I can evaluate a design.
Des-5	I can recognize changes needed for a design solution to work.

Teamwork

Team-1	How comfortable are you working as a team member?
Team-2	How comfortable are you asking for help from others?
Team-3	How comfortable are you asking for information from others?