Work in Progress: Implementing Project-based Learning Into Sophomore Mechanics Course

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As a member of the Integrated STEM Education Research Center (ISERC) at LaTech, Ethan's primary research area is engineering design education with a focus on developing prototyping skills through both class-based projects and extra-curricular clubs, competitions, and activities. This includes a focus on hand-drawn sketches and how they are used as tools for generating ideas and visual communication, especially when it involves the skill to generate quick and realistic sketches of an object or idea. He has also conducted research on the impact involvement in academic makerspaces has on students in engineering programs.

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Abstract

The primary goal of an engineering curriculum is to lay the groundwork for the remainder of the students' training. 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. The project detailed in this paper is a redesigned and scaled-down version of a project previously used for this course [1]. With the restrictions from COVID, the previously group-based project had to be revamped into an individual based project. Despite this change, this project still requires the students to combine knowledge from other areas, including circuits, controls, and mechanics of materials. They learn to build a microcontroller driven device, in conjunction with a load cell, to test the mechanical properties of a material.

For analysis, an experimental section of this class was compared to a control section, using an engineering self-efficacy survey. While the two showed similar result on concepts learned, there were a few concepts where the experimental section was behind the control section. However, the main goal of this survey was to show that the project in the experimental section didn't cause those students to fall too far behind their counterparts.

Introduction and Background

In higher education, especially in the STEM fields, there is an ever-growing pool of knowledge to be learned in a relatively short amount of time. Until recently, the method of teaching engineering undergraduate students was a traditional direct instruction approach, which is a teacher-centered approach where the students are passively involved. The drawback to this method is that the students only obtain the lower levels of Bloom's Taxonomy: Knowledge and Comprehension [2]. They do not get exposure to the higher levels of the taxonomy: Application, Analysis, Synthesis, and Evaluation. These levels must be achieved by the students outside of the classroom [3]. To allow the students to reach the higher levels of learning in the classroom, the method of teaching needs to move away from the instructor-centered learning and towards a more student-centered learning [4].

Two basic types of teaching methods have emerged in education: 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 [5]. In a paper by Georgiou et al. [6] they describe a method that combines these two systems into one learning method, using Kolb's learning cycle as a framework, that uses both an inductive and deductive approach to teaching: the inductive side using concrete experience and the deductive side using abstract conceptualization. While both methods are deficient on their own, when these methods are merged, they can be used effectively [6]. 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 [7].

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 has an effect on a student's engineering self-efficacy. Self-efficacy is defined as a person's perceived ability to perform a task [8]. The researcher's expectation is that an improved self-efficacy among the students 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 [8], [9]. Beier [10] showed that project-based learning can have an effect on STEM (Science, Technology, Engineering, and Math) career aspirations.

Courses Using Tensile-tester Project

The basic design of the tensile tester assembly is used in two courses in the engineering program. The first is the sophomore-level Statics and Mechanics of Materials course that is required for all undergraduate engineering disciplines. The second course is Applied Mechanics of Materials, which is a sophomore-level course for the engineering technology program. While the basic design of the tensile-tester is used in both disciplines, the assembly for the engineering technology program has additional modifications that are not covered by the scope of this study. This paper will detail the version of the assembly used for the Statics and Mechanics of Materials course. Table 1 shows the topics covered by each course [1].

Table 1. Course Topics in Approximate Order Introduced

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

The Statics and Mechanics of Materials course is part of a sophomore-level series that is required for all engineering disciplines. The course introduces the basic concepts of both statics and mechanics of materials in a lecture-lab setting. In a typical 12-week quarter, the class meets three times a week for an hour and fifty minutes per meeting. While it can vary, the class time is typically broken into 1-2 hours of lecture, and the rest dedicated to project work. This project work time gives the students dedicated time to build and/or test their assemblies or talk with the professor or classmates about any potential issues with the project or the homework assignments. The project build is broken into successive homework assignments, which allows the students to progressively build and test their assemblies. The project-based course only consists of a mid-term and final exam, as opposed to the three-exam format used by the problem-based version of this course.

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. That goal is what drove us to incorporate a student-built project, as opposed to using a commercial device. Building the project themselves gives the students a deeper understanding of the underlying concepts of the material testing, instead of just the base knowledge of how to run a machine.

As with every other aspect of life these days, the COVID pandemic drove changes to this project. In the past, the class project was assigned as a group project. With the closure of campus during lockdown, and the need for social distancing, the project was changed to an individual build. That was the main driving force to updating the design of this project, which is discussed in further detail in the following sections. Because we were having to teach remotely, the students were required to purchase individual project kits. While some of the cost was already offset by the fact that there is no textbook required for the course, the cost needed to be reduced further to relieve some of the financial burden on the students. This new project design reduces the size and part count of the kit, as well as removes some of the larger, costlier, components in the assembly. The largest contributor to that cost was the load cell. Previously the load cell (a 100 Kg Type S Load Cell) was replaced with a smaller 10kg bar-type load cell that is more cost-effective to lower the price of the individual student kits. The total kit contains the following:

- Barrel jack and rocker switch (for 12V power supply input)
- Four, colored, pushbutton switches
- 400-pt. Breadboard
- Stepper motor, motor driver, and motor bracket
- Load cell and amplifier
- Carriage assembly (described in detail below)
- Pulleys and belts
- 3D printed end bracket
- Frame parts and associated fasteners

The microcontroller used for the project, the Arduino Uno, is not included in the kit for this course. The students are given an Arduino board 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 1. The goal of this stage is to have the students assemble the platform, connect a majority of the electronics components, and ensure proper wiring. Components used at this stage of the build are the microcontroller, the buttons, the stepper motor, and the stepper motor driver. The stepper motor driver used for this assembly is upgraded from the previous design [1]. This design is using a larger stepper motor, and subsequently needed an upgraded driver. The previous driver was tested with this motor during the design phase of this build, but it was found that it couldn't supply the proper amount of power for this larger motor.

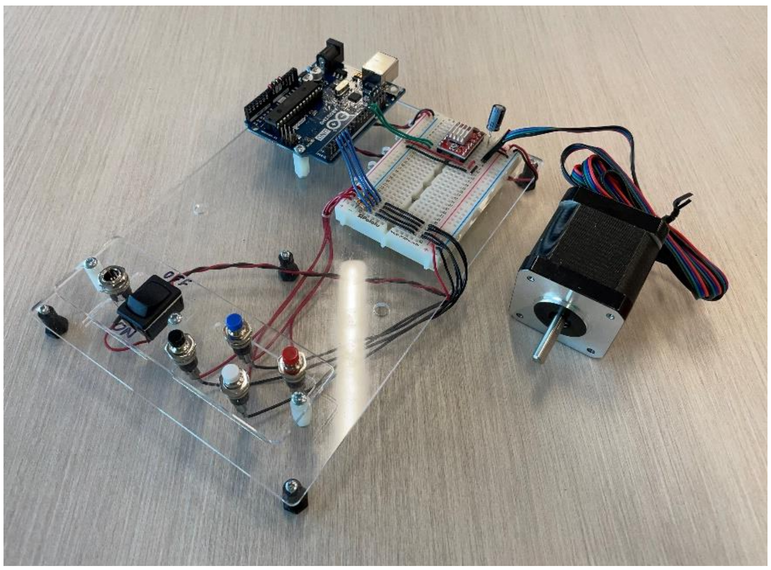

Figure 1 – Tensile-Tester Electronics Assembly

This first stage of the build is separated out into separate homework assignments for the students, with each assignment focusing on one particular component type. The first homework set has the students uses a single button, the microcontroller, and an LED. This assignment is to ensure that the students can properly wire the LED and control it through code on the microcontroller. They are asked to write two sets of code, or sketches, that control the LED:

- The first, the LED should come on as long as the button is being held, and turn off when the button is released.
- The second, the LED should come on and stay on when the button is pressed and released. The LED should remain lit until the button is pressed again, essentially creating a light switch.

The next two homework assignments focus on the stepper motor. In these assignments they will wire the stepper motor to the microcontroller, test that it is functioning, and write code that will control the stepper motor. The first assignment has the students wire the stepper motor to the microcontroller. It then asks them to write a code that moves the motor one rotation clockwise, pause, and then move the motor counterclockwise. This is a standard set of code that is used to test a stepper motor, and that block of code is provided for the students. Their goal is to replicate it for their setup and test that they can get their stepper motor to function. The next homework set has the students now code the stepper motor to work in conjunction with two of the pushbuttons. They are asked to write code to perform two tasks:

- One button should cause the stepper motor to rotate clockwise
- The second button should cause the stepper motor to rotate counterclockwise

The students are then asked to create a circuit diagram of everything connected at this point. This includes the microcontroller, stepper motor, motor controller, and pushbuttons. This step is to ensure that the students understand how to properly lay out a schematic.

With these assignments complete, the majority of their electronics assembly is built and tested. There are additional electronic components, the load cell and load cell amplifier, but those are assembled and tested once the full frame of the assembly is built.

Frame Assembly

With the completion of the electronics assembly, the next stage of the build is the frame assembly. This phase of the assembly includes the 20mm x 40mm extruded aluminum bar stock, which is the main "backbone" of the assembly, along with the stepper motor bracket, the carriage assembly, and the 3D printed end bracket that holds the load cell and pully wheel.

The basic theory of this assembly is to turn the rotation of the main driver motor, the stepper motor, into a linear actuator. The extruded aluminum acts as a rail, along which a carriage rides to provide the mobile piece of the assembly. The motion is transferred from the motor to the carriage using a belt and pulley system. The pulley system, as seen in Figure 2, is comprised of commercial off-the-shelf (COTS) belt components used in most desktop 3D printers and CNCs. This was a low-cost choice used because it was readily available, and it helped keep the cost down for the individual student kits.

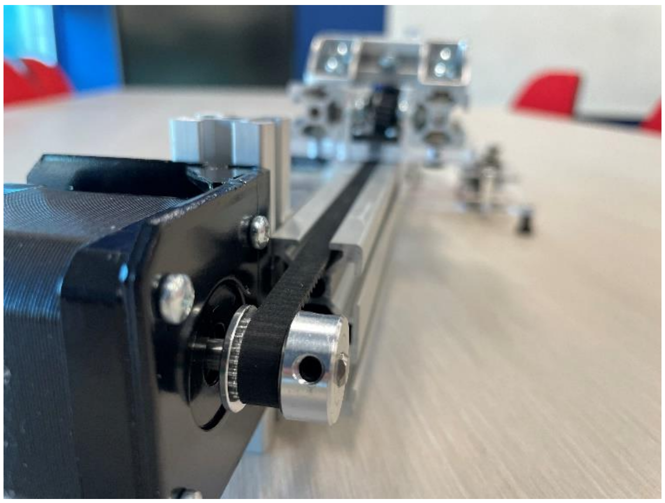

Figure 2 –Pulley system

The carriage assembly used in this design went through some iteration before what is seen here in Figure 3.

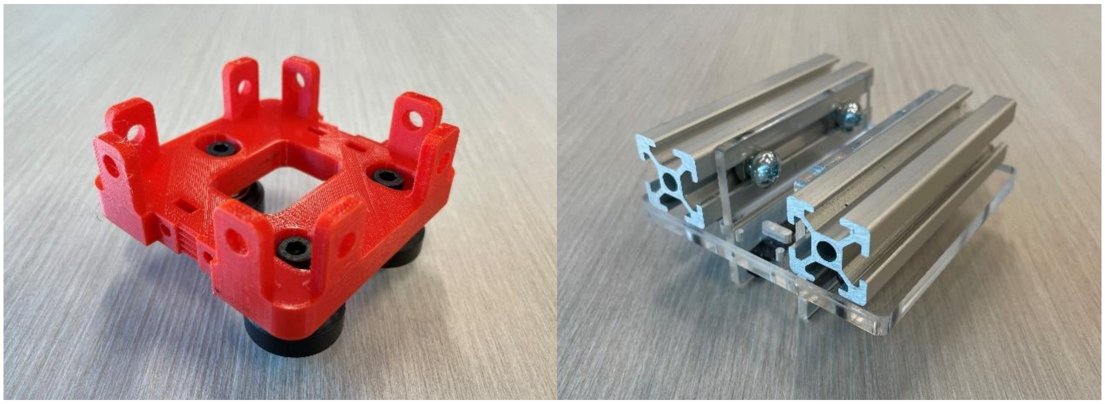
Figure 3. Left: Old Carriage Design; Right: New Carriage Design

The first version of this design used a fully 3D printed carriage base, and was moved along the extruded aluminum rail using COTS bearing wheels. While this worked well for its intended purpose, there were some issues that drove a design change. The 3D printed base was very time intensive to print in the quantity needed, and the attachment tabs on the top were prone to breaking. The COTS bearing wheels were difficult to obtain and were costly. To combat these issues, a new design was implemented that used primarily laser cut pieces for the base of the assembly, since laser cut parts are much quicker to produce that complex 3D printed parts. In place of the bearing wheels, simple 3D printed runners were used. A comparison of the wheels and rails can be seen in Figure 4.

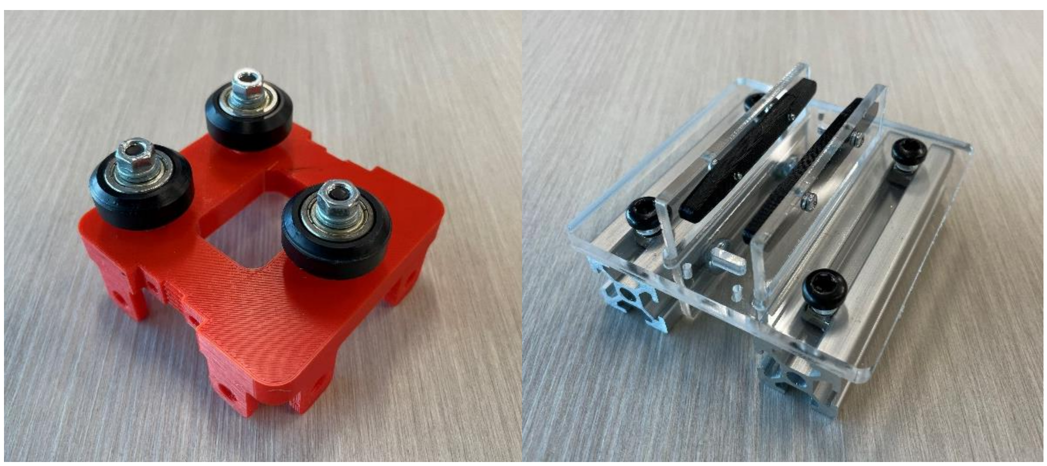
Figure 4. Left: COTS Wheels; Right: 3D Printed Runners

With this updated design, the carriage assembly could be produced mostly in-house with minimal COTS parts, making the preparation easier and quicker, and driving down the cost of the individual kits.

The previous design used a lead screw as the means to transfer the motion from the stepper motor. An example of that can be seen in Figure 5. This design update allowed for us to move to the individual kits for this assembly, since it wasn't feasible to include a lead screw in every individual kit. The final build of this kit can be seen here in Figure 6. Like the electronics assembly, the buildup of this stage of the build was done in stages through homework assignments.

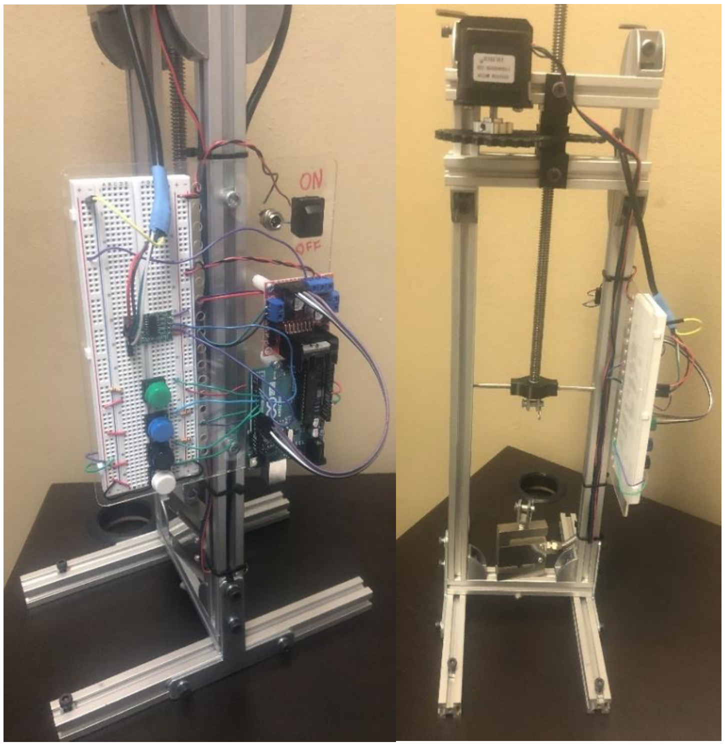

Figure 5 – Previous Tensile-Tester Design

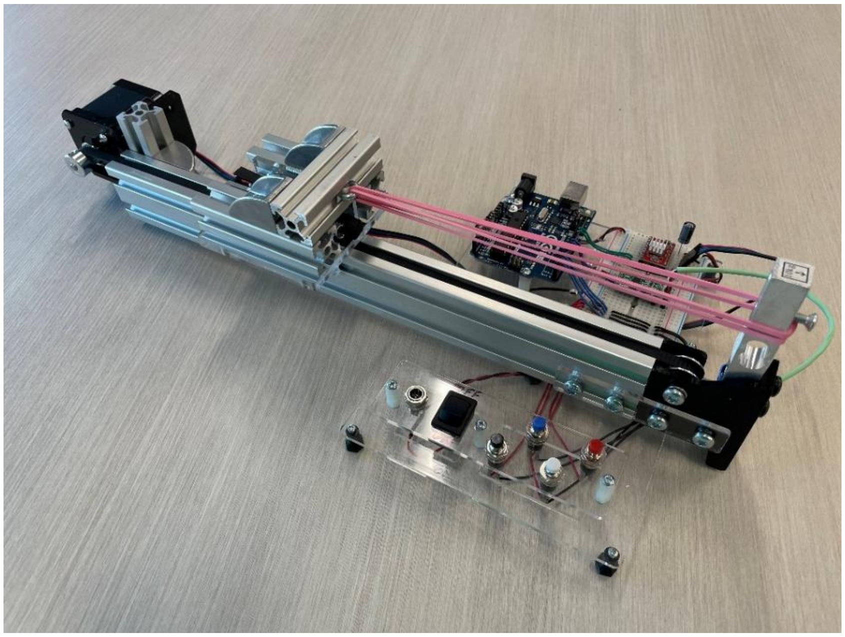

Figure 6 – Fully Assembled Tensile-Tester

The first of the frame assembly assignments is to attach the extruded aluminum, brackets, and stepper motor to the assembled electronics assembly. At this point the students should have the motor completely attached and operational using the pushbuttons from the electronics assembly.

The next assignment has the students install the load cell to the frame assembly, and wire it into the electronics assembly, along with the load cell amplifier. At this point, in class, the load cell is calibrated. Ultimately, the students are to produce a code that accomplishes the following:

- Two buttons that causes the screw to move left/right when pressed (jog mode).
- A button that causes the screw to move up until a set distance. This set distance needs to be an easily changed variable as you will need to change it frequently in testing. This should be demonstrated using a specified distance given to the class.
- A button that functions as an “Emergency Stop” that ends the testing mode immediately.
- A monitor readout of the current load applied and elongation of the specimen
    - Elongation is just how far the carriage has moved (how much you’ve stretched)

The students are to demonstrate their system working correctly and are graded for how well the system works and how cleanly their tester is assembled and wired. 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

Once the students have a fully functional assembly, the next step of the class is to perform material testing with their assemblies. The ultimate goal of this testing phase is to obtain the modulus of elasticity (E) of a material. The students are free to choose the material, with the limitation that it must be something capable of being tested with this setup. Examples of some materials chosen include electrical wire, guitar strings, human hair (given from a willing participant), and 3D-printed dog-bone specimen. The testing of the material includes:

1. Jog the tensile tester to the length of the specimen and attach it to the carriage and load cell
    a. You will have to figure out how to attach your specimen to the load cell and carriage. You may need to get a few extra parts to do this.
2. If using a wire or something similar, jog the carriage so there is no slack.
3. Program the tensile machine to move slowly, to a set distance, stretching the material.
4. Read the load output from the load cell.
5. Convert this read-out to a meaningful load (newtons or pounds based on your calibration)
6. Unload the specimen.
7. Repeat steps 1-6, using a different set distance in Step 3.

The students are asked to collect a minimum of 10 data points with at least 5 unique distances. This data is then converted to strain and stress using the geometry of the tested specimens and plotted on a stress/strain chart. Students use this data to determine what the modulus of elasticity is for their chosen material.

For the written report, the students are asked to describe their system, the code, and the material testing. For the description of their assembly, they should describe in detail how the system works, and include with it an image of the assembly with the major components labeled. In particular, they are asked to describe how the rotational motion of the motor is translated into the linear motion of the carriage. With this they are asked to include the circuit diagram of their system (with 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, detailing how the microcontroller receives input and from what components, as well as the output the microcontroller sends out to the system. Finally, the students are asked to describe their methodology used for testing their chosen material. From the data collected during testing, the students are required to state their calculated elastic modulus, as well as compare it to a similar elastic modulus found in a textbook or academic paper. They are to compare those to numbers and note the difference between them and discuss what may be the cause of the difference. Typically, most of the difference is from internal tolerance of the system and slippage of the stepper motor. Some students will recognize this and note it in their report. While it is not a requirement for the class, some students even correct for these disparities. Class time is not dedicated to this since it would require more instruction on the necessary coding required and would take away from the time invested in teaching the students about the theory and testing of the mechanics of the materials.

Pilot 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. While true understanding of the impact of the project will not be understood until the full research plan is implemented, student performance on exams can be analyzed during this pilot study period. To determine if the changes are maintaining the same level of student understanding, students in three sections of the course were studied. One course included the project described in this paper. This section will be referred to as the Experiment section and included 38 students. The other two sections did not include this project, but instead included two in-class labs that tested the mechanical properties of given material and a short project using an online truss designer. These sections will be studied as one group and referred to as the Control sections and included 64 students.

To allow the students in the Experiment section the time needed to complete the project, less problem-based homework was given. In comparison to the Control sections, the Experiment section was given about two-thirds the number of problems to work for a grade. The additional problems were also made available to the students, but for no additional grade. Also, as the project took considerably more time than the lab assignments given in the Control sections, the grade distribution varied between the Experiment and Control Section, as seen in Table 2.

Table 2. Grade Distributions

Experiment Section		**Control Sections**	
Exams	50%	Exams	60%
Project Homework	5%	Truss Project	10%
Project Demonstration	10%	Labs	10%
Project Report	20%	Homework	15%
Homework	10%	Attendance/Participation	5%
Attendance/Participation	5%		

Other than the inclusion of the project and the necessary adjustments made, all sections of the course teach the same course topics shown in Table 1. To test how the project may be impacting students’ understanding of the course material, several similar problems across various topics covered in the course were given on exams for both the Experiment and Control sections. The following hypothesis was made for the pilot study:

Hypothesis: Students who participate in the new project will demonstrate a knowledge of the course material equal to that of students who do not participate in the new project.

Data Analysis

Student exam data was gathered from the Experiment and Control sections of the course and the average scores on each problem were calculated and compared between the two groups. Table 3 shows the average scores out of one for each group and the results of a t-test for the two independent groups, assuming the variances are not equal.

Table 3. Exam Problem Comparisons

	Averages			t-test		
Problem Topic	**Experiment (n=38)**	**Control (n=64)**		**t**	**df**	**p-value**
Stress v. Strain Relationship	0.851	0.856		0.122	100	0.903
2D Resultant	0.921	0.881		0.850	100	0.398
Axial Deformation	0.805	0.891		1.238	100	0.219
Torsional Shear Stress	0.711	0.839		1.594	100	0.114
Bearing Stress	0.627	0.653		0.312	100	0.756
3D Equilibrium	0.524	0.697		2.165	100	0.033†
Axial Deformation	0.404	0.375		0.325	100	0.746
Truss (Method of Joints)	0.684	0.747		0.862	100	0.391
Truss (Method of Sections)	0.811	0.766		0.653	100	0.516
Pressure Vessel	0.908	0.968		1.300	100	0.197
Stress Concentration	0.339	0.651		3.641	100	<0.001‡
Frame	0.624	0.619		0.050	100	0.960
Machine	0.161	0.317		2.032	100	0.045†
Centroid	0.724	0.651		0.864	100	0.390
Moment of Inertia	0.520	0.564		0.518	100	0.606
Bending Moment	0.268	0.402		1.961	100	0.053
Beam Deflection	0.516	0.603		1.003	100	0.318
Key: †significant at α=0.05 ‡significant at α=0.001						

For the majority of the problems, the average scores were not found to be significantly different between the two groups. Only three problems were found to have statistically significant differences between the experiment group and control group. For all three of these problems, the control group had a significantly higher score than the experimental group.

Discussion of Pilot Data Results

Overall, the data supports the hypothesis that students in the Experiment section would demonstrate a knowledge of the material equal to that of students in the Control sections. While the exam does show how well the students learned the conceptual material, it does not show the skills learning from building and testing with the project. The main purpose for comparing exam results was to show that the change in the course did not cause the experimental section students to fall too short on learning the course concepts, when compared to the control section. However, there were a few areas that students in the Experiment section did not grasp as well as their counterparts in the Control sections. These areas were 3D static equilibrium, stress concentrations, and static analysis of machines. The most likely cause for these few shortcomings is the difference in the number of homework problems worked for the class. These homework problems are arguably the best preparation for the exam as many of the questions have similar problem descriptions and solution paths. Another potential factor is the overall lower weight of the homework and exams on the final grade. This could result in students having less urgency to complete the homework and study for the exams. In order to more fully understand how to help student gain a firm grasp on the material, more in-depth data will need to be collected. Furthermore, the project and the course as a whole must constantly evolve towards giving students the best possible instruction of the material as they prepare for more advanced courses and the workforce beyond.

Limitations and Future Work

As this is only preliminary data, there are several issues that could not be avoided. Firstly, the Experiment and Control sections of the course were taught by different instructors. Therefore, the differences in exam grades could be a result in a difference of teaching styles. The exams were also spaced slightly differently in each section which could have resulted in students doing better or poorer in certain areas. Finally, students are allowed to choose their own section, which may lead to certain self-selection of the experiment groups as students may choose a section on the perceived difficulty of the instructor or the time of day the class is offered. Hopefully, future iterations of the experiment will include the same professor teaching both an experimental section and a control section to help mitigate these extraneous variables.

Based off student feedback, some changes will likely be made to the project itself. As it becomes more feasible for students to safely work in pairs or teams, at least a portion of the project will become team-based on future course offerings. This will help mitigate some of the added work from coding and building the project. The project build will be modified to reduce the amount of coding and wiring the students will be required to perform. This will free up more class time to be devoted to course content. We are also looking into ways to make the tensile tester more powerful. This will allow students to test a wider variety of materials and potentially see the plastic deformation of a material and how the stress and strain measurements react to this situation firsthand. As the project progresses, 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 limitation of different teaching styles. This, of course, will depend on the limitations of staff availability at the university.

The research team will continue to look at the effect of project-based learning on a student's engineering self-efficacy through the use of a mixed-methods study, combining data collection through both quantitative and qualitative means. The course used for the study, the sophomore-level Statics and Mechanics of Materials, is typically offered through multiple sections each quarter. This allows for at least one experimental section using the tensile-tester assembly, and a section to be used as a comparison group. The quantitative portion will look at comparing the pre- and post-course self-efficacy surveys, as well as comparing students' understanding of the material through continued exams with similar problem or performance on a concept inventory. The qualitative portion of the study will use in-class recordings of the students and post-course interviews for analysis. These recordings and interviews will be transcribed and coded in an attempt to gain a better understanding of whether or not the project will give students a broader understanding of the material taught in class.

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