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Development and Implementation of a Project-Based Framework for Introduction to Engineering

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Development and Implementation of a Project-Based Framework for Introduction to Engineering

Abstract

This paper is considered complete evidence-based practice. In Fall 2023, Robert Morris University piloted seven different semester-long projects in one section of an Introduction to Engineering course. Students were assigned in groups of four and given specific roles and responsibilities. The projects were designed to complement the curriculum of the class and allow each group to meet learning outcomes through an exploration and application of technology to solve engineering problems. The projects were created with a framework that would allow other faculty who teach the course to select any number of the projects to offer (based on resources available and instructor experience) or design their own projects to fit the framework. Most projects required the purchase or reuse of available hardware and software, but one project was designed specifically to require only free software, and be easily learned by any instructor for use with the entire class. This allows the project-based curriculum to be implemented by any university instructor or a college-in-high-school teacher, regardless of their specific engineering background. A detailed curriculum and project manual were created for the class to aid instructors. In this work, the curriculum framework and the seven initial projects are presented and discussed along with student feedback on learning outcomes and instructor observations.

Keywords

Introduction, engineering, curriculum, projects, 3D printing, robotics, laser, Arduino, LEGO

Introduction

Students pursuing a 4-year degree in engineering at Robert Morris University are required to take an Introduction to Engineering course to learn about the degree and profession. It is typically completed in their first semester of the program and has no prerequisite courses. The curriculum for the course had remained largely unchanged for over a decade and following a successful ABET re-accreditation the author proposed updating the curriculum to introduce more project-based learning in the course. Working with a group of three junior engineering students, the author followed the course during the Fall semester of 2022 week by week, reviewing the current content. For each week’s lesson, the author and students researched ideas for alternative instruction and drafted suggestions for more interactive learning in place of the traditional lectures. The practices of other schools were examined and discussed to see how they integrate projects into their introductory engineering content [1-6], and the literature reinforced the benefits of incorporating project work into the course. Textbook options were reviewed with the emphasis placed on smart books with guided reading and examination through quizzes to ensure students had done the pre-reading and came prepared for discussion, activities, or project work. Lecture content was reduced to make room for project workdays. Changes were made with consideration to the assessment of ABET outcomes selected by the engineering department for this course. The revised class was piloted in the Fall semester of 2023.

For the BS in Engineering, ABET has 7 outcomes which must be achieved to attain or retain accreditation. [7] The program must have documented student outcomes that support the program educational objectives. [8,9] Attainment of these outcomes prepares graduates to enter the professional practice of engineering. For Robert Morris University, the Introduction to Engineering ENGR1010 course is designated to assess outcomes 3, 4a, 4b and 7.

> 3. an ability to communicate effectively with a range of audiences.
>
> 4. (a) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, (b) consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
>
> 7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

The 4th outcome has been split into section (a) and (b) to address ethics separately from societal impacts of engineers. Any redesign would have to retain these aspects of the course with assessment metrics and rubrics adapted for the new format. Outcome 4 will be evaluated through the ethics lessons and ethics quizzes in the course. But for outcomes 3 and 7, a semester long engineering project can easily address both topics and provide opportunities to assess them. [10,11]

The Engineering Department also has established specific course objectives for Introduction to Engineering that are in alignment with topics typically covered in the course and in textbooks commonly used by engineering programs. These objectives include:

- Understand the roles and functions of a practicing engineer
- Distinguish between different engineering disciplines and sub-disciplines.
- Learn to solve engineering problems.
- Understand the process of engineering design.
- Practice technical communication for engineering projects.
- Understand the importance of teamwork for engineering.
- Expose students to the tools and technology available at their university.
- Understand what four years of engineering education involves.

Methods

In the reevaluation of the course with student input, the topical objectives were reviewed in the current textbook and several potential alternative textbooks. A change of textbook was recommended to use a unique digital compilation from McGraw Hill, called their "Best Collection" in their Connect platform. The publisher has several introductory engineering texts available and instructors can piece together the "best" textbook based on their classroom needs, chapter by chapter. A McGraw Hill SmartBook was assembled from "Foundations of Engineering" by Holtzapple and Reece, and "Engineering Fundamentals and Problem Solving" by Eide et al. with guided reading assignments. Required comprehension quizzes prior to class ensure most students arrive prepared for the day's discussion or activity. A full course calendar is shown in Table 1 laying out the order of the topics and the inclusion of time for a semester long project. The pre-class reading quizzes are used to shorten the lecture time in favor of interactive learning experiences.

Table 1 Semester course calendar with weekly topics. Class is scheduled twice per week, 75 minutes per meeting. Project workdays are on the second meeting of the week when scheduled as in bold.

Week #	Course Calendar: Introduction to Engineering
1	Introduction; Networking; Definition of Engineering; Engineering Disciplines
2	Engineering Roles/Functions
3	Engineering Majors; Preparing for 4 years of Engineering Education; Our Engineering Program, Facilities and Faculty, Traits of a successful engineer.
4	Graduate degrees, Engineering Credentials, and Societies, Engineering Career Statistics, **Project Day 1: Research**
5	Engineering Ethics, **Project Day 2: Explore**
6	Ethics Continued; Academic Integrity; Proper citation
7	Engineering Basics: Number, Units and Conversions. Computer Tools
8	Computer Tools and graphing data, **Project Day 3: Experiment**
9	Team Forming and Organization, Technical Communication, Midterm (Take Home), **Project Day 4: Teamwork and Communication**
10	Problem Solving **Project Day 5: Problem Solving**
11	Engineering Design **Project Day 6: Engineering Design**
12	Engineering Design Continued **Project Day 6: Engineering Design (Continued)**
13	Introduction to future courses, Life Long Learning, Continuing Education options, **Project Day 7: Schedule and Tasks**
14	Global engineering, **Open Project Workday**
15	Finals Week: Take home Exam. **Project presentations and demonstrations during the final exam time**.

In developing the initial project ideas, the goal was to have a range of projects at various levels of skill. Some students are entering engineering with minimal programming or CAD experience, but others have had courses in high school that would allow for more challenge and growth with the project, utilizing their existing experience. Also, the project design was cognizant of resources needed and the cost per class for implementation. Some projects required only computer access, while most require some hardware available to students. The projects were primarily designed to align with ABET outcomes 3 and 7. For outcome 7, students would be acquiring new knowledge by building/learning new hardware and software, and using it to complete an engineering task. Their ability to communicate effectively with a range of audiences would be measured by their design reports and their final presentation/demonstration to the class. The selected projects also had to align with a framework that corresponded to the lessons and project day built into the course calendar. Table 2 shows the basic framework applied to the projects, which is expanded in Appendix A. In the appendix, the assignments and deliverables from each day of the project are listed, as given to the students. Some days have instructions differentiated by project, others have general instructions that apply to all.

Table 2 Framework for Projects

Project Day	Task	Deliverable
Project Day 1: Research	Search for information about your project (manuals, tutorials, technical specifications, help documents, wikis, discussion boards, etc.	A short report that summarizes and documents the sources found, along with citation information.
Project Day 2: Explore	Set up hardware and software. Assemble devices and install all necessary software/drivers/apps. Make sure software talks to hardware correctly.	Turn in a document listing software and hardware accomplishments, with evidence in the form of pictures and/or code
Project Day 3: Experiment	Test the systems. Run calibrations, demos, examples. Play around and be creative.	Turn in a document with the accomplishments and evidence
Project Day 4: Teamwork and Communication	Establish team roles. Continue to work with the device/software. Create an introduction for the team and project. Brainstorm how you could use these resources to make something interesting or something that will solve a problem.	A set of slides introducing the team and project hardware/software, including ideas for using the device/software to solve a problem.
Project Day 5: Problem Solving	Explore problem solving using the device/software. Given a task from the instructor can you use the device/software to make something that satisfies a set of technical specifications?	A set of slides describing the problem given to the team and how it was solved using the device/software.
Project Day 6: Engineering Design	Agree on a challenge to be solved using the device/software with the instructor. Apply the engineering design process to brainstorm solutions, evaluate alternatives, create a prototype and verify performance.	Upload slides that document the team's process of conceptualize, synthesize and evaluation
Project Day 7: Schedule and Tasks	Continue working on the engineering design process. Create a Gantt chart for remaining tasks with deadlines and allocate personnel appropriately.	A document with summary of project to be completed by final presentation and schedule of tasks.
Open Project Day	Work on Project, Final Report and Final Presentation	Have final report and presentation ready for the final exam meeting time.
Final Project Presentations	Each team presents. Every person in the team needs a speaking role.	Submit Slides for final presentation and final report document.

Pilot Projects:

1. **Filament 3D Printer**: Assemble and use a Fused Deposition Modeling 3D printer to design and make a custom object to solve an engineering problem. CAD experience helpful. One FDM 3D printer kit needed per group. [12]
2. **Resin 3D Printer**: Assemble and use a Resin 3D printer to design and make a custom object to solve an engineering problem. CAD experience helpful. One Resin 3D printer needed per group. [13]
3. **Laser Marking System:** Assemble and use a laser marking system to design and make a custom marked object to meet a set of customer requirements. One laser marking kit needed per group. [14]
4. **EggBot:** Assemble and use a robot for marking round surfaces to design and make a custom marked object to meet a set of customer requirements. One EggBot kit needed per group. [15]

5. **LEGO Mindstorms Robotics:** Use a LEGO Mindstorms Kit (with motors, distance sensors, color sensor) to solve engineering problems with mechanical and software solutions. Intended for novice programmers. One LEGO Mindstorms Robotic Inventor kit needed per group. [16] Note: the Robotic Inventor Kit was prematurely discontinued but a similar platform is available as LEGO's Educational Spike Prime set. [17]
6. **Arduino Controlled LEGO Mindstorms Robotics**: Use an Arduino [19] with a Bricktronics shield [18] to connect to devices from LEGO Mindstorms NXT (motors, distance sensors, light/dark sensor, sound sensor, push button) [20] to solve engineering problems with mechanical and software solutions. Intended for experienced programmers. Need one Arduino Uno or Mega with the appropriate Bricktronics shield and components from a LEGO Mindstorms NXT set per group.
7. **LEGO Design Studio:** Use a CAD-type software to design, assemble and model a custom LEGO set and generate a set of instructions with bill of materials and pricing. One computer with access to free design software needed for each student in each group. [21]

The class conveniently had 28 students and most were able to have their first-choice project, with four students on each project. Every week that had project work also had deliverables from the group in the form of a memo, slides, or report. To keep the team on track, four team roles and responsibilities were defined and assigned: Engineering Manager, Compliance Engineer, Hardware Engineer and Software Engineer. Roles could rotate at the start of each project day or could be maintained throughout the semester. For this first iteration, we chose the latter. For a three-person team, there would be a combined hardware/software engineer. In a two-person team, the engineering manager and compliance engineer would each also divide the software or hardware duties.

- Engineering Manager - sets agenda for the class and out of class work, assigns tasks, keeps the group focused and progressing, settles team disputes.
- Compliance Engineer - monitors the lab document to make sure pertinent information is being captured, documents design decisions, captures and uploads images, drawings, sketches for lab report. Documents tasks and assignments, updates progress notes on those assignments, ensures that knowledge is retained from the progress made during each work session.
- Hardware Engineer - responsible for retrieving and storing the hardware for their project on work days, seeking out any needed tools or items, and leading construction or repairs.
- Software Engineer - responsible for having a laptop with working software on project days, and taking the lead in software related problems. *Note: Projects without hardware would have two Software Engineers.*

In large engineering programs with several sections, storage of these systems becomes an issue both during the semester and after the class ends. Reusability was a key consideration. For the 3D printers and the laser marking system, students were given the option of purchasing the kit for themselves. The group would use the student's kit for the semester and that student would keep it after the class concluded. One female student chose to purchase the laser marking system for her team and retained ownership after the semester ended. The two 3D printers were purchased with engineering club funds. Ownership reverted back to the clubs after the semester, which made them available to all engineering students. This was beneficial for the club because several first-semester students were already trained on new club equipment and could guide others. The EggBot robot was borrowed from an engineering club for use in the class. The LEGO sets were available as legacy items from outreach activities, summer camps, and club purchases. At Robert Morris University, we are fortunate to have lab space for several of our clubs to store their tools and equipment for student-driven research. There are many devices that can be borrowed for class projects with club permission, which enhances the educational return on investment for underutilized resources.

The LEGO design project only requires software and can be easily implemented at high schools or colleges with limited resources, since the Bricklink Studio software is free and there is no hardware needed other than a computer. It also serves as an introduction to CAD concepts since the engineering graphics course follows Introduction to Engineering in our curriculum. This design project was recommended to our college-in-high-school partners because it required the least resources. If a large number of kits for 3D printers or laser marking systems are purchased for one-time class use, the assembled systems could be donated to local schools after the semester. The students that assembled the systems and learned how to use them can host trainings for teachers. College-in-high-school partners who are offering Introduction to Engineering would be likely recipients. Grant funding could be pursued to cover the cost of the systems that would get used for one semester in college, then transferred to local secondary schools.

Finals week at Robert Morris University schedules a 2-hour block for a final exam. The final exam meeting time was allocated for final project presentations, so students were given a timed, online take-home exam on the course material to complete during finals week. Students had to submit a final report on their project, which was mainly a compilation of the weekly deliverable they had already created. They were provided with the following rubrics to help them prepare their report and presentation:

Final Report Outline and Scoring Rubric (70 pts total)

- Problem Statement (5 pts)
- Resources (5 pts)
- Brainstorming Solutions (5 pts)
- Evaluation Process for Ideas (10 pts)
- Initial Design with Sketch and Pictures of Build (10 pts)
- Evaluation of Design Performance and Modifications for Improvement (10 pts)
- Images of Final Design and Link to Video on YouTube of the Machine Running (10 pts)
- Recommendations for Improvements (5 pts)
- Document Team Roles, Responsibilities, and Member Contributions (10 pts)

Final Presentation and Demonstration Outline and Scoring Rubric (30 pts total)

- Design Process (5 pts)
- Design Evaluation and Interactive Improvements (5 pts)
- Working Demonstration (5 pts)
- Effective Language, Organization, and Delivery (10 pts)
- Question Handling (5 pts)

To assess the students' opinions on their engagement with the project and alignment with course content, a survey was taken after all the presentations. It was completed by 26 of the 28 students. The questions are as follows:

Select the appropriate answer.

1. Select your Project Group (drop down list of projects)
2. Which other projects would you have wanted to do? Select as many as you want that interest you, including your own if you would do it again (don't select your project if you didn't like it). You may choose all, some or none. (check boxes by each project)
3. Would you recommend that this project be done again for this class? (Yes, Yes with improvements, No)
4. How would you describe the difficulty of your project? (Very Difficult, Difficult, Just Right, Easy, Too Easy)

On a scale of 1 to 5, with five being best:

5. How much did you enjoy your project topic? (1-5)
6. How well did this project align with our lessons on Teamwork and Leadership? (1-5)
7. How well did this project align with our lessons on Engineering Communication? (1-5)
8. How well did this project align with our lessons on Engineering Design? (1-5)
9. How well did this project align with our lessons on Problem Solving? (1-5)

Open-ended response:

10. What specifically did you like about your project?
11. What could be improved about your project for next time this class is taught?

Results

The student feedback was valuable in assessing the utility and enjoyability of the projects. The general interest poll can be seen in Figure 1, indicating which projects interested students. Students could vote for multiple projects including their own. No project was universally liked by all students and no project was completely rejected. The most popular projects were 3D printing and laser marking. This high interest level makes them attractive prospects. When done in the future, the price of the systems used should be kept reasonable to encourage students to buy their own printer or laser system for the project; they would own a piece of technology to tinker with as extra-curricular enrichment. The resin printer was much more expensive than the filament printer, and presented more safety challenges. The filament printer was preferable from an instructor viewpoint.

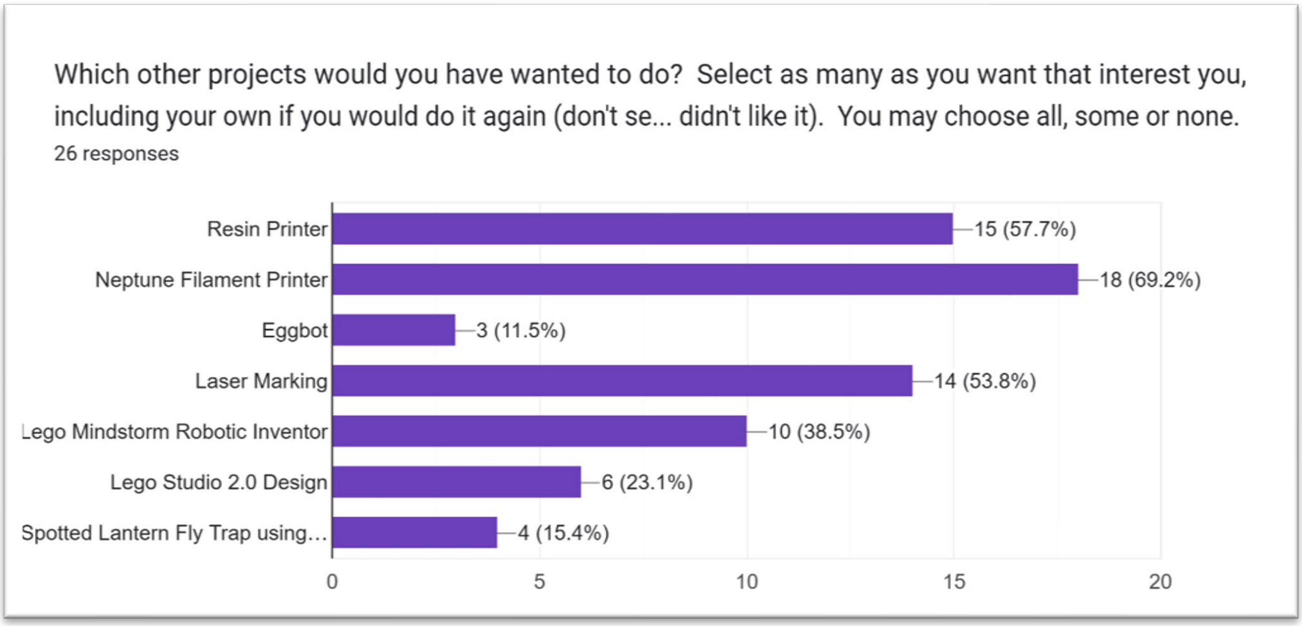

Figure 1. Popularity of project AFTER finale presentations to the class. The top three projects were the 3D printers and the laser marking system.

In Figure 2 we see that all of the students recommend that their project be used again in future semesters, with 70% suggesting it be conducted the same way, and 30% recommending some modifications to their project to improve the experience. Not a single student recommended a project be removed from consideration. In Figure 3, the students' opinions on the difficulty are encouraging, with 2/3 of them believing their project was appropriately challenging. The remaining students are closely split between being too difficult and too easy, which is to be expected. These margins could probably be decreased with more informed decision making into the projects by the students. If the instructor provides greater visibility into the difficulty level of each project, students can choose the level that best meets their expectations and skill level. This would encourage novices to choose easier projects and students with more technical experience can be challenged commensurate with their abilities. It is reassuring to also know that no students found the projects extremely easy or extremely difficult. In Figure 4 we see that nearly 75% of students enjoyed their project with 6 students neutral on their project and one student who had a low level of enjoyment. In Table 3, the next four questions inquire about the students' ability to connect the course material with the project. Hopefully the students saw the relevance to teamwork/leadership, communication, engineering design and engineering problem solving. These topics are covered in the reading and class discussion then also applied through the project. All four had average scores above 4.2 on a 5-point scale for the alignment of the project and course topic. It is encouraging that the project-based approach is complimenting the course material and reinforcing it through practical application.

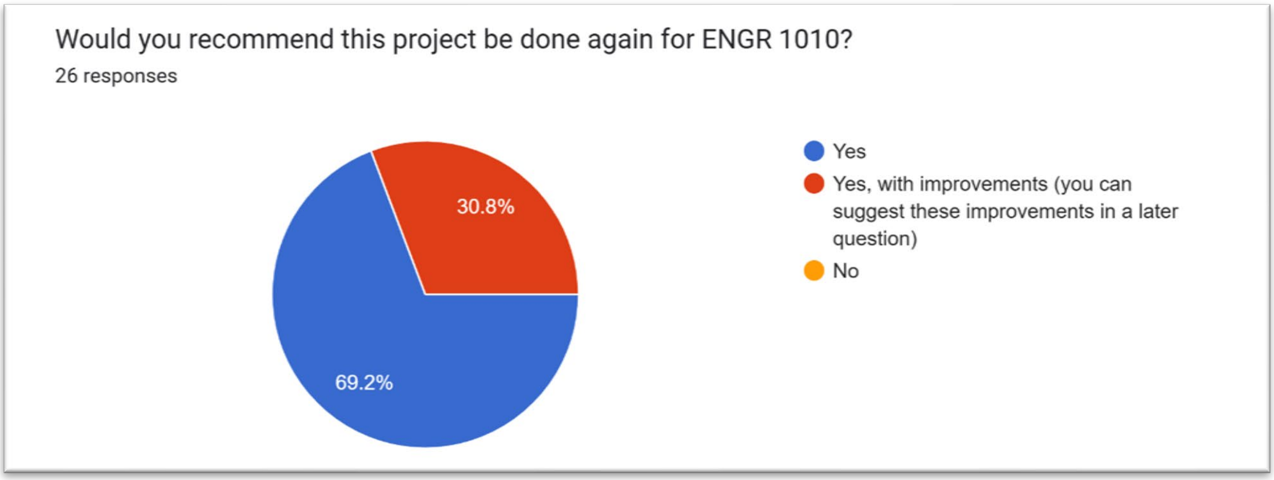

Figure 2 Assessing student opinions on the viability of their project for future classes.

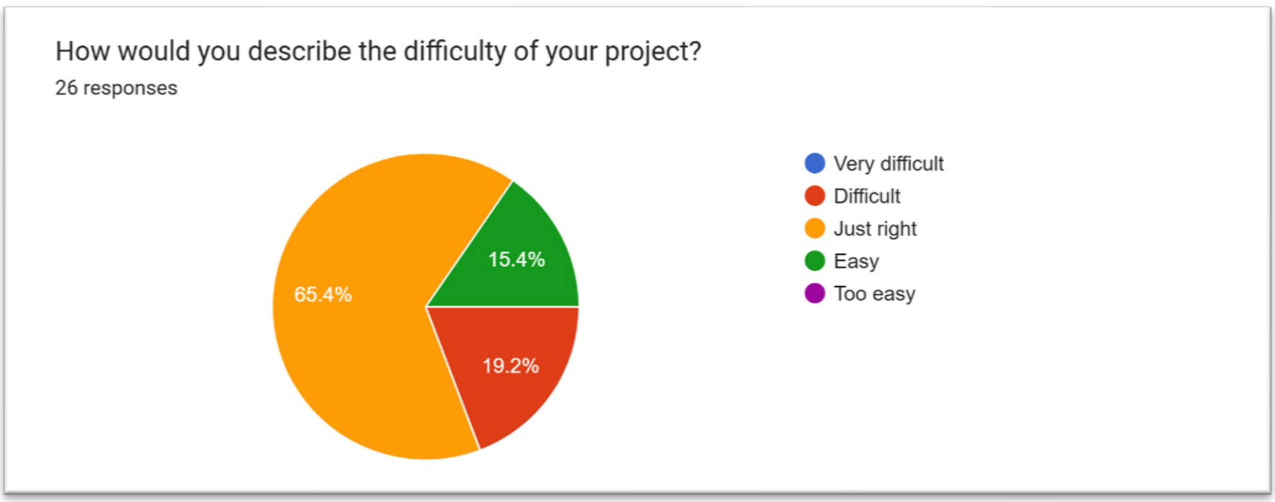

Figure 3 Student assessment of the difficulty of their project

Table 3 Table of responses for questions 5-9 with average response value

Measurement of Attribute, (5 being best)	**1**	**2**	**3**	**4**	**5**	**Average**
Enjoyment Level for your Project	0	1	6	11	8	4.0
Project alignment with Teamwork and Leadership	0	0	4	12	10	4.23
Project alignment with Engineering Communication	0	0	5	9	12	4.27
Project alignment with Engineering Design	0	1	2	9	14	4.38
Project alignment with Problem Solving	0	0	6	6	14	4.31

The final two survey questions responses for student feedback about what they liked and what could be improved are shown in Appendix B and separated out by each project. There is a table for each of the seven projects with detailed descriptions including the justification for each, the specific hardware and software used, costs, tasks, timelines, and pictures. Overall the students' comments show that the projects were engaging with several commenting on the ability to be creative when problem solving. There was also beneficial constructive criticism asking for more organization and structure to some of the projects (some students struggled with the open-ended problem solving). Several asked for more time. One suggested moving up the engineering design lesson, which they felt would have been helpful during the problem-solving step. These student suggestions will be considered and many will be incorporated when these projects are used again in the future.

Discussion

The results show that all seven projects are viable for future use by the author or other instructors. Students endorse them all being used again. The difficulty level was near the target for a first semester engineering class, with only a few students thinking it was too easy or too hard. The students overwhelmingly enjoyed the projects. They successfully connected the project's activities in alignment with lesson content on teamwork/leadership, communication, problem solving and design. The individual feedback on each project found in Appendix B will be helpful in revising these projects for a future semester. Also, with future offerings we hope to encourage more students to buy the devices for their project if they are reasonably priced. This has the threefold benefit of reducing costs to the department to supply the equipment, prevents the need to store the device after the semester, and it makes it more accessible for student use to grow their skill set with the system.

The instructor observed that students tended to become more engaged with class during the project time. The smaller groups and differentiated project required students to apply themselves to their specific challenges and all of the work product was unique to each group. When classes do identical lab activities, there is a concern about students sharing data or getting results from another group instead of doing the work for themselves; but that was not possible with each group having a unique project. Unfortunately, offering seven different projects simultaneous was a strain for one instructor. If multiple groups needed assistance simultaneously, the instructor had to prioritize and often responded to the simplest problems first, to keep as many groups progressing as possible. Occasionally, the engineering department's lab engineer was able to assist and lend expertise to students. The author would not recommend offering so many different projects at once, ideally limiting the options to 2 or 3 with several groups doing the same project with their own device. Some of the projects were resource limited and could not be scaled up to more than a few groups at once. If multiple groups worked on the same project in one class, the instructor could benefit from peer assistance for problem solving. For widespread adoption to several section there are many logistical issues to be addressed, including space for all of the projects during the semester.

Since each instructor differs on experience and interests, a general template for this framework similar to Table 2 was included in the curriculum document created for the course to assist with developing semester long projects. With the new Smart Text reducing lecture time, an alternative approach to long term projects could be to insert more class activities and several smaller projects. It is at the instructor's discretion to decide how they want to engage the students.

For Fall 2024, the author was not assigned any sections of Introduction to Engineering. The curriculum design document was shared with the two instructors teaching 3 sections of the course. They adopted the new textbook with guided reading and created more time for project work. They choose to do two shorter projects rather than one semester long project. The LEGO Studio design software was introduced and students did a small design project creating their names or initials out of LEGO. The other project was a gear ratio project. Students were given an assortment of 3D printed gears with a motor, metal base plate, and tachometer. The students measured the power input and output and verified the configuration with a hand calculation for gear ratios. Each project only occupied a week of class time (two 75-minute periods). Written feedback on the shortened projects indicated:

- "I feel like the Engineering Design Gear Train activity was interesting and informative. It took something we learned about theoretically and allowed us to get hands on experience and visuals on the topic."
- "The single most interesting group activity was the gear train activity. More hands-on labs like that would be nice."
- "My personal favorite type of group activities are ones that allow students to be hands-on. Therefore, the first most interesting or informative group activity is the Week 14 Engineering Design Gear Train. Then, I would say that my second favorite was the Brainstorming from Week 12. I do also like the LEGO activities, but I wish we could have done more with those."
- "Week 11 LEGO Brickworks Studio Design, I think this is a good hand on activity that can be personalized. It is fun and easy for peoples first time experimenting with a software. Week 14 Engineering Design Gear Train, this was another nice hands-on activity that was informative."

Those instructors observed that the students in Fall 2024 enjoyed the new gear train activity and the short LEGO design activity. Multiple students requested more hands-on labs and more time with those activities. From the comments it appears that returning to the semester long projects used in Fall 2023 would be preferable to both have more hands-on experience and more depth with the projects.

For ABET assessment of outcomes 3 and 7, the projects gave opportunities for both individual and group assessment. For outcome 3 (related to communication), we can assess the group's ability to communicate through the written final project report and the power point presentation. But on an individual level, since each student is required to participate in the presentation, a scoring can be made on the student's technical content, effective language, organization, delivery and how they handle questions. For outcome 7 (relating to acquiring and applying new knowledge), we can assess the technical content of their presentation and the demonstration portion of the presentation. Also, in the final report students include individual contributions and several projects have tasks where students work independently on their own design before collaborating with the group. Since this was a pilot effort for the project, and several projects evolved over the course of the semester, the assessment items and rubrics are still in development. But based on examples from the literature and the student work products generated, the author is confident that the projects can effectively be assessed for ABET outcomes 3 and 7.

Conclusion and Future Work

An Introduction to Engineering course for a 4-year Engineering BS program at Robert Morris University was redesigned successfully to reduce the amount of lecture time and replace it with hands-on learning experiences and in-class activities. Seven semester-long projects were piloted and all proved to be successful and popular enough to be offered again in the future. Students had overall positive reviews and also provided constructive feedback for improvement.

The projects also produced ample material for assessment of ABET outcomes 3 and 7 relating to communication and acquiring/applying new knowledge. The projects could be expanded to include an ethical component to contribute to the assessment of ABET outcome 4. In the next offering of the class, shorter projects were used instead and students feedback showed positive engagement with the activities, but a desire for longer and more in-depth project work. With expanded future offerings we hope to encourage more students to purchase and keep the project devices. An alternative would be to seek out grants to fund the purchase of the kits which would ultimately be donated as assembled devices to local schools at the end of the semester. It would be interesting to revisit the student participants as seniors to learn if they built upon the work they did in their first semester for subsequent class projects or extracurricular activities.

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Appendix A: Daily Project Curriculum in the Framework of the Course Content

Project Day	Task	Deliverable
Project Day 1: Research	In your project group, create a google doc and work together to locate as much information as you can find: • reference materials • instructions • tutorials • hardware descriptions • software/code • video guides • service/repair info • and other relevant information you might need for your project.	Capture the link and write a few sentences about each source you find to summarize what it contains to help you use your device, try to keep your links organized by topic. Some links may be specific (like to your model of 3D printer) other may be general (like an introduction to 3D printing). Try to keep the sources as relevant to the model or software you are using as possible. Document your findings, download the google doc and submit before next class. One submission per group. This could be formalized to a memo, short report, or annotated bibliography of the information gathered.
Project Day 2: Explore	Filament Printer, Resin Printer, Laser Marking System and EggBot: Review manual and setup instructions. Unpack and Assemble. Install Software on student laptops. Try sending basic commands to it. LEGO Mindstorms Robotic Inventor: Install software on your laptops or run off lab computer. Build "Tricky" robot and explore the software for motor and sensor control. Arduino and LEGO: Install software on your laptops or run on lab computer. Explore the Arduino software for motor and sensor control. LEGO Studio Design: Install software on your laptops or run on lab computer. Practice building with the software. Learn how to use the collaborative mode so you can work on the same design at once. Build something together.	Turn in a word document with the following: • Which group members were present • A description of what your group accomplished today • Which students have laptops that are set up to run software you are using • Pictures of the hardware you worked with today • Screenshots of any code or designs generated.
Project Day 3: Experiment	Filament Printer: Level the bed of the Printer. Use a thin metal business card for measuring gap Resin Printer: Review wash and cure station instruction Unpack and Assemble wash and cure station. Laser Marking: Test it on different materials. Design something original to mark. EggBot: Set to hold ping pong balls. Test the commands to control the pen. Find or set up a template for the markable range on the ball. Create some test marks. LEGO Mindstorms: build/test accessories to become familiar with the interface components like distance and color sensor with motor functions. Arduino and LEGO: Use the two boards with shields to work in pairs to interface with components: Color Sensor, Motor, button, distance sensor. LEGO Studio Design: In groups of 2 practice with the collaborative function to work together to produce a small LEGO creation. Generate an instruction book and list of parts for each of the 2 small sets.	Turn in a word document with the following: • Which group members were present • A description of what your group accomplished today • Pictures of the hardware you worked with today • Screenshots of any code or designs generated.

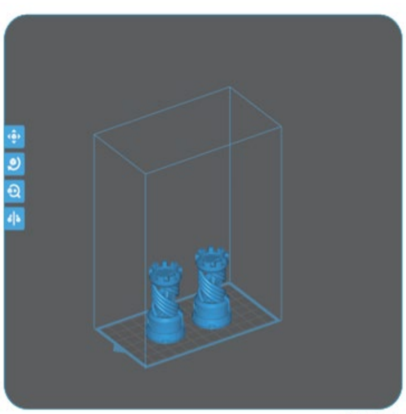
Project Day 4: Teamwork and Communication	This week we talked about Leadership, Teamwork and Technical Communication. Your task is to create a PowerPoint or google slide show. Your audience is your fellow classmates. You will create a 6 slide presentation to introduce your team and your project Engineering Manager: the leader who keeps the team organized and track during project work days, delegates/coordinates tasks Compliance Engineer: responsible for reviewing all submissions for completeness and alignment with task objectives, ensures documents are submitted by deadlines. Hardware Engineer: Responsible for retrieving and storing the hardware for your project on work days, and seeking out any needed tools or items. Software Engineer: Responsible for having a laptop with working software on project days, and taking the lead in software related problems (LEGO Studio 2.0 team will have two of these and no hardware engineer) Questions: Printers, EggBot, Laser, what would you like to create? LEGO projects, what will your design/build task and what preliminary ideas do you have?	Slide 1: Team name and Project Members, Roles for each member Slide 2: Introduce your project - what technology are you working with an what can it do? Slide 3: Details about the hardware for your project. (LEGO Studio group describe computer requirements for the software) Slide 4 Details about the software for your project. Use images and text to describe the interface and capabilities. Slide 5. Progress to date in learning/operating your system. Slide 6. Specific ideas of what you would like to do with it this semester
Project Day 5: Problem Solving	*At end of first meeting this week:* Based on our discussion of Analytical and Creative Problem Solving this week, add the following slides to deck for homework by Thursday's class. I will review them with each group while you work with your hardware/software Thursday. *Second meeting this week*: continue working with your hardware/software in class, make sure you understand how to operate it and do practice runs or prepare software files that could contribute to your final project.	1-3 slides: What types of problems can be solved using your project hardware/software? Show examples you have found and cite your sources. 1 slide: Definite your problem statement. What problem are you trying to solve, or what are you trying to accomplish with your project. 1 slide: progress report. what have you accomplished in the first 5 days of working with your project?
Project Day 6: Engineering Design	**Conceptualize:** (3 possible solutions to your problem) •Generate ideas or concepts that could offer reasonable solutions to your problem –Identify the components of the system –Analyze the merit of the developed concepts •Evaluate alternatives **Synthesize** (describe details pertinent to implementation) •At this point you begin to consider details (may not be pertinent to all projects) –Perform calculations –Run computer models –Narrow down the type of materials to be used –Size the components of the system •Answer questions about fabrication **Evaluation:** •Analyze the problem in more detail •Identify critical design parameters and consider their influence in your final design •Identify the best solution from alternatives	Over the last several project days you have started the engineering design process by recognizing a need for a project/service, defining the problem, and collecting information and generating ideas for applications. Today we will conceptualize synthesize and evaluate. Take your specific problem statement from last week and devise specific solutions to it, being as detailed as possible with design ideas. Upload your conceptualize, synthesize and evaluation slides.

Project Day 7: Schedule and Tasks	You have one class this week and one class next week to work on your project. You will have to meet outside of class if you need more time to finish your project. Work on your project today. By the end of class today submit 3 slides	1. Summary of project to be completed by final presentation 2. Tasks remaining to complete project (build/make/test/refine, create presentation) 3. A schedule of when the tasks will be accomplished and who will be doing them. (can be combined with previous slide, to have tasks, dates and people)
Open Project Day	Work on Project, Final Report and Final Presentation	Have final report and presentation ready for the final exam meeting time.
Final Project Presentations	Each team presents. Every person in the team needs a speaking role.	Submit Slides for final presentation and final report document.

Appendix B: Detailed Project Descriptions

Project Name:	Filament 3D Printer
Reason for Selection:	3D printers are a common tool for modern engineers and hobbyists. The technology allows projects to be scaled to the experience of the students.
Hardware & Software	ELEGOO Neptune 3 Pro with Cura Slicing Software (https://us.eLEGOo.com/products/eLEGOo-neptune-3-pro-fdm-3d-printer-225x225x280mm)
Cost and Reusability	$159.99 (as of Jan 2025) Systems can be disassembled and stored back in original box until next semester. Filament is relatively inexpensive and consumable.
Specific Tasks:	Novices will master printing from existing files, then attempt to merge two existing designs into a new design. Experienced users will design and create a variation or customization on an everyday object. Students chose to create a dinosaur with duck feet.
Project Plan Timeline:	1-2 classes of assembling the 3D printer 1-2 classes of refining the print and making tiny test prints. 1-2 classes of learning about slicer programs, printer code and CAD 1-2 classes of designing and printing an original object to solve and engineering challenge. have size limitations for quick prints. 2-4 classes of design and print of final project following engineering design process, potentially using other printers
What specifically did you like about this project? (student responses)	• I loved the range of what we could make, since we could print any basic parts or structures • "I liked working with the 3D printer and getting more hands on experience. It was really enjoyable to work on and helped me learn more to take back to my own 3D printer. I liked our original idea but even though it didn't work out I really liked how we pivoted and had fun with the process. • I liked having the ability to print what I wanted and attempting different styles of prints. The free ability to change what we wanted to work on and the problem statement wasn't cemented and was available to be switched around. • I liked the problem solving process. We had an initial plan and that plan didn't work out and we had to think quickly to come up with another idea.
What could be improved about this Project? (student responses)	• I think more project days or a schedule of specific project days and more structure for teams to follow when it comes to expectations and weekly submissions. • I think it was good. I liked how independent it was. We didn't spend a lot of time talking about it. We just got to work and worked on the project.
  Photo Credit: https://us.eLEGOo.com/cdn/shop/products/ELEGOO-Neptune-3-Pro-2_160x_crop_center.jpg?v=1710302200	

Project Name:	Resin 3D printer
Reason for Selection:	A new resin printer was available for class use. There are more safety considerations and post-processing of the print
Hardware & Software	ELEGOO Resin 3D Printer Mars 2 Pro Mono MSLA 3D Printer UV Photocuring LCD Resin 3D Printer with 6.08 inch 2K Monochrome LCD, Printing Size, 5.1x3.1x6.3inch. Software: CHITUBOX 64 (https://a.co/d/jkhhNnG) ELEGOO Mercury X Bundle with Separate Wash Station and Cure Station for Large Resin 3D Printed Models (https://a.co/d/hGahSVG)
Cost and Reusability	$300 for the printer (currently unavailable) and $160 for the wash and cure station. Future classes would use the assembled printer and curing station. Resin fluid is more costly than filament for an FDM printer.
Specific Tasks:	Novices will master printing from existing files, then attempt to merge two existing designs into a new design. Experienced users will design and create a variation or customization on an everyday object. Students chose to design an create a dental insert
Project Plan Timeline:	1-2 classes of assembling the 3D printer 1-2 classes of refining the print and making tiny test prints. 1-2 classes of learning about slicer programs, printer code and CAD 1-2 classes of designing and printing an original object to solve and engineering challenge. have size limitations for quick prints. 2-4 classes of design and print of final project following engineering design process, potentially using other printers
What specifically did you like about this project? (student responses)	• Everything • Being able to come up with multiple fun ideas of what to make • Learning how to use the printer and the software. • The freeness of being able to create whatever you desired or that your group chose.
What could be improved about this Project? (student responses)	• More knowledge about printer • Incorporating more of a design yourself rather than the just allowing a design to be selected and printed. It would incorporate more of a learning how to create a structure as well as using the device.



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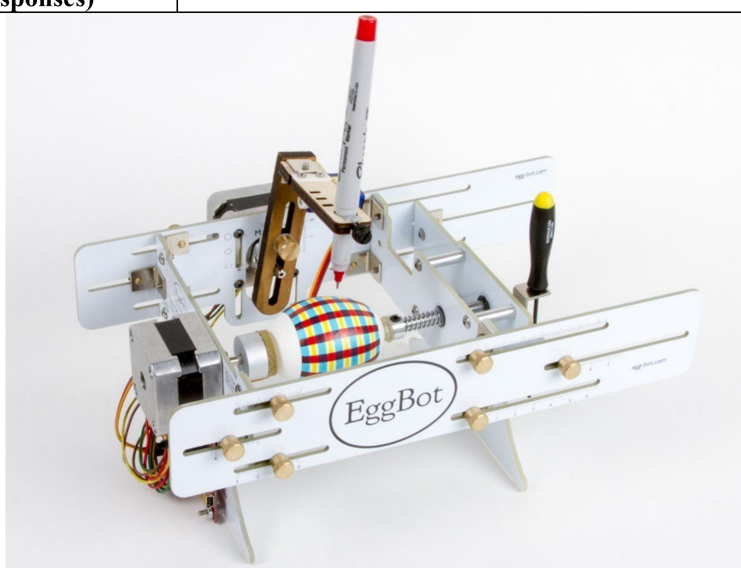
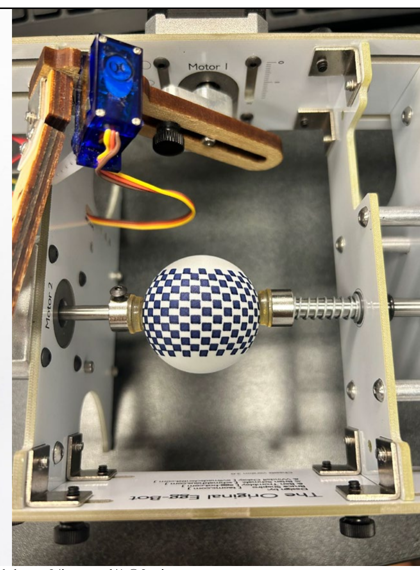
Project Name:	Laser Marking System
Reason for Selection:	Laser Marking systems can be low cost and teach many manufacturing principals through product design and testing.
Hardware & Software	TTS-10 10W Laser Engraver Machine Laser Cutter Laser Cutting Engraving Machine Engraving Tool. Software: Laser GRBL. (https://a.co/d/3dH8qxe)
Cost and Reusability	Purchased for $150 in 2023, currently available for $240 an Amazon or $150 on Temu. System can be disassembled, repacked and reused each semester.
Specific Tasks:	Students tested marking and cutting various materials. Designed and laser engraved metal business cards with QR codes
Project Plan Timeline:	1-2 classes of assembling the laser marking system 1-2 classes of refining the marking process and making tiny test marks. 1-2 classes of learning about image processing programs, Inkscape, and vector images 1-2 classes of designing and marking an original object to solve and engineering challenge. test different materials. 2-4 classes of design and mark final project following engineering design process, potentially adapting mark to be used on other marking systems (IR Fiber and CO2) with different materials. Business card design or other customized product. make tooling for the item to be marked.
What specifically did you like about this project? (student responses)	• We got to build a real working thing and had the opportunity to take it home. • Using the software and problem solving • I liked the creativity that everyone was able to have with the project. You could make a final project that you were actually interested in. • The space for creativity
What could be improved about this Project? (student responses)	• Nothing • Create a specific challenge to complete • I feel like there could be more that we could have done and there could be more to be graded on. Like using multiple Bases like cardboard, paper, and metal. • maybe have more structure to the projects.

Photo credit: https://m.media-amazon.com/images/I/719fSMnsL2L.jpg

Project Name:	EggBot
Reason for Selection:	EggBot can be quickly learned and the mechanics for printing on a curved surface are readily apparent. Students have to consider how 2D images maps onto 3D curved surfaces.
Hardware & Software	The Original EggBot: Deluxe Edition with Inkscape software (https://inkscape.org/) using EggBot plugins.
Cost and Reusability	Originally purchased for $200. Currently available for $285. Inkscape software is freeware. (https://a.co/d/4ckrbJS). EggBot can be disassembled and rebuilt each semester. Eggs are not practical for class, but ping pong balls can small and inexpensive as a consumable.
Specific Tasks:	Students learned the software and created custom designs for ping pong balls with our university logos or student organization names
Project Plan Timeline:	1-2 classes of assembling EggBot, Install Software and plugins and show connectivity. 1-2 classes using the hardware/software to make basic patterns on ping pong balls 1-2 classes of learning how to make continuous patterns across a completely round object and create layers with different colors 1-2 classes of a demonstrate custom designs marked on pink pong balls. 2-4 classes of engineering design process to design and mark a pattern to the instructor's specifications.
What specifically did you like about this project? (student responses)	• I liked building the project. • I liked being creative, but that's about it. • That I was the Software Engineer who operated the EggBot • I liked the customizable outcome of the product.
What could be improved about this Project? (student responses)	• More time spent for the project. • I think there was too much time to do the project, my groups machine was extremely easy to use and operate, so 90 percent of the time, we were just sitting around staring. • We could be a little more organized.





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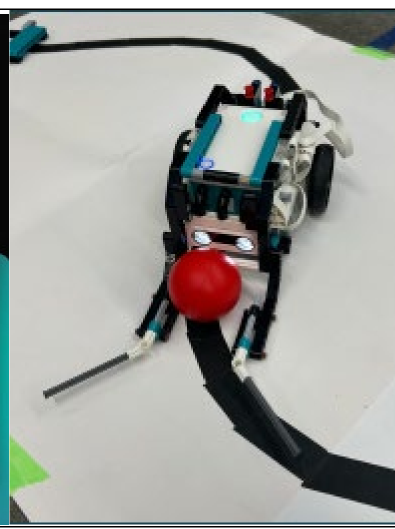
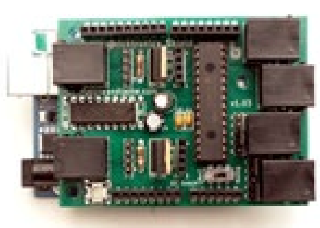
Project Name:	LEGO Mindstorms Robotics
Reason for Selection:	Students are typically familiar with the LEGO platform which make construction and application of design principals easier than a more complex construction system. The software interface is based on the language Scratch, which is easy for students without programming experience to learn.
Hardware & Software	LEGO Mindstorms Robotics Inventor Set #51515
Cost and Reusability	LEGO Set #51515 was $350 but has been discontinued. As an alternative, use LEGO Education SPIKE Essential Set #45345 $330 (https://education.LEGO.com/en-us/products/LEGO-education-spike-essential-set/45345/). These sets can be used every semester.
Specific Tasks:	Programming robot to find and pick up a ball, navigate a path using the color sensor, and shoot the ball into a basket that launches rockets when the point is scored.
Project Plan Timeline:	1-2 classes researching spotted lantern flies and available traps 1-2 classes of brainstorming and designing an improved, original spotted lantern fly trap. Identify materials to collect 1-2 build 1 prototypes with the materials you collect. (consider metal, wood, 3D print etc) 1-2 build a second prototype and seek permission for placement on or off campus. Deploy them in close proximity for comparison 2-4 collect prototypes and analyze/assess effectiveness. Propose final design changes. Make a final version of the trap.
What specifically did you like about this project? (student responses)	• I liked how we had to problem solve and improvise to make everything work. We had to add many things that were made out of LEGO to try and make the build more of a success. • Room to expand and attempt new tasks • Brainstorming different ideas for our project
What could be improved about this Project? (student responses)	• I think the laser and 3d printing are the most beneficial in terms of experience, challenge, problem solving, and overall learning. • More time to try and solve the problems we had. • Nothing
  	

Project Name:	Arduino Controlled LEGO Mindstorms Robotics
Reason for Selection:	Older LEGO Robotics Systems like the Mindstorms NXT (2006-2013) have components that often outlive the control hardware and software. Arduino with a custom controller shield can extend the life of these sets and also increase the complexity of the system for college level work.
Hardware & Software	Parts from 9797 Mindstorms Education Base Set (retired). Arduino Uno microcontroller Bricktronics Shield for Arduino Uno. The standard free Arduino IDE interface was used.
Cost and Reusability	Bricktronics Shield $44 (https://store.wayneandlayne.com/products/bricktronics-shield-kit). Arduino Uno R3 $28 (https://a.co/d/d4q6CEp) LEGO set #9797 can be found on eBay and other resale sites for a range of prices. All of these items are reusable in future semesters.
Specific Tasks:	Using LEGO and Arduino, create a trap for the invasive insect, the Spotted Lantern Fly
Project Plan Timeline:	1-2 classes of learning Arduino code and shield interface, build LEGO housing unit for control module and battery pack. 1-2 classes of demonstrating the motor. 1-2 classes to demonstrate sensors controlled through the shield 1-2 classes preliminary design, build and test a trap 2-4 classes of final design and building of final project following engineering design process
What specifically did you like about this project? (student responses)	• I like how everyone contributed in the project and I like making new things. • Had the opportunity to set objectives early and felt they were just right in terms of difficulty, but still had some modality to adjust out scope and objectives if things needed; made things still fell worthwhile without being stressful. • Building
What could be improved about this Project? (student responses)	• If possible, get the Engineering Design lesson earlier in the project, we accidentally made some design decisions before we were taught the conceptualization and synthesis of options, and had to step back redo some concepts.



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Project Name:	LEGO Design Studio
Reason for Selection:	For students that have never done CAD design, this software is an introduction to CAD concepts but using the familiar building medium of LEGO. This is the most scalable project option since there is no hardware needed and the software is free. Students would have the option of purchasing the bricks for their design and making a physical model.
Hardware & Software	Bricklink's LEGO Design Studio (https://www.bricklink.com/v3/studio/download.page)
Cost and Reusability	No cost. Software is free. Access to a computer with the software for each student is required.
Specific Tasks:	Design a LEGO set unique to our university and include a mini figure of the instructor. Include build instructions, bill of materials and cost information for purchasing pieces.
Project Plan Timeline:	1-2 classes of watching tutorials and experimenting with the software 1-2 classes make a simple 3D LEGO design 1-2 classes for creating instruction books and bill of materials for designs 1-2 classes learn how to create custom mini figures and labels for pieces 2-4 classes of final design project
What specifically did you like about this project? (student responses)	• I liked being able to build LEGOs while learning certain engineering principals. It creates a fun way to learn. • I liked that the project involved LEGO, despite the software challenges I still enjoyed the conceptual side of it. • I liked the software it was fun to learn and use • I enjoyed being able to make anything out of LEGOs without having to do it in person, and it was without cost.
What could be improved about this Project? (student responses)	• Maybe spending more in class time on learning the software instead of the presentation. Would be able to create better, more detailed work, and would be able to get more out of it. • The software was extremely difficult to work with, we also found ourselves for the majority of the first work sections doing solely the presentation and brainstorming as opposed to working on the project. • Just a little more clear cause it took a while to learn the software, it was fun but took a while • I think the slideshow presentations took up a lot of time, and time kind of flew by. Maybe a clearer timeline of what needs to be completed for each project as the weeks go along might be helpful?