Engaging First-Year Students with a Hands-On Course using Student-Driven Projects

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Abstract

This evidence-based practice paper describes the development of a second-semester project-based learning course for freshmen in the College of Science and Engineering at the University of Minnesota, Twin Cities. The course grew from a collegiate effort to develop community and equip freshmen with the knowledge, experiences and skills they need to be successful and remain engaged in science and engineering. It builds on a first-semester required course for freshmen that addresses vital topics such as choosing a major, becoming engaged in activities, understanding diversity and developing a resume. The topic of this paper is a second semester, hands-on, elective project-based learning course that is designed to give freshmen the chance to explore their interests and experience the satisfaction of completing a challenging, student-driven team project.

Background

First-year project-based learning (PBL) experiences are an important and common occurrence at many universities today [1]-[3]. This paper addresses PBL as defined by Dym *et al.* [4], where projects enhance specific learning objectives and are differentiated from project-oriented curricula [5],[6] where specific learning topics are driven by a large project. Many currently implemented first-year programs have highly structured projects [2],[7]. While engaging, these do not truly serve the need for science and engineering students to apply creativity and exercise the design process as described by Dym *et al.* [4]. Newer technologies, including 3D printing and microcontrollers, offer the possibility of creative, unique team projects; however, project-based courses using these technologies are frequently targeted at honors and senior level students [3,8,9]. Interdisciplinary team-oriented projects enhance engagement and retention [10], and are, at least, equally effective at engaging both male and female populations of students [5]. This paper describes a course that brings exciting, new technologies and skills to a first-year PBL course with the aim of enhancing engagement and providing an authentic multidisciplinary, creative design process that includes student-proposed projects.

At the University of Minnesota, Twin Cities, a large R1 research institution, an effort to develop engagement, community and connections between freshmen and faculty began with the development of a required, one-credit first semester course. This course covers topics important to all new university students – selecting a major, exploring extracurricular opportunities, writing a resume, appreciating diversity and understanding ethics – and for three years it was expanded to add a faculty co-instructor, who led a small group project centered around a common project challenge or theme. For example, one year the groups built cardboard sleds that met a set of specifications, and a competition was held at the end of the semester. While this effort was a success in giving students a chance to work on a project and get to know a faculty member in a smaller class setting (40 students), it was a challenge to fit this activity into a one-credit class. Therefore, faculty-led projects were eliminated from this first semester class, and an elective, two-credit project-based learning course was developed as a second semester follow-on to the first semester class, beginning in the 2016/2017 academic year.

The principal aim for this project-based learning course is to provide freshmen the opportunity not only to complete a hands-on project but also to learn and develop real skills that would benefit them in future coursework, student group activities, research and internships. Moreover, the course was also designed to meet in small (24 students) sections to allow engagement between students, and between the faculty instructor and the students. Lastly, the project focus affords students the opportunity to gain experience with the design process, teamwork, and communication. In this paper, the course is described in detail along with examples, results, impact and future plans.

Course Organization and Development

An important first consideration in the development of this project-based learning course was the types of projects or project themes that would be offered and the skills that students would learn as they carried out the projects. The project themes would need to be accessible (*i.e.*, the students would need to be able to acquire the skills to make progress in their projects quickly), applicable (*i.e.*, students with interests across a broad range of science and engineering would need to find the projects connected to their academic and career goals), and practical in terms of space, equipment and supplies required. Based on these considerations, the first offering of the course (Spring 2017) had a theme of 3D printing and included skills of computer-aided design (CAD) as well as 3D printing. The College of Science and Engineering is home to the Anderson Student Innovation Labs, a large hands-on learning space with 3D printers, a wide variety of tools, and workbenches. The College also has several well-equipped computer labs that can be used for classes. These sites were ideal not only for students to work on their project, but also for building individual skills, as discussed below. The topic of 3D Printing has broad appeal and applications across science and engineering disciplines and is becoming popular in a variety of contexts in education [11-14]. In the second offering of the course (Spring 2018), an additional theme that combined microcontrollers with 3D printing was introduced. With this second theme, students not only learned the fundamentals of CAD and 3D printing, but they were also introduced to microcontrollers and the code that is needed to operate them. Similar to 3D printing, microcontrollers and the internet of things is a topic that engineering and science students are curious about [15] and that has far-reaching applications. These two themes are also currently underway in Spring 2019.

The second consideration was how to make the course appealing to both students and potential faculty instructors. The themes and skills factor very strongly into the appeal for both students and faculty. For students, the course offers the opportunity to learn new skills that are helpful as they go through their college career and beyond, and to get involved with exciting new technologies. For faculty, the course also provides the chance to dig into an interesting topic that may not be familiar and learn along with the students. These new skills can then be used in their teaching of other courses as well as in their research. Another factor in making the course appealing is the two-phased design of the course - individual skill building and team projects. The structure is welcoming to novices. Lastly, for both students and faculty, having the course meet one time per week was ideal to allow it to fit into their schedules. Therefore each section of the course has one, two-hour class meeting per week.

The course is organized into two phases. In the first phase, students learn fundamental skills as individuals through a series of hands-on activities in class and assignments to be completed outside of class. There are no lectures. The purpose of the first phase is to make sure that all students learn and develop their skills before beginning the project. Then, in the second phase, the emphasis shifts to the team project. The week-by-week plan for the two themes of the course to-date are shown in Figure 1. The first five or six class sessions focus on individual learning activities in CAD, 3D printing and microcontrollers, depending on the section theme. Then the emphasis shifts to the project phase of the course. The content of these two phases is described in the next section.

3D Printing

Week	Class Activity/Topic	Assignment Due
1	Introduction, tours, SolidWorks I	none
2	SolidWorks II	SolidWorks I
3	3D Printing I Team project introduction	SolidWorks II
4	SolidWorks III	3D Printing I Project idea submission
5	3D Printing II	SolidWorks III
6	Team Meeting, Brainstorming, Project development	3D Printing II
7	Project Workday	Project Memo 1
8	Project Workday Project Check-In 1	SolidWorks IV
9	Project Workday Project Check-In 2	Midway questionnaire
10	Presentations about prototypes	Project Presentation and Project Files
11	Redesign Project Check-In 3	Project Memo 2
12	Project Workday	3D Printing – Individual Project
13	Report panel preparation, video editing	Project Memo 3 Individual Reflection
14	Final project panels/ videos	Final Project Report Panel and Video

3D Printing and Microcontrollers

Week	Class Activity/Topic	Assignment Due
1	Introduction, Tours, Microcontroller Set-up	None
2	SolidWorks II	SolidWorks I
3	Microcontrollers I	SolidWorks II Microcontrollers I Pre-Lab
4	3D Printing Team project introduction	Microcontrollers I
5	SolidWorks III	3D Printing Project idea submission
6	Microcontrollers II	SolidWorks III Microcontrollers II Pre-Lab
7	Team Meeting, Brainstorming, Project development.	Microcontrollers II
8	Project Workday Project Check-In 1	Project Memo 1
9	Project Workday	Midway questionnaire
10	Project Workday Project Check-In 2	Project Memo 2
11	Presentations about prototypes	Project Presentation, Project Files
12	Redesign Project Check-In 3	Microcontroller - Individual Project
13	Report panel preparation, video editing	Project Memo 3 Individual Reflection
14	Final project panels/ videos	Final Project Report Panel and Video

Figure 1 Week-by-week schedules for the class with (Left) *3D Printing* theme and (Right) *3D Printing and Microcontrollers* theme.

Phase 1 - Individual Learning

The first part of the course is designed for hands-on, individual learning. Students learn by doing with comprehensive, self-contained activities that they start in class and finish on their own. The handouts for the activities walk students through a discovery process with tangible objectives and exercises to complete. During the class session, the faculty instructor sets up the class activity and gets the students started. Then the instructor and teaching assistant (TA) circulate to answer questions and assist students. Students also are encouraged to help each other.

Computer-aided design (CAD)

Computer-aided design (CAD) is essential for both of the current course themes. SolidWorks [16] was chosen for the CAD platform. Importantly, it is a powerful CAD program that is widely used in industry and also used in several engineering departments in the college. Through a site license, all students have access to the program in the computer labs on campus and on their own laptops, which facilitates learning. In addition to tutorials integrated into the CAD program, there are many resources for students to learn online on their own. For example, Lynda.com [18] has a training course for SolidWorks that students can access via the University of Minnesota site license. In the *3D Printing* sections, students meet for two and a half class periods in a computer lab for the in-class portion of the CAD individual learning activities. They complete four SolidWorks assignments (see Table 1) that lead them from exploring the interface and set-up of the program to a variety of useful skills. This sequence is abbreviated to two classes and three assignments for the *3D Printing and Microcontrollers* section.

Table 1 Computer-aided design topics covered in individual learning activities in the *3D Printing** and *3D Printing and Microcontrollers*** sections

Week	**Title**	**Concepts Covered**
1	SOLIDWORKS I (in class*) (at home**)	Basic concepts in SOLIDWORKS*,**: ● User interface, viewing a part ● Sketch tools: Rectangles, Circles ● SmartDimension tool ● Feature tools: Extruded Base/Boss, Extruded Cut, Fillet and Shell
2-3	SOLIDWORKS II (in class*,**)	Exploration of SOLIDWORKS tools ● Sketch tools: Sketch relations, defining a sketch, Sketch Fillet ● Feature tools: Linear pattern, Mirror plane ● Other: rollback bar, reference plane Creating a unique part without instructions
4-5	SOLIDWORKS III (in class*,**)	Parameterized scaling Creating assemblies from parts Feature tools: Revolve and Sweep pattern features Creating drawings (only*)
8	SOLIDWORKS IV (at home*)	Learning a new feature independently

3D Printing

Individual learning activities for 3D printing take place in the College of Science and Engineering Anderson Student Innovation Lab, which has Lulzbot TAZ 6 3D Printers, ten of which are dedicated to the course when it is in session. The TAZ 6 [18] is a fused filament fabrication printer with a heated build plate and self-leveling capability. The printers can print a range of filament materials, but for this course poly(lactic acid) (PLA) is used exclusively. PLA is easy to print, has good mechanical properties for most applications, and is biodegradable. The use of a well-maintained space, robust commercial printers, and PLA help mitigate some of the known pitfalls with 3D printing projects [13]. Students in the *3D Printing* section spend two class periods completing 3D printing hands-on learning activities. In the first class, students work in groups of four to explore the features of the printer and the slicer (Cura [19]), and the impact of printing conditions on the part characteristics and print time. They follow a handout during class, complete a report after class and print one of the objects that they designed in an earlier CAD activity outside of class. In the second class, students are challenged, again in groups of four, to overcome common 3D printing challenges such as correcting poor fit between separately printed parts and selecting the best orientation. Again, a short report is due after class. Students in the *3D Printing and Microcontrollers* section learn the fundamentals in a single class session, with a focus on selecting part orientation and addressing challenges involving fit between parts.

Microcontrollers

In the *3D Printing and Microcontrollers* section, basic computer programming for controlling the microcontroller is taught using self-learning lab manuals with activities both at home and in the lab. As shown in Figure 1 (above), there are three in-class microcontroller labs (Weeks 1, 3, and 6), and two at-home pre-lab activities (due on Weeks 3 and 6). Given the limited number of hours dedicated to the microcontroller part of the course, basic programming skills had to be taught in a few hours to enable students to write simple, yet interesting programs for their final projects. After considering many microcontroller platforms, the Photon board from Particle [20] was chosen for several reasons: (i) it provides an easy, out-of-the-box operation with a simple programming platform, and has decent online documentation, (ii) it is relatively cheap and is compatible with other popular platforms, such as Arduino, providing students with a vast selection of software libraries and examples, and (iii) it allows programmers to seamlessly connect their microcontroller and circuits through a Wifi connection with their cell phones and other internet-connected devices and websites, hence enabling them to remotely control their circuits.

In terms of the devices to be connected to the microcontrollers, beginner programmers focus on two broad categories of devices: input devices such as light, humidity, and thermal sensors, and output devices such as LED lights, motors, speakers. Given the limited time in this course, and the fact that some students have no prior background in programming, we decided to focus on output devices, and specifically on RGB LEDs, servo motors and DC motors. These devices are relatively simple to program and empower students to design interesting and exciting designs that integrate 3D-printed components with motors.

Table 2 shows more details about the microcontroller assignments for the *3D Printing and Microcontrollers* section. Students set up their Photon microcontrollers to connect to the internet in Week 1. In Weeks 2 and 3, they complete a pre-lab to learn very basic programming concepts. In Microcontrollers I (Week 3), students learn more complex programming constructs, such as using conditional statements (if-else), and writing programs to increment a variable up to a predefined maximum and resetting it back to 1 using an "if" statement. They also learn to use state variables to make the program go through different phases, such as first increasing the light intensity of an RGB LED in a number of steps, and then dimming it gradually. We consciously decided to avoid covering explicit loops (e.g., for loops and while loops), and rely on the Photon firmware, which calls the loop() function in the user program once every 1ms. Students can write programs that perform repetitive tasks without having to learn the C/C++ syntax for loops. In Microcontrollers II, they learn to interface to their cell phones, remotely giving commands to their circuits and monitoring variables in their programs. They also learn how to control servo motors and DC motors, how to move the servo motor to a new location, and how to use diodes to protect the microcontroller from potentially high back-flow electric currents from the motor.

Table 2 Microcontroller and programming topics covered in individual learning activities in the *3D Printing and Microcontrollers* section.

Weeks	Title	Concepts Covered
1	Microcontroller Setup (in class)	Setting up the microcontroller with wifi credentials and running a simple blink-an-LED program.
2-3	Microcontrollers I Pre-Lab (at home)	Basic programming constructs ● Data types, variables ● Functions Debugging skills ● Compiler error messages ● Showing variable values on the screen Wiring a blink-an-LED circuit, changing the rate of blinking in the program.
3-4	Microcontrollers I (in class)	Programming constructs ● Incrementing variables and making counters ● If-else conditional statements ● "State" variables Using libraries (e.g., to control an RGB LED)
5-6	Microcontrollers II Pre-Lab (at home)	"Cloud" connectivity ● Viewing variable values on the web (or on their cell phones) ● Giving commands to the circuit using the web (or their cell phones)
6-7	Microcontrollers II (in class)	Controlling Servo and DC motors. ● Basic operation of servo and DC motors ● Programming a servo motor ● DC Motor driver, and circuit protection

Individual Project

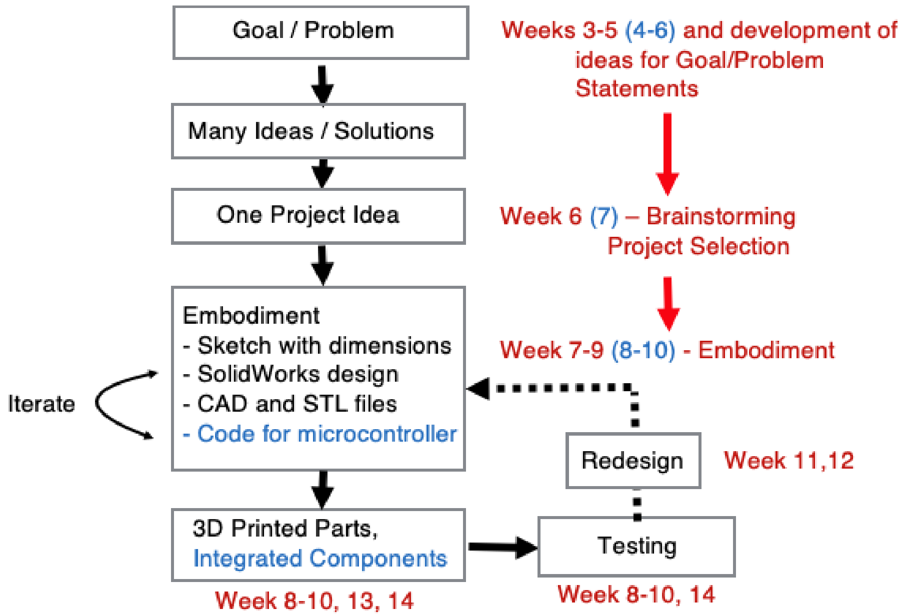
In both the *3D Printing* and the *3D Printing and Microcontrollers* sections, an individual project helps students to gain confidence and experience. In the *3D Printing* sections, students redesign a keyholder that they created in the SolidWorks III assignment in order to improve the 3D printing and performance of the keyholder. In the *3D Printing and Microcontrollers* sections, students create their own sequence of code to operate their microcontroller via a cloud command and perform a function involving one of the motors and/or an LED light. Therefore, they also must wire their microcontroller and devices appropriately.

Phase 2 - Team Project

The team project portion of the class becomes the main focus in the second half of the course. Before this phase begins, students answer questions in an online survey so that teams can be formed. The questions include day and time preferences for team meetings, dorm or commuting status, and prior experience with the skills associated with his or her section. The students also have the option of listing one person in the class that they would like to work with. Faculty instructors construct four-person teams from this information, using principles developed in the literature [21]. A key goal in this course is to spread the more experienced students between teams. In this way, those more experienced students can help the less experienced learn.

Figure 2 shows the flow diagram and specifications for the team projects. Students are introduced to the project in Week 3 or 4 and challenged to think of a problem or goal statement for a project. In this short exercise, students consider the project specifications (see Fig. 2. right) and project categories such as “Tools and Fixtures”, “3D Model or Visualization” and “Helping Others”. Students also reflect on their own interests and their experience so far in the course as they think of a problem or goal statement. Further, several examples are provided to help them understand the elements of a well-posed statement. The faculty instructors and TAs then read through these statements, which are submitted online, and select some to share with the class during the team meeting in Week 6 or 7. This list gives the teams some ideas and talking points as they begin to work together to develop their own unique project idea. In the first team meeting, students get to know their teammates, discuss and debate project problem or goal statements, develop their own draft statement and begin brainstorming ideas for their prototype.

The project development follows a classic engineering design series of steps [22, 23], as shown in Figure 2. First, the student teams identify a goal for their project or problem to solve with their project. Teams are introduced to the basics of idea generation, and then they consider their common interests as well as the project categories mentioned above to narrow down their project ideas and develop their project or goal statement. Therefore, each student team has a unique problem or goal for their project. Given that our students have a wide variety of interests across science and engineering, as documented below, this student-driven format for the projects is especially important. After deciding on a problem or goal statement, the teams brainstorm possible solutions or embodiments and begin work on a prototype.



Project Specifications:

1. The project must fit into one or more of the themes and have at least one clearly defined function.
   The project must have at least one clearly defined function and incorporate at least one microcontroller and component (e.g., motor).
1. The project must have multiple 3D printed parts and be designed with the strengths and weaknesses of 3D printing in mind.
2. The project may include simple non-3D printed accessories, if necessary, such as rubber bands and glue. The project may also have one or more components that are made with a laser cutter or thermoforming apparatus.
3. The project ideally has a feature that makes it clear that it is from the University of Minnesota.

Figure 2 Team project flow diagram (Top) and specifications (Bottom) for *3D Printing* theme and the *3D Printing and Microcontrollers* theme. The blue text is specific to the *3D Printing and Microcontrollers* theme.

The project work occurs during the regular class time and team meetings outside of class. Students have access to the 3D printers, SolidWorks on their laptops or lab computers, and their microcontrollers during class. These classes also include periodic Project Check-Ins, which involve the teams answering questions about their project and progress, and then instructors reviewing their check-in document and offering feedback. The formal documentation of the projects comes in the form of project memos. The required memo contents and format are provided to the students. Additionally, one class period is set aside for presentations about the prototype. These presentations spark questions and discussion, which benefits the entire class. The iteration and improvement of the project continues until the end of the semester. Teams document their project in a single PowerPoint panel and in a two to three minute video, which are shown during the last class. Lastly, all sections join in a final project show at the end of the semester.

Results and Discussion

One aim of the course was to attract students with interests across a range of science and engineering disciplines to enroll in this elective course. In the first offering (Spring 2017), four sections of the *3D Printing* theme were taught, attracting 101 students (three sections of 24 and one section of 29). In the second offering (Spring 2018), five sections of the *3D Printing* theme were taught along with one section of the *3D Printing and Microcontrollers* theme, for a total of 143 students. In Spring 2019, there are five sections of the *3D Printing* theme and two sections of the *3D Printing and Microcontrollers* theme, for a total of 168 students. In each offering, the classes filled quickly. Students were informed about the course in their first-semester, required course. One week of this fall course was set aside for a discussion of experiential or hands-on learning. During this class, students did a short design and build activity and then a faculty instructor from the second-semester project-based learning course gave a presentation, showed examples and answered questions. This face-to-face mode of discussing the course proved to be effective. College advising staff also spread the word as did students who previously completed the course.

At the beginning of each project-based learning course, students completed a survey to assess their interests in majors in the college as well as their prior experience with the skills featured in their section. Figure 3 shows the responses to the question about the interest in major. The topics clearly have broad appeal across the science and engineering disciplines. Interestingly, the section on *3D Printing and Microcontrollers* attracted more students interested in Computer Science and Computer Engineering. The incoming students had a range of expertise in the skills featured in the course but on average the students had little prior experience, as shown in the survey results in Figure 4. This data demonstrates that the topics chosen have broad appeal and that students feel comfortable entering into the course with little to no experience.

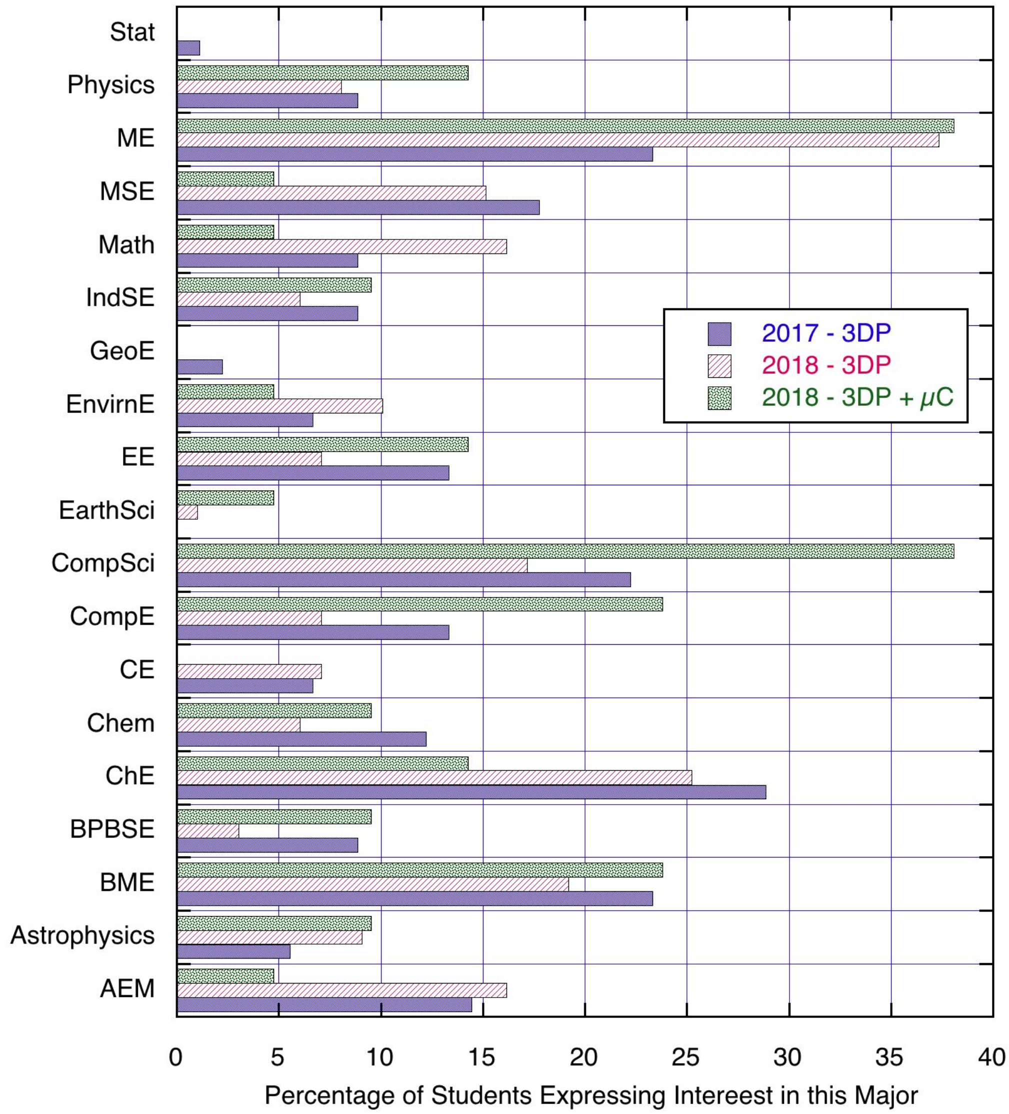


Figure 3 Student responses to the course survey question: "Which majors are you interested in? Check all that you are considering." Results are shown for the *3D Printing* sections in 2017 (4 sections) and 2018 (5 sections) sections as well as the *3D Printing and Microcontrollers* section in 2018 (1 section).

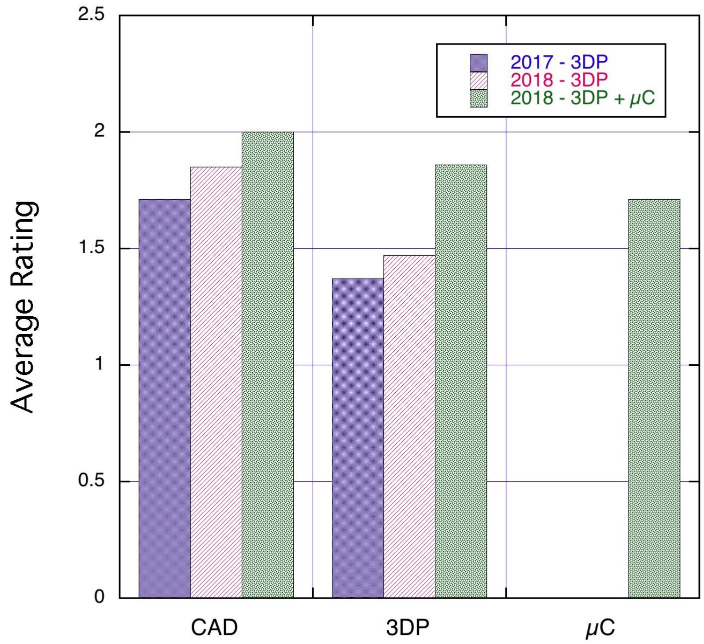


Figure 4 Average of experience level on entry into the course on a scale of 1 (no experience) to 4 (extensive experience) on CAD, 3D printing (3DP) and microcontrollers (μC). Results are shown for the *3D Printing* sections in 2017 (4 sections) and 2018 (5 sections) sections as well as the *3D Printing and Microcontrollers* section in 2018 (1 section).

Another aim was to attract faculty to become instructors of individual sections of the course. In Spring 2017, the first offering, four faculty instructors from a range of departments joined the instructional team. Only one of the instructors, the organizer of the course, had extensive experience with CAD and 3D printing. The other instructors learned along with the students. In Spring 2018, the number of faculty instructors grew and content experts in microcontrollers were added. The *3D Printing and Microcontrollers* sections, which were more demanding due to the three skills, were taught by two co-instructors. Instructors meet on a weekly basis to discuss curriculum and plans. A teaching assistant, typically an undergraduate with experience, is assigned to each section. Anecdotally, the instructors provided positive feedback on the experience. They enjoyed the opportunity to work with freshmen as well as learn a new skill that could be transferred to their research and teaching.

A testimony to the success of the course is the wide range of creative and complex projects. See Figure 5. Projects in the *3D Printing* sections in 2017 and 2018 included tools and fixtures, such as attachments for bunk beds and bicycles, models such as one with embedded magnets that demonstrates molecular polarization and another that shows the distribution of electoral college votes across the United States. Those in the *3D Printing and Microcontrollers* section in 2018 brought in the added functionality of the microcontroller and motors; for example, one team designed a maze that tilted on two axes so that a player could move a small steel ball through a maze and a fixture that controlled a thermostat setting. These projects demonstrate advanced learning and student capabilities.

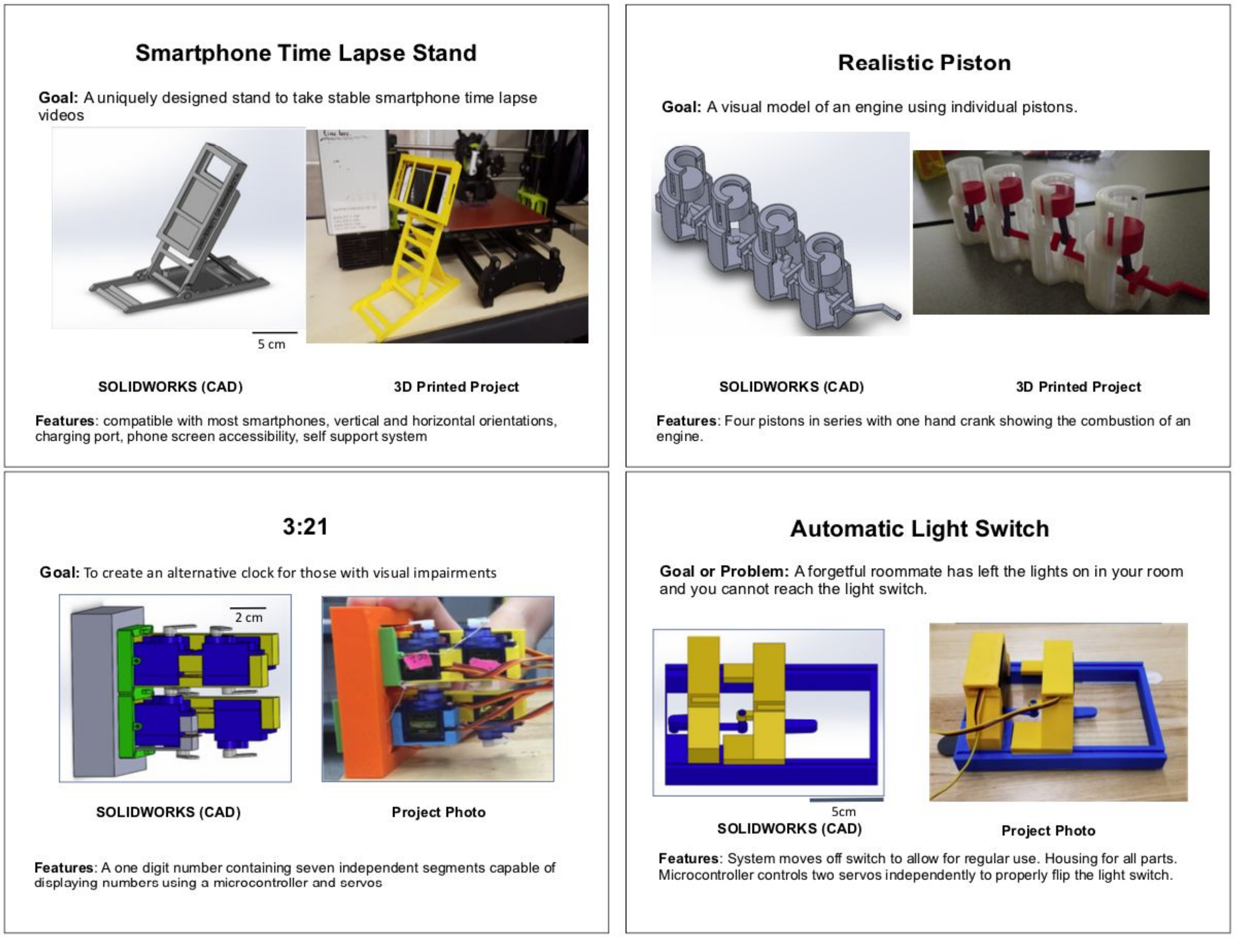


Figure 5 Examples of final report panels for the (Top) *3D Printing* and (Bottom) *3D Printing and Microcontrollers* sections.

Student feedback was collected formally through a midway questionnaire, an individual reflection assignment near the end of course, and the University of Minnesota standard student evaluation of teaching survey. The overall student impression of the course was positive from these assessments. On the midway questionnaire, students gave feedback on the course, after the bulk of the individual learning activities were complete and just as the team projects were getting off the ground. The data in Figure 6 shows a very positive response for all items.

In the second to last week of the course, students completed an individual reflection in which they answer specific questions about what they have learned over the course of the semester. See Figure 7. Student responses were qualitative. A preliminary assessment shows that the vast majority of the students had positive comments and noticed specific things that added to their understanding and experience. They also offered outstanding suggestions for future students who take the class. Overall this assignment showed that the students gained a lot from the class.

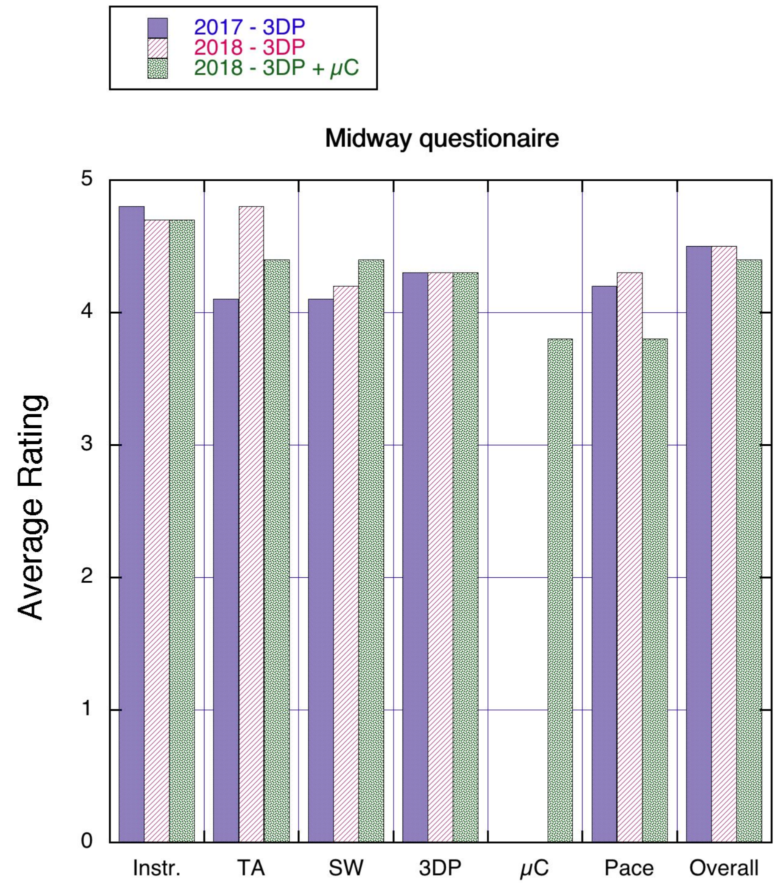


Figure 6 Average of responses to the midway questionnaire. Ratings were on a scale of 1 (not satisfied/negative) to 5 (very satisfied/positive) on the instructor, TA, SolidWorks (SW) activities, 3D printing (3DP) activities, microcontroller (μC) activities, the pace of the class and overall impression of the class. Results are shown for the *3D Printing* sections in 2017 (4 sections) and 2018 (5 sections) sections as well as the *3D Printing and Microcontrollers* section in 2018 (1 section).

Questions on Individual Reflection for 3D Printing Sections

- How has [the course] added to your understanding and experience with CAD (SOLIDWORKS) and 3D Printing?
- How has [the course] added to your understanding and experience with the series of steps involved in the design process?
- What have you learned about teamwork based on your experience in [the course]?
- If you could offer advice to the next students who take [the course], what would it be?

Additional Question on Individual Reflection for 3D Printing and Microcontrollers Section

- How has [the course] added to your understanding and experience with microcontrollers and coding?

Figure 7 The questions students answered on the individual reflection assignment.

Lessons Learned and Future Outlook

With each offering of the course, lessons were learned and improvements made. Several of these were included creating individual learning activities with the right mix of step-by-step guidance and learn by doing, addressing the particular challenges of getting students with a range of incoming expertise up to speed on programming, helping student teams understand how to define their problem or goal, and setting appropriate specifications on the project.

In terms of individual learning, the design of SolidWorks activities required a transition from very specific instructions to less detailed exercises that required the students to try and perhaps fail and recognize how to correct their parts. Not having enough detail early could lead to frustration and discouragement. Later, in SolidWorks III and IV, the students are ready for challenges and learning that requires them to branch out and consult resources, such as Lynda.com tutorial videos.

Concerning programming, one challenge is the wide range of incoming student experience. Some students enter the course with years of FIRST Robotics Competition experience and other students have no experience. For all our students, we have two goals: (i) to provide an education that allows every student to program the microcontroller to make decisions and take a variety of actions and (ii) to provide every student the opportunity to add to their prior knowledge. To reach both goals, it was critically important to provide a layered educational process. The first layer was a step-by-step guided process to get the students to program basic sequential machines using the actuators in the course and cloud connectivity (Microcontrollers I and II). The first layer includes exercises where students must repeat the process on their own, to solve slightly different problems. The second layer is a set of debugging and error fixing exercises where students are asked to fix intentional errors in code using the development tools' often cryptic messages! The third layer is a set of optional materials that students can use to self-teach themselves more advanced concepts (like timer driven events, HTML webpage design, and use of input devices.) During the current, second offering of the *3D Printing and Microcontrollers* theme, additional support is being introduced and assessed, including an optional "first-time programmers" session and the addition of links to short video lectures (3-10 minutes) that review basic concepts to the microcontrollers handouts.

There were several key lessons learned in the team project portion of the class. First, students need encouragement and specific examples in order to clearly define the problem their project solves or the specific goal for the project (*i.e.,* the first step in the design flow diagram in Fig. 2). One way we helped the students with this process was to ask each student to submit a problem statement a few weeks before the first team meeting. This individual assignment then facilitated the team process of deciding what problem to tackle. Second, the students enjoy pursuing a problem or goal of their own choosing and they tend to resist a project specification that limits the size or complexity of their design, resulting in projects with long print times. To overcome this problem, the option of creating a portion of a project by laser cutting was introduced and the current specifications stress the need to make use of the strengths and weaknesses of 3D printing rather than a size constraint.

With two successful offerings complete and one currently underway, the future plan for the course includes modest increases in the number of sections for the current themes and expanding the course to include new themes. Based on current space and equipment capacity, we anticipate expanding the number of sections based on the current themes to around ten. We are considering how themes that make use of different resources could be developed so that more students can take advantage of the opportunity to do hands-on learning in their freshmen year. Freshmen in the College of Science and Engineering have a wide range of interests and new themes with broad appeal across the disciplines could draw even more students in. A new theme should: (i) offer freshmen real skills that they can use in their studies as well as extracurricular activities, research and industrial internships, (ii) be conducive to hands-on projects that can be easily carried out in an on-campus facility, and (iii) have broad appeal to science and engineering students. The 'skills' should be also accessible to freshmen. The combination of a computer-based skill and a more physical object-based skill has proven effective to-date and might also be a good model for future topics. For each skill, two or more learning activities are needed for individual students. The assignment format used in the current themes can be used as a model for assignments related to other skills. Lastly, the overall structure of the course, as well as the assignments, memos, etc. geared toward the project portion of the course, can be used for other themes with only minor changes.

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