# From Design to Reality: Guiding First-Year Students from Design to Makerspace Reality

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## Abstract

An existing introduction to engineering and design course at the NYU Tandon School of Engineering for first-year students was adapted to include guidance for first-year students to grow from early conceptual design to using the makerspace. A Rapid Assembly and Design (RAD) challenge embedded in NYU's culture of invention, innovation, and entrepreneurship was created that allows students to work on their own unique project. Lab exercises, instructional videos, and project working space were developed to support the open-ended projects that required the use of the makerspace. An end-of-semester survey was conducted to see if the participants in the RAD project benefited from the makerspace training and if the projects improved their engineering design abilities. A timeline of events and descriptions of the training are documented for others to reproduce.


## Introduction

This complete research paper will describe a study of training, assignments, and projects that encourage students to use makerspace and bring their designs into reality. This addresses the first-year programs division topics of interest for project-based and hands-on course activities in the first-year and integrating engineering design. Makerspaces have become a valuable tool for teaching the engineering design process. They provide students with an opportunity to focus more on building, testing, and evaluating their design. Makerspaces also provide more creative opportunities for engineering design projects through rapid prototyping electronics and additive manufacturing. For some students in the first-year this can seem like a daunting task, particularly when they are working alongside senior design capstone teams and graduate researchers in a makerspace. This first-year introduction to engineering and design course added several aspects to the course to guide and support students through makerspace usage.

Training is essential to prepare students to enter the makerspace. This is accomplished in the first-year course through dedicated training times and class exercises. Students attend a mandatory fundamental training and orientation to the university makerspace during the fourth lab of the semester, which is the week after they have completed the third lab in their project teams. This training covers safety and desktop 3D printer operation. After they receive this training, they tour the first-year engineering prototyping lab, which is a smaller, dedicated space for the first-year engineering course. All of the equipment in the prototyping lab is available in the makerspace, but only first-year students use the prototyping lab with the supervision and mentorship of a teaching assistant.

Technical training for makerspace skills takes place during some of the lab exercises for the course. Nine labs are completed each semester. The first lab of the semester guides students through building a keychain with the university logo in computer-aided design (CAD) software. Another lab that tested the mechanical design of a robot has been updated to test the accuracy and precision of sensors. An experimental lab is being tested that trains students how to code using an Arduino microcontroller using a custom version of the Sparkfun Inventors Kit. They also test the reliability of a temperature sensor and make accuracy and precision calculations. Videos were created to assist these labs through pre-lab instruction on breadboarding, CAD, and 3D printing. Initially the course attempted to introduce makerspace skills in the semester-long project by allowing students to 3D print robot parts. New projects have been introduced that focus on complete product designs being constructed in the makerspace.

The initial project that focused on makerspace skills was an entrepreneurial venture project. Students could identify any problem that they wanted to solve using technology and propose a prototype that would consider the consumer needs. Based on the success of this project a Rapid Assembly and Design (RAD) Challenge was created that allows students to identify a passion project and develop a prototype that would be useful for future projects in the first-year course. There is the potential to extend this Rapid Assembly and Design Challenge to the Grand Challenges for Engineering or student project teams at the university. RAD has the potential to prepare first-year students to tackle a small problem of a larger project that is being worked on by large teams. Surveys were used to determine how effective the in-class training and out-of-class project work has helped students to understand the engineering design process.

## Background

At California Polytechnic State University, San Luis Obispo incorporated rapid prototyping technology in the early 2000s [1]. In their introductory engineering course students would design and 3D print parts for biomedical applications. The course project connected project-based learning with industry partners. After learning how to use CAD software and 3D print, students created an accurate 3D digital and physical model of human heart to be used in the development of pacemakers.

Another inspiration for incorporating makerspace technology into an introductory course came from Youngstown State adding 3D printing to their first-year engineering design project [2]. At Stanford University first-year students used microcontrollers and electronics from Sparkfun and Adafruit to build music players [3]. Grand Valley State University incorporated holistic learning of the maker movement by incorporating 3D printing into the first-year robotics design [4].

An example of incorporating makerspace usage into a first-year course is the Drexel University Innovation Studio [5]. Students could choose either the super-cap challenge or music maker project. The super-cap challenge required students to build a supercapacitor-powered toy car to compete in a distance based competition. The making music project required the creation of a self-playing musical instrument. Their survey found an increase in satisfaction of the makerspace supporting educational activities, but a decrease in quality of instruction when the space is not an open-concept floorplan [5].

Eastern Mennonite University created a first-year project that focused on problem definition, conceptual design, preliminary design, detailed design, and design communication [6]. Example projects include a solar-powered cell phone charge and a persistence of vision wand. Regardless of the project student teams created a plan, an engineering notebook, parallel prototypes, final report with market research, and a presentation.

The University of Iowa developed a dedicated space to support first-year project development. Upon investigating other university makerspaces their library found that three areas were most common for integration of coursework and makerspaces. Almost all makerspaces rely on prototyping tools including 3D scanning, 3D modeling, and 3D printing. Many makerspaces were also using virtual reality as a tool for students to explore new technology. In order for students to implement their ideas they need to have resources for computer programming and circuit building [7].

At Portland State University and Northeastern University, a year-long first-year sequence of courses was established that focused on active learning projects [8-11]. These projects solved large scale problems or focused on product development. The primary tool for student projects was the Arduino platform. The courses provided student with prototyping kits and project topics included robots, a desktop fan, energy production, virtual reality games, and sustainability.

**Method**

The first-year introductory engineering course at NYU Tandon School of Engineering is a 3 credit-hour multidisciplinary program that is required for all engineering majors. Introduction to engineering is offered in both the fall and spring semesters with up to 350 students enrolled each term. Course meeting times include a one-hour lecture, 90-minute recitation, and three-hour lab each week. Course projects are completed outside of scheduled class time, with the exception of two lab sessions. Recitation and lab are taught in 21 different sections with a maximum of 18 students per section.

In order to prepare first-year students for work in the makerspace, the first-year program faculty and teaching assistants developed new lab exercises, projects, and trainings. Each semester there are nine lab sessions and one 12-week team project. Figure 1 depicts the timeline for the introduction to engineering and design course. The methods section will describe the training, labs, and projects that support makerspace activities. The students completing the new course projects that focus on product development and the maker movement were the subjects of the end of semester survey described in the results section.

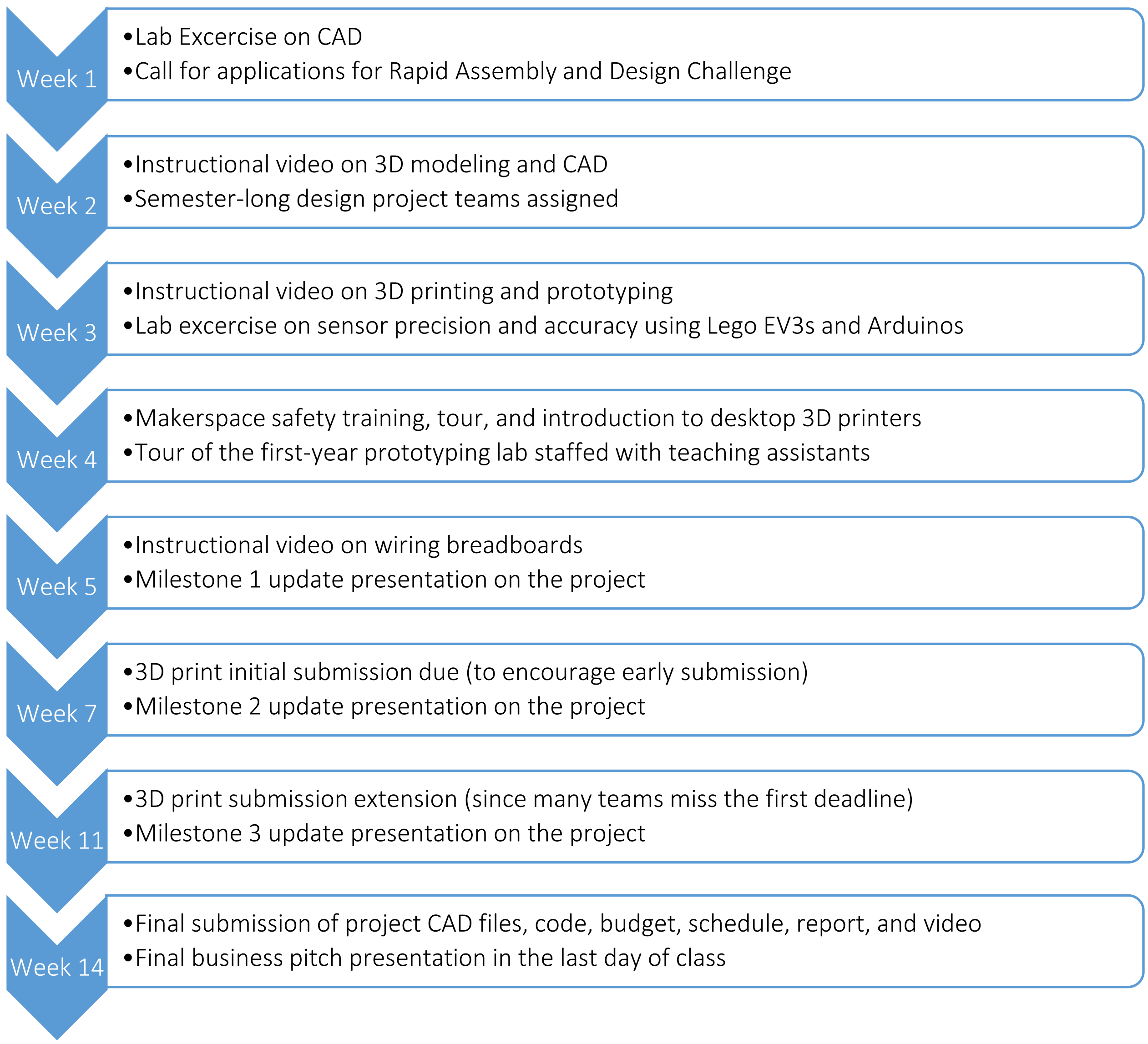


Figure 1: Semester Timeline of Makerspace Activities in Introductory Engineering Course

*Makerspace Training*

During the fourth week of the semester, all students in the course attend a makerspace orientation training during their scheduled lab. The makerspace is on the first floor of the engineering building and the first-year labs are on the fifth floor. For any given lab periods, there are three lab sections run at the same time, so the roaming teaching assistant will accompany each section down to the makerspace in a rotation. Because of this, not all students are at the end of their lab activity when they stop and go down to the makerspace. The orientation sessions are scheduled specifically for the first-year class, so those sessions are not open to other students.

The makerspace orientation training includes a tour, safety information, and training on the Ultimaker 3D printers and corresponding Cura software. The tour is meant to provide a brief overview of each type of machine in the space and motivating anecdotal examples of how the machines can be used. Safety information includes locations of fire extinguishers and first-aid, what to do for a more severe injury, and simple lab rules. Makerspace student staff then walk through the printing process and best practices for slicing CAD files in Cura. All student IDs are scanned so there is a log that they have attended orientation and can then attend any of the more advanced trainings offered.

*Prototyping Lab*

When the makerspace first opened, first-year students informally commented on the desire to have an entry-level space that was not so intimidating. The school of engineering's makerspace was designed to be open and inclusive, but some first-year students were still nervous learning the new equipment next to seniors working on their capstone project and graduate researchers. In response, the first-year engineering program built a mini-makerspace named the prototyping lab. The equipment purchased for this space mimics the makerspace to provide first-year students with continuity.

The key to the success of the prototyping lab has been the teaching assistants who staff the space to guide students through CAD software, 3D printing, soldering, and general prototyping advice. Figure 1 shows that students are introduced to the prototyping lab in week 4 of the semester, and are later required to return after they submit their 3D printer file in week 7. Students submit the CAD files online and are required to meet with a prototyping teaching assistant to start their 3D print. In the third semester of the prototyping lab's operation, a second deadline was added at week 11 for students who still wanted to create a 3D print, but missed the first deadline. This schedule was found to be helpful to prevent the lab from becoming too crowded or back-logged.

*Lab Exercises*

In the first week of lab students create a keychain with the university logo in CAD software. The winner of the lab competition then has their keychain model printed. In the third week, students test sensors using Arduino or Lego Mindstorms and calculate the accuracy and precision of the collected data. These labs teach students the foundation of CAD and programming required for their projects.

Three instructional videos have been added as pre-lab assignments in the second, third, and fifth week. The first two videos are a two-part sequence starting with CAD and 3D modeling followed up by 3D printing and prototyping in the next week. This sequence follows the engineering design process to 3D print a part for the semester-long design project. The third video provides instruction for wiring a breadboard.

*Semester-Long Design Project*

Makerspace training was initially incorporated into the course project by adding it to the existing robotics project options. At first, students could 3D print a logo that represented their team's company for extra credit. As students started taking advantage of this opportunity and the prototyping lab opened, students were then allowed to 3D print robot parts and terrain modifications that help them overcome the obstacles on their robot courses.

A new project was then piloted in the fall of 2016. This project focused on a student proposed entrepreneurial venture. As this project was tested on a single 18 student section of the 350 students enrolled in the course each fall and spring, the project requirements and expectations were refined over three semesters. The focus of the project became teaching students the engineering design fundamentals to be successful on future team projects such as CAD, programming, data analysis, scheduling, and budgeting.

In the fall of 2017 a student team outside the pilot section reached out to the first-year faculty about a passion project they wanted to pursue – the student wanted to design and build a drone. As a result the entrepreneurial venture projects have evolved into a Rapid Assembly and Design challenge. In the future, students will propose projects in the first week of the semester and the proposal will be accepted based on feasibility and support that the course can provide. As the RAD projects continue to develop, the first-year program hopes to prepare students for project-based courses in their second year.

## Survey and Results

A voluntary survey was sent to students in the entrepreneurial venture pilot course. Responses were collected over three semesters: fall 2016, spring 2017, and fall 2017. Survey questions included 15 Likert style statements to assess student perception of their project, the course, and the learned skills [10]. Response rate was low, n = 17, but aggregate responses are shown in Figures 2 and 3. These preliminary results help to guide the faculty on updates to the projects.

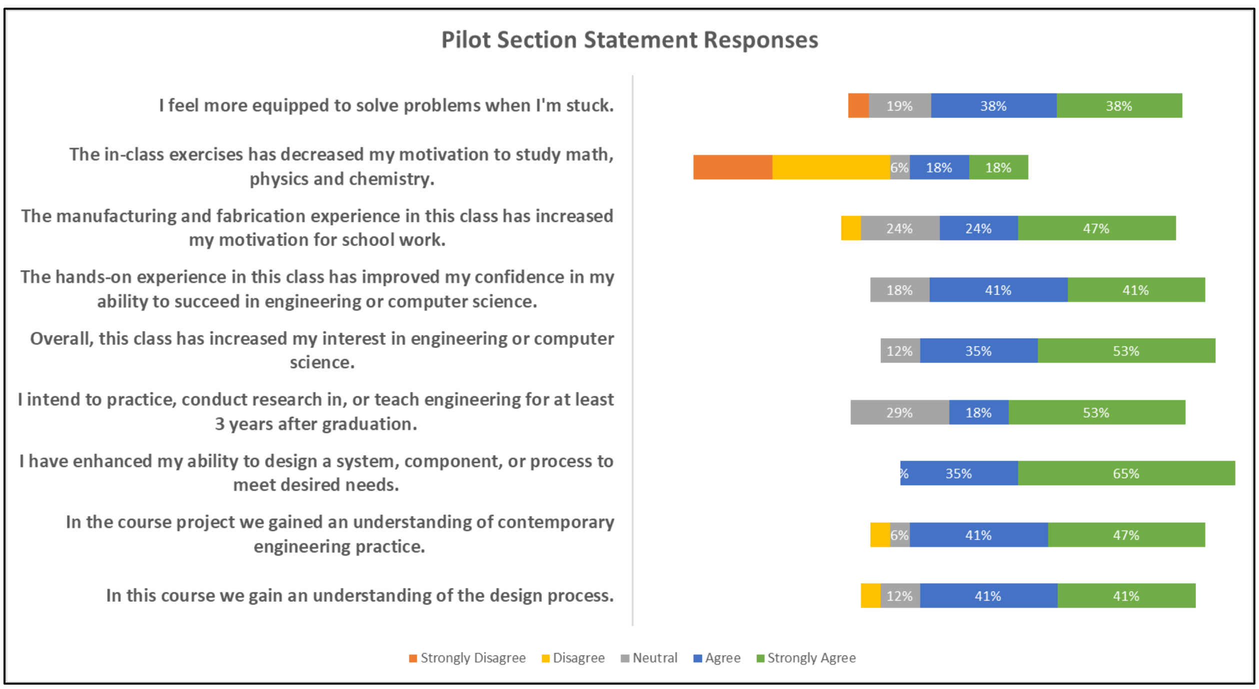


Figure 2: Survey Responses on Impact of Makerspace Activity on Engineering Self-Efficacy

Figure 2 reveals a generally positive assessment of the makerspace training and the course project on engineering self-efficacy and desire to study engineering or computer science. In particular, many or all students felt that the project enhanced their ability to design a system, component, or process to meet desired needs. No students reported that the course or their project decreased their confidence or interest in engineering and computer science. Also, the negatively phrased Likert statement regarding motivation for math, physics, and chemistry indicates that students paid attention to the wording of each statement.

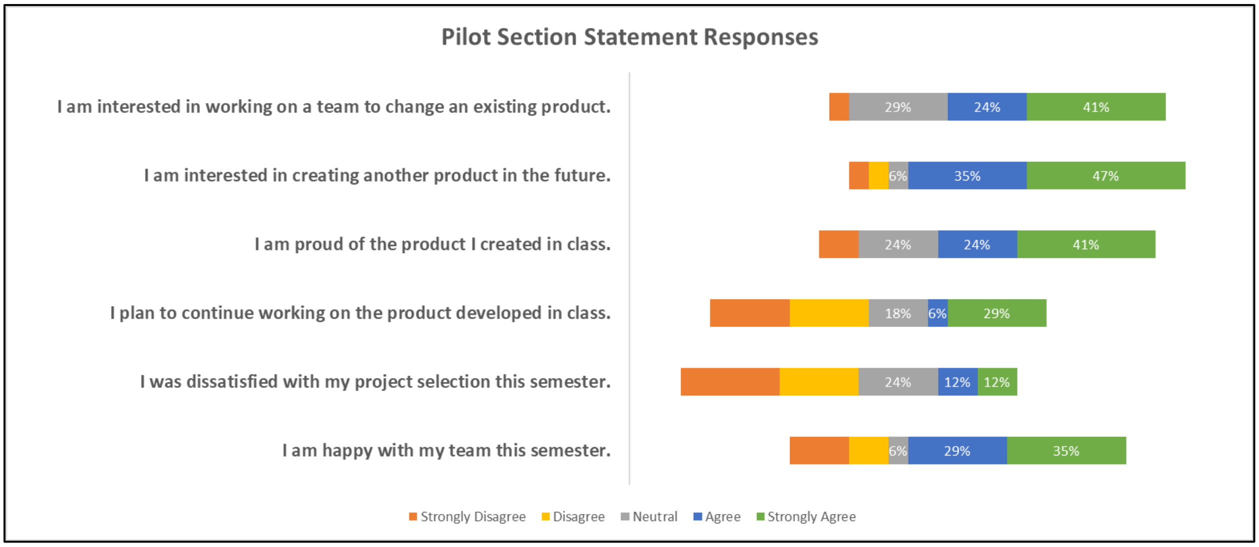


Figure 3: Survey Response to Team and Product Development

Figure 3 focuses on student responses related to the project. It is interesting to note that although students were mostly not dissatisfied with their project, very few plan to continue working on the project after the class. This is not an entirely negative outcome since the project is intended to be a first exposure to the design process skills to be used for future projects. In general, it appears a majority of students are interested in working on future team projects that use makerspace skills.

Figure 4 collects common sentiments from the students' qualitative responses. Five open-ended questions were asked to give students a chance to respond in a short-essay form with as much detail about their experience as they wanted. The responses over the three semesters were:

Table 1: What did you struggle with the most during this course?

| **Fall 2016** |
|---|
| • I struggled a lot with choosing an idea that all my teammates were also passionate about.<br>• I struggled with picking up and learning the coding language. I'm going to need to spend a lot more time practicing coding in order to become decent at it.<br>• Coming up with a feasible timeline to create a prototype within the semester.<br>• Since I am in charge of creating physical prototype of project, the most challenging part was learning CAD and creating the model that would best fit the idea.<br>• Trying to design the prototype as well as debug the code by myself. |

| **Spring 2017** |
|---|
| • I think the thing that I struggled most with, initially, was trying to develop a project idea.  The open mindedness of the project definitely scared me at first because I am usually more of a structured person but once the project was decided upon it was a lot better. <br>• It was difficult to work on a team with unreliable teammate <br>• Humongous time commitment. |
| **Fall 2017** |
| • I wish we were given more class time to work on the product. <br>• Teamwork <br>• Working with my teammates. <br>• I struggled with working with my group. |

Table 2: What did you enjoy most during this course (what shouldn't change)?

| Fall 2016 |
|---|
| • The fact that we were allowed to make ANYTHING <br>• I enjoyed the freedom to create what I wanted with only minimal guidance |
| Spring 2017 |
| • My favorite part was probably the fact that we could really do anything. <br>• It was fun to be able to attempt to design something almost fully independently with the safety net of a mentor behind you. |
| Fall 2017 |
| • I think you should definitely keep the same concept of picking your own product to develop. It was super interesting and helped me understand which field I was interested in. <br>• Creating a physical prototype <br>• I really do believe that this course is something that has been extremely important to my education this semester. Having the opportunity to create a product from nothing in my first semester of engineering school really solidified my interest in this field. |

Table 3: What tools and resources would you have wanted for your project?

| Fall 2016 |
|---|
| • For other resources, throughout the semester, I wish I can have more support on CAD drawings and 3D modeling in general in class. I like the 1003 labs with Arduinos and 3D drawing at the beginning of semester. It would be great if we could have more labs like these <br>• I definitely think that a TA to help specific sections would be amazing. Not necessarily one per team, but perhaps 2 or 3 TAs total. 1 to help with programming, one with 3d printing, and one with concepts. |
| Spring 2017 |
| • I think that one thing we could have benefited from was a little more instruction on really the entire scope of the project. <br>• It would be great if the 3D printers were more reliable |
| Fall 2017 |
| • A better team and a more involved advisor <br>• A metal shop, with training, A test area <br>• A programming tutorial. <br>• I think having more mentors available and more access to things early on would be great. |

Table 4: What additional instruction would be helpful for the design project?

| Fall 2016 |
|---|
| • I would like to learn and hear more about how experienced engineers go through the design and production processes for a project because their approaches to problem solving would teach us good attitudes to take on when tackling a problem.<br>• Clearer guidelines for what was expected out of the final products |
| Spring 2017 |
| • Spend more time coming up with a good idea, even if you lose time from actually working on the project.<br>• People to go to for technical help and help with design. |
| Fall 2017 |
| • More makerspace and construction training<br>• A programming tutorial and a better Arduino tutorial<br>• Idea development<br>• I think the only thing that would have been more helpful is learning about the design process and all the aspects that go into the ideating process earlier in the semester. |

Table 5: Do you have any other recommendations for this course?

| Fall 2016 |
|---|
| • Labs that are more related and focused on the tools that the teams are using for their Semester-Long Design Project<br>• I really enjoyed this course and I hope it will be expanded in the future.<br>• I really liked this course, and was surprised to see how much we can actually achieved in one semester in freshman year. Change some of the labs towards programming on Arduino or Raspberry pi, and training of CAD and 3D modeling.<br>• Overall, it was a great first engineering course!<br>• I loved the course and would recommend it to everyone. However, I think it is still very important for there to be an application process because this class is not for everyone. |
| Spring 2017 |
| • I think that overall this was an amazing course and something that I very much enjoyed.<br>• MAKE SURE IT SAYS THAT THIS IS AN ADVANCED/TECHNICAL SECTION ON OUR TRANSCRIPT PLEASE. |
| Fall 2017 |
| • Allow students to choose their partners. Dedicate the first class to the students being broken down into groups and from there, they evaluate who they would like to work with/ have mutual interests with<br>• The teams were kind of a problem.<br>• I do think that this course is something that has been indispensable to my first semester, and I think as it grows, the class will become something great |

Some trends that appear in Tables 1 through 5 indicate that the makerspace training improved throughout the three pilot semesters. In fall 2016 the video on 3D modeling and CAD was made available, and in the spring of 2017 the video was made mandatory by including questions on the pre-lab quiz. The 3D printing and prototyping video was made available in fall 2017. The 2017-2018 academic year is when we started to include the prototyping lab tour during the lab with the makerspace tour. Since the makerspace opened in fall 2016, we have seen improvement in the student responses to preparation for using the available tools and equipment. This is indicated by student struggling less with the prototyping, CAD, and coding phases of the project. Instead, in the later semesters students struggle more with the scope, time management, project selection, and teamwork. These are issues that will be addressed in future research.

## Conclusions and Future Work

The introductory engineering course has had success with the incorporation of makerspace training into the course activities and projects. Based on the experience of the first-year engineering faculty it is recommended for these adaptations to be incorporated over several semesters to modify and refine the operations of the course. Doing too much in one semester can be hard to scale to a large first-year course. Multiple solutions including lab exercises, training, instructional videos, and mentorship are critical to the success of open-ended projects.

The next major focus of the first-year engineering program is develop a mentorship program to support course projects. When students propose their own ideas, it helps to have a mechanism that finds experts to support their project. Teaching assistants with experience in the proposed areas are a valuable resource to guide students from their conceptual design to product development. Further research is needed to understand and improve the role of the mentors for each RAD project.

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