Results of Integrating a Makerspace into a First-Year Engineering Course

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Introduction

This Complete Evidence-Based Practice paper explores the integration of makerspace lessons and projects into a first-year *Introduction to Engineering* class. Beginning in 2013, the study body representing traditional students starting their degrees immediately following high school began to switch from Millennials to Generation Z (Gen Z). As our student population changes, their interests and characteristics should influence our teaching pedagogy. Seemiller found that students prefer to work independently, involving others only when necessary [1]. Cruz found that over half of the interviewed Gen Z students identified that they enjoyed creating and tinkering as children, suggesting an association between engineering as a career choice with the activities of making and creating [2]. It is likely that Gen Z students will continue their strong preference for hands-on, practical education activities that provide meaningful experiences as young adults as they continue into college courses and higher education [3]. Rickes proposes that craft-shops and/or makerspaces may match students' interests in creativity with a venue on campus in which to make and design.

A makerspace is typically defined as a space in which various tools and technologies are provided to support rapid prototyping and creation of products [4]. Typical technology will include 3D printers, laser cutters, hand tools or power tools, and electronics support, as well as light-prototyping supplies including craft supplies and/or Legos. Beyond the technology, these spaces are often viewed as a place for students to be creative, learn new skills, and practice various behaviors typically identified with engineering. Prior research has suggested the informal-learning that happens in the makerspace is often due to the sense of community from students working closely and learning from peers [4, 5].

The integration of makerspaces into a first year engineering course can complement learning objectives and improves student interest in the materials presented. Students surveyed by Avrithi reported that the single most important change that could be made to their introduction to engineering class would be to provide more information about the available engineering disciplines (59%) and have lab-sessions incorporated into the course (23%) [6]. Makerspace classes can meet these needs by not only showcasing the modern innovations in science and engineering behind the makerspace equipment, but also provide students related in-class lab activities to learn how to use the equipment. Traditionally, course goals for first year engineering courses often focus on teaching technical competency, design thinking and problem solving, and rapid prototyping [6]. However many universities view the introductory engineering course as a critical retention class to reduce the number of students who change majors or drop out [7]. Many institutions are focusing on instilling a sense of identity and belonging to the field of engineering in their students in an effort to increase retention [8,9]. As one way to instill a sense of belonging, Carbonell et al. found that the integration of the makerspace into various coursework increased technology self-efficacy, affect toward design, design self-efficacy, and sense of belonging [5].

There are multiple examples of universities already using makerspaces with their first-year engineering courses at various levels of integration. New York University requires first-year engineering students enrolled in an introductory course to visit the makerspace for orientation, enticing students to try 3D-printing to earn extra credit on the final project [10]. New Jersey Institute of Technology has used 3D-printing as a way to reinforce 3D modeling with a mini design competition and creation of a spinning top [11]. At the University of Florida, their first-year Engineering Design and Society course teaches human centered design while incorporating makerspace training classes to prepare students for the final term project which must include Arduino and 3D printed designs [12].

This paper documents an effort to modify an existing design project in a first-year engineering course to a team-based project that utilizes various technologies in the campus makerspace, including Arduino, hand-tools, a laser cutter, and 3D-printing. The logistical aspects and challenges of integrating the makerspace into the existing curriculum are discussed, as well as the guidelines for the revised class periods and final project.

This paper also provides an analysis regarding whether integration of a makerspace into a first-year engineering course positively or negatively impacted first-year students developing: 1) an engineering or maker identity, 2) technical skills, and 3) general engineering skills such as curiosity, problem solving, and/or teamwork. Students completed pre/post surveys regarding prior makerspace experience, their first-year makerspace experience, engineering identity, and general engineering skills. The survey results of students who participated in the maker-sections of the course are compared with survey results of a control group who did not have the maker-integration in the same course.

Course Background

The *Introduction to Engineering* course at the University of New Haven (EASC1107) is intended to be the first engineering and design course taken by students majoring in chemical, civil, electrical, industrial, and mechanical engineering, and a few other less-represented majors. The 3-credit course meets twice a week for two, 100-minute class periods in a flexible classroom. The table and chairs are on wheels usually positioned for teams of 4 and rolling whiteboards are available for each group. While prior classroom activities including building a balsa-wood bridge, estimating the capacity of a cup lifeboat for penny passengers in a body of water, and making spaghetti towers for the marshmallow challenge occurred, the physical room itself is not equipped with traditional “maker” technology. However, the campus makerspace is in the basement of the same building and is open to students of all majors. The University of New Haven makerspace is equipped with 3D-printers, laser cutters, a vinyl cutter, a tabletop Carvey CNC, hand tools, sewing machines, craft supplies, and support for hobby electronics. Currently, the makerspace is able to financially support modest course projects through industry donations.

The existing course model was structured around three projects, with an additional customer-awareness infused term project. As the introductory course to a spiral curriculum infusing multiple engineering topics and disciplines into each course, much of the content covered in class was lecture-based with handouts or problem sets and demonstrations aimed at helping students achieve proficiency with basic engineering calculations from the fields of electrical, mechanical, civil and systems engineering. The term project tasked students with developing a new puzzle for a specific market segment (e.g., elementary school students, senior citizens). Students would complete multiple interviews with stakeholders, brainstorm and evaluate ideas, and individually design a puzzle to be 3D-printed by the class teaching assistants. While students worked in teams to engage their specific stakeholder group, individually each student designed their own puzzle, which minimized the reliance on teamwork typically seen in introductory courses. Additionally, though students were given documentation for how to create designs that would be successful when printing, poor attention to detail and the nuances of designing for the 3D printers often resulted in failed prints and students needing to redesign quickly to have the teaching assistant reprint the design for them.

After attending the 2019 KEEN faculty development workshop, “Making with Purpose,” the EASC1107 course was identified for its opportunity to better integrate the makerspace not only into the final term project, but also throughout the course to assist with meeting various learning objectives.

Methods

Course Redesign

Three class periods of EASC1107 were transformed into makerspace class periods to instruct students on: 1) Laser cutting and hand tools, 2) 3D-printing (50% existing content based on 3D modeling), and 3) Arduino. To make room for the 2.5 new class periods, other content in the course curriculum was simplified to have less in-class coverage (i.e., the math review section on units and basic math became one class period and homework rather than two class periods).

The laser cutting and hand tools lesson took place in the makerspace and introduced the importance of rapid prototyping by asking students to design a ring-toss game, first with cardboard, then with hand tools, and finally showcasing how a laser-cutter could refine their prototype. Students were taught safety using metal files and coping saws, while also learning the Adobe Illustrator software for laser cutting. The 3D-printing class period was a modification of an existing lesson that instructed students in the 3D modeling software, Inventor. In the new lesson, rapid prototyping was emphasized again as well as how 3D-printing is changing the field of manufacturing. Students then used Inventor to create various shapes, and followed along as the instructor took a design, formatted it for 3D-printing, and sent it to the printer with the printer beginning to print. The importance of shape orientation, overhangs, and supports were all emphasized by passing around examples of 3D-printed items showcasing the various successes/flaws of 3D-printing. The last maker class on using Arduino was inserted into the curriculum after the introduction to electrical circuits and calculations. Each team was provided with an Arduino kit and was tasked with completing three tasks including making LEDs blink in certain patterns and using a light sensor to change the brightness of an LED. Full lesson plans and slide decks for these activities are available online at EngineeringUnleashed.com [13].

The term project was modified to have a heavier emphasis on teamwork and facilitate student usage of the makerspace equipment themselves (as opposed to through a teaching assistant). While students were still tasked with designing a puzzle for a specific stakeholder group and completing market research and stakeholder feedback surveys, students had to find a way to showcase STEM technology in their puzzle by using the makerspace to manufacture various parts of their puzzle. Each team of four students had to incorporate at least one component made with each of the makerspace technologies showcased in class (hand tools on wood, laser cutting, 3D-printing, and Arduino). Specifically, each student was assigned to be the lead designer for a specific technology that would integrate into the project, ensuring individual contributions to the team project while still ensuring the team must work together to successfully complete the puzzle design. Teams were provided with a small amount of supplies (two 12" square sheets of cardboard and two 12" square sheets of plywood), and were informed they could use other available materials in the makerspace to manufacture their prototype (e.g., acrylic). Project assignment handouts and grading rubrics are available online at EngineeringUnleashed.com [14].

Research Questions & Assessment Plan

Three sections of the EASC1107 course during the Fall 2019 semester included the makerspace initiatives, and three did not. The class sizes were capped at sixteen students, with a range of 11-16 students per section. Two different faculty facilitated the pilot sections using the makerspace, and three faculty facilitated the prior format in their sections.

It was hypothesized the integration of the makerspace into the *Introduction to Engineering* course would have both benefits and disadvantages. As such, the faculty leading the pilot sought to investigate:

1) Does incorporation of the makerspace into a first-year course improve or diminish engineering or maker identity in first-year students?
2) Are there specific technical skills that are developed in first-year students when using the makerspace in a course?
3) Are there general engineering skills (i.e., curiosity, problem solving, teamwork) that are developed in first year engineering students when using the makerspace in a course?

Prior investigations into the effectiveness of courses leveraging the makerspace typically have used student pre/post surveys with both Likert and free-response questions, covering topics related to technology efficacy, design efficacy, sense of belonging, and more [5, 12]. Similarly, the faculty of the pilot sections prepared a pre and post survey that all students taking EASC1107 would be asked to complete. IRB approval was obtained, and students were asked to consent before completing surveys. The surveys had students create an anonymous identifier by which we were able to match their pre and post surveys while retaining student anonymity. Due to the challenges of having all students complete the pre/post survey, as well as one faculty member not passing out the post survey in time, the analysis is presented for 3 sections of makerspace courses with 22 paired responses, and two sections of the traditional course model reflecting 25 paired responses.

The pre survey was passed out in the middle of the semester, just prior to starting any of the makerspace-infused lessons. The various sections included: demographic information, prior makerspace experience, engineering and maker identity questions, and general engineering skills. Questions asked for Likert-scale as well as short-answer responses to collect a variety of feedback while keeping the target survey response time to 5 minutes. The post survey contained the general concepts, but removed the demographic and prior makerspace experience sections, replacing them with a section summarizing makerspace utilization during the semester. All data was transcribed and matched into pre/post pairs based on the anonymous identifier. Various statistics were calculated, and short-answer questions were coded for themes.

Results and Discussion

The student demographics of the makerspace and traditional cohorts

We first analyzed the demographics of our students, comparing those in the makerspace sections of the course and those in the traditional model. The makerspace sections consisted of 31.8% identifying as female, 13.5% as Hispanic, 22.7% as a race besides White, and 31.8% as first generation college students. The control sections self-identified as 12% female, 12% Hispanic, 24% as a race besides White, and 12% as first-generation students. Figure 1 shows the difference in student majors between the two groups of students. The differences in demographics and student major are not unusual with small class sizes and are unable to be avoided.

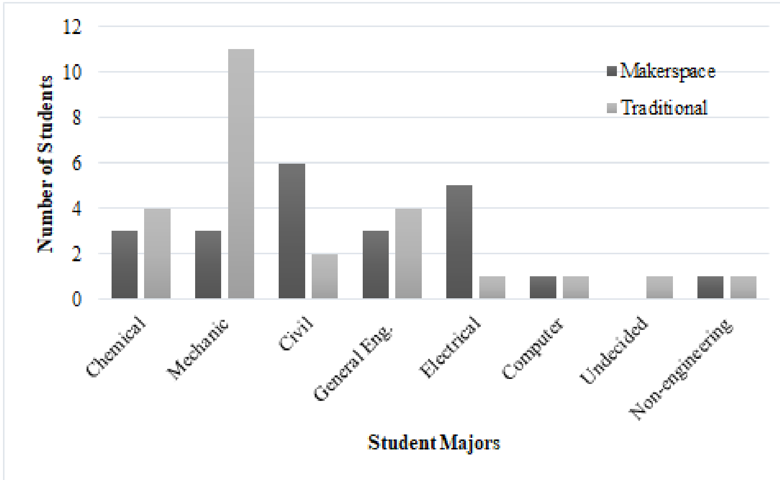

Figure 1: Student majors in the course sections included in analysis.

It was expected that we would have students of different skill levels on the makerspace equipment before beginning the class curriculum, especially as makerspaces have become more prevalent in high schools and other non-university settings. Figure 2 shows how many times students had visited the makerspace prior to starting this course.

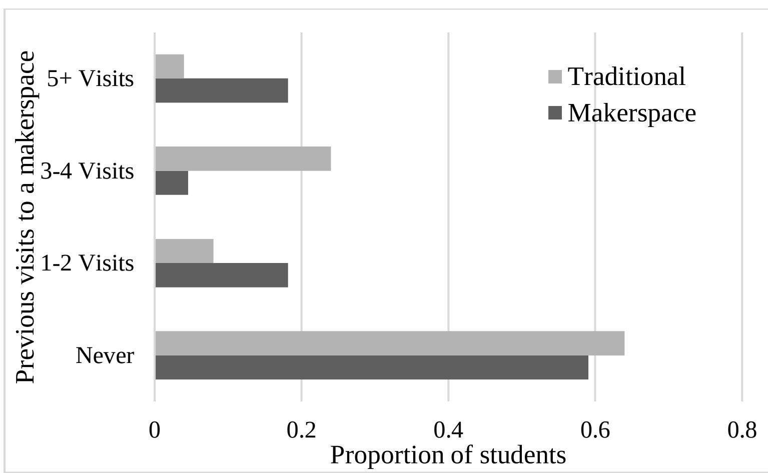

Figure 2: Percentage of students who had visited a makerspace before this class.

Figure 3 shows the comfort level of students on the various types of equipment that would be used during the course, where 1 indicates “not at all comfortable” and 5 indicates “extremely comfortable.” The experience level of the students in this study varied greatly with most having minimal/no experience in the maker technologies, which follow similar trends to other first-year programs using a makerspace [12]. Of particular note is that in our student population, most felt comfortable with hand-tools and more students had prior experience in 3D-printing than expected. There was little difference seen between students in the makerspace sections and students in the traditional sections of the course with respect to existing comfort using makerspace equipment.

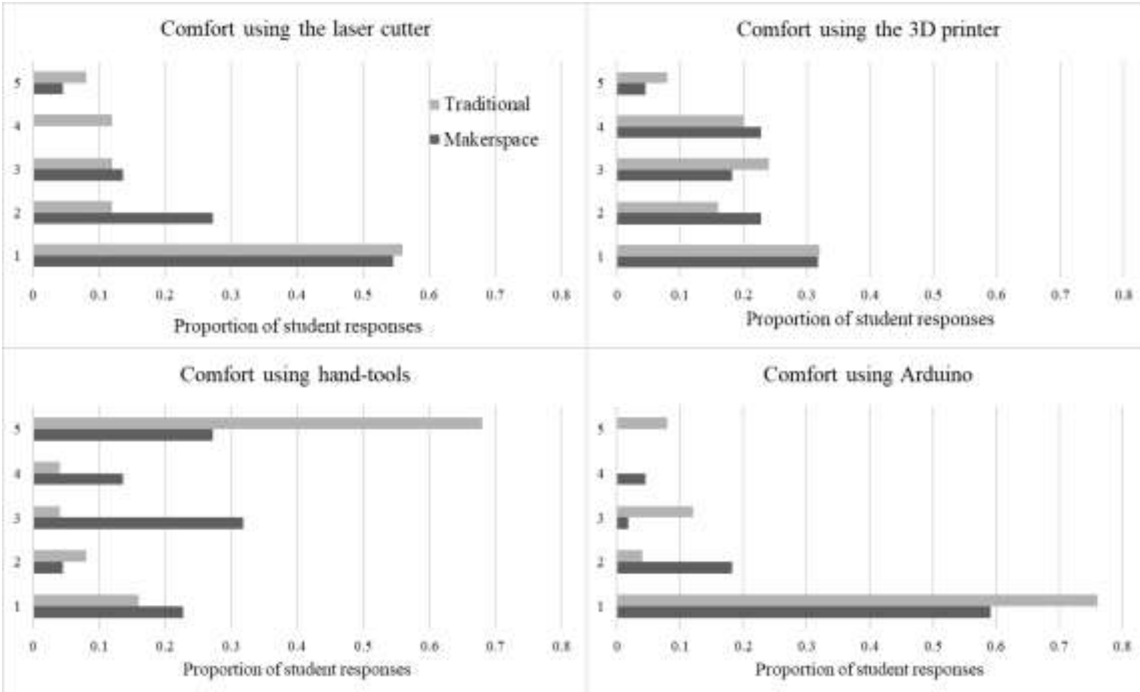

Figure 3: Student's self-reported initial comfort using the makerspace equipment

RQ1 Results: Impact of makerspace inclusion on identity

The two specific questions aimed at identity on the pre/post survey asked: *Do you think of yourself as an engineer? Why or why not?* and *Do you think of yourself as a maker? Why or why not?* Student responses were numerically coded with "2" for a yes answer, "1" for a somewhat answer, and "0" for no answer. Table 1 shows the mean results of both groups on the pre and post survey questions. Comparing the pre/post surveys for the two groups shows a small positive shift in the average answer across all students, but no statistically significant differences at the $p<0.05$ level. Similar analysis by Dickrell showed a general trend that students were more likely to identify as a maker and gain confidence in their making and building skills, but responses were coded using a 6-point Likert scale and statistical significance was not reported [12]. The numeric 3-point range used from our questions was likely too narrow to see any detailed trends.

Table 1: Mean numeric coded scores for identity questions, range of 0 (no) to 2 (yes).

	Pre-Survey Mean	Post-Survey Mean
Traditional Sections- Do you think of yourself as an engineer?	1.40	1.43
Traditional sections- Do you think of yourself as a maker?	1.76	1.86
Maker sections- Do you think of yourself as an engineer?	1.45	1.70
Maker sections- Do you think of yourself as a maker?	1.22	1.40

The importance of instilling identity in engineers is often related to retention [8,9]. As such, three additional questions were asked in the pre and post survey: *How likely are you to remain an engineering student next semester?*, *How likely are you to complete your engineering degree?*, and *Explain your answers for the two previous questions*. The averages calculated from the 5-point Likert-scale questions did not reveal any trends nor statistical significance, with all group means in the narrow range of 4.04-4.64. The students who increased their response between the pre and post surveys often cited reasons related to enjoyment: "*I am truly enjoying and interested in engineering*" and "*I enjoyed this course and learned a lot through it*." Students who lowered their response between the pre and post survey often cited challenges with math or other courses: "*My mind isn't mathematically inclined*" and "*My classes right now are very hard and I can only think that they will only get harder from here.*"

RQ2 Results: Impact of makerspace inclusion on technical skill development

In order to assess technical skill development, we first examined at how often students visited the makerspace outside of class time for class-related work. The traditional section students visited for an average of 3.76 visits, while the makerspace section students visited an average of 5.91 visits (statistically significant at the 0.05 significance level, $p = 0.019$). Figure 4 shows the distributions between the two sections regarding the number of visits a student made to the makerspace outside of class time. Additionally, 63% of students in the makerspace sections visited the makerspace for a non-class reasons compared to only 42% of those in the traditional section. The data suggest that by strategically introducing students to the equipment in the makerspace, they were more likely to visit the makerspace outside of class time and for non-class purposes.

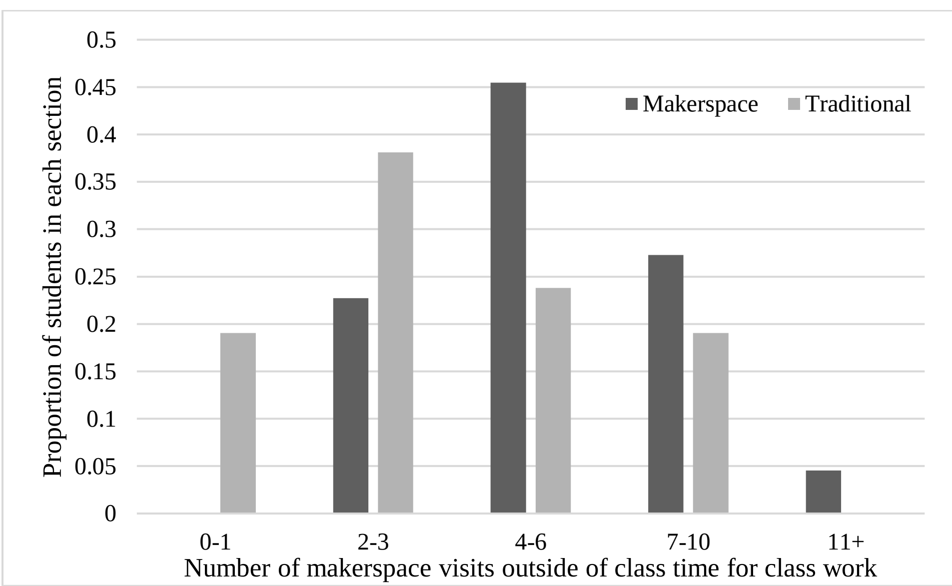

Figure 4: Number of visits per student to the makerspace outside of class time

An understanding of how to personally use the various pieces of equipment in the makerspace is an important part of being able to create high-fidelity prototypes, as well as promoting competency in the various software related to each technology (e.g., 3D modeling in Inventor, or coding in Arduino). Most students across both sections reported using between one and three pieces of equipment in the makerspace over the course of the semester. Figure 5 shows the differences in equipment utilization between the makerspace sections and the traditional sections. The students in the makerspace sections reported using the 3D printers, hand tools, and Arduino technologies more, while the students in the traditional sections reported using craft supplies more. The larger than expected number of students in the traditional section who used the laser cutter could be due to two reasons: 1) the students in some sections were permitted to use the laser cutter with makerspace-staff assistance to create their final project if they had a 2D design that would be better suited for cutting than 3D-printing, and 2) the first-year Engineering Living-Learning Community did an event at the makerspace using the laser cutter and it is possible that many of the students of the EASC1107 course participated since ~30% of first-year engineering students are enrolled in the living-learning community.

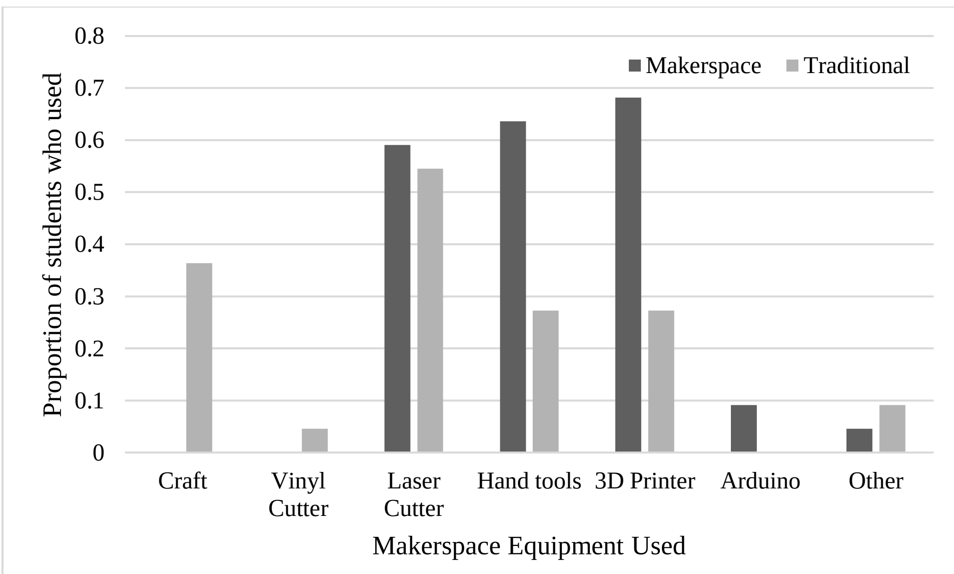

Figure 5: Percentage of students who documented using various makerspace equipment.

The expanded project requirements for the makerspace sections required that a single prototype that integrated all four types of showcased makerspace technology (laser cutting, hand tools, 3D Printing, and Arduino) be built. All eleven teams participating across the three sections were successful in meeting this requirement, demonstrating technical competency in software and hardware not usually included in a first-year engineering course.

RQ3 Results: Impact of makerspace inclusion on general engineering skill development

Responses to the question *What do you think is the most important part of being an engineer?* were coded to identify either skills (i.e., creativity, teamwork, design process, solving problems) or attributes (i.e., hardworking, desire to give back, passion). Figure 6 shows that students in the makerspace sections were more likely to identify skills as being important than the students in the traditional sections. This could be an important differentiation as students come to college to learn skills, but changing characteristics related to personality, even when desired, can be significantly harder without additional help and support [15].

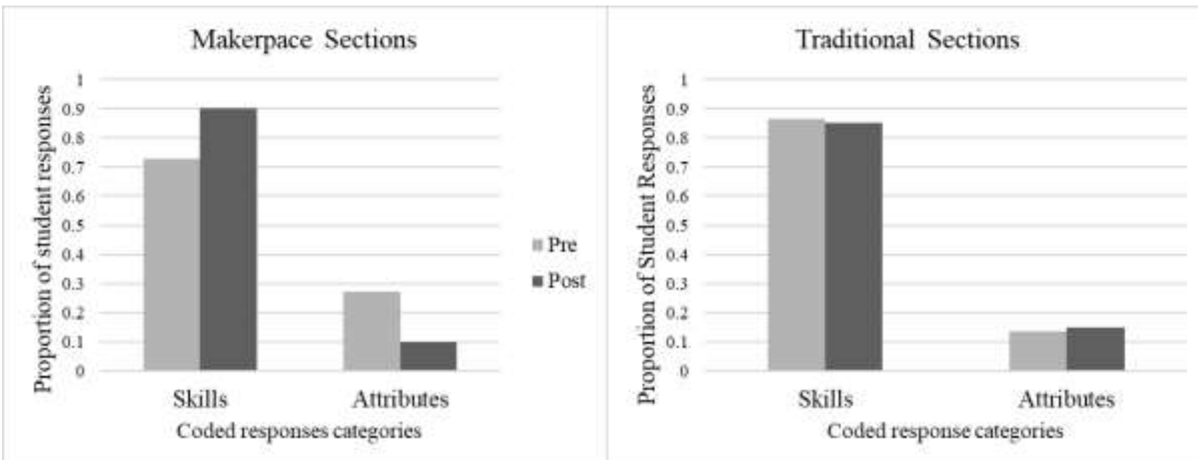

Figure 6: Percentage of student responses indicated skills or attribute for the question *What do you think is the most important part of being an engineer?*

Teamwork is an essential role for all engineering students. Students were asked what type of role they preferred to take in a team setting (manager, facilitator, secretary, or technical expert) in the pre/post surveys. Changes in the results of the surveys were not significant between the two sections of students, but a general trend indicated that fewer students selected manager in the post survey (makerspace sections: 30 % pre, 17% post; traditional sections: 64% pre, 50% post) and were more likely to serve in other roles such as the technical expert role (makerspace sections: 10% pre, 17% post; traditional sections: 4.5% pre, 22% post). This may show self-efficacy in technical abilities, but further analysis with more students is needed to draw conclusions.

Two additional questions were asked regarding how students approach a roadblock in an engineering analysis problem and hands-on problems. Students were asked, *When you are working on an analysis (math-based) problem, if you don't know how to do the next step, how do you try to solve the problem?* and *When you are working on a physical design (hands-on) problem, if you don't know how to do the next step, how do you try to solve the problem?*. Paired student written responses were coded according to any changes in approach. Table 2 documents the changes in student responses by type.

Table 2: Documented types of change in student responses to how they approach roadblocks in an engineering analysis (math-based) problems and physical design (hands-on) problems.

	Type of Change	% of Students from Makerspace Sections	% of Students from Traditional Sections
Engineering Analysis Problem	No documented change	77%	60%
	Ask for help immediately	4.50%	8%
	Ask for help secondary	4.50%	4%
	Develop independence (try to solve on own)	18%	28%
Physical (Hands-on) Problem	No documented change	64%	80%
	Ask for help immediately	23%	8%
	Ask for help secondary	0%	0%
	Develop independence (try to solve on own)	13%	12%

While both groups saw the majority of students keep their same problem-solving approaches, students in the makerspace sections were less inclined to develop individual independence when solving an engineering analysis (math-based) problem than those in the traditional sections. This could be a result of reduced in-class time for math-based problems due the makerspace-lessons added to the curriculum. However, students in the makerspace sections were more likely to show changes in their inclination to ask for help immediately with respect to hands-on problems. Much of the makerspace research focuses on community building and the importance of feeling comfortable asking for help. At the NYU makerspace, it was often seen that new users felt training provided by student TAs were too technical in nature, assuming baseline knowledge that did not exist, which results in students feeling uncomfortable asking the TAs for help [10]. As such, having students in the makerspace more often for class periods, class-homework, and non-class related activities may help students feel comfortable asking for help if they feel lost on what step to take next.

Faculty reflections on scaffolding student makerspace projects for success

Reflecting on the process of leading the new makerspace-infused lesson plans and project, both faculty members thought students seemed engaged throughout the project. As students enter university with more varied technology backgrounds, offering students the option to pursue what technology they can use in a project rather than limiting it to a subset allows students to continue gaining new skills even if they have prior experiences. Often, the Arduino technology was seen by students as the most complicated to learn and thus if there was a student on the team with prior experience coding, they often took the lead and advanced their own skill set in that area beyond their level from the start of the semester before entering the class. Similarly, Hira suggested allowing flexibility in makerspace technology usage allows students to explore what they are most interested in within the scope of their project or learning goals [16].

Nadelson identified that students often took longer than expected completing makerspace activities with possibly fewer learning outcomes met when compared to more traditional teaching styles [4]. As such, it is important to structure the project in such a way that the leading faculty appropriately estimate the time requirements of each component and provide sufficient class time and additional work time for students to complete their project. While students in the makerspace sections had a minimum of two full class periods to work on their project, as well as at least two weeks outside of class time, the late Thanksgiving holiday break impacted makerspace hours available to students on campus toward the end of the semester. One faculty member took six hours on a weekend to open up the campus makerspace for teams who needed additional time on the equipment. The authors encourage new faculty to strongly consider the added benefit to the students of utilizing the makerspace. However, if students are only using the equipment to complete a requirement and are not gaining any knowledge on the purpose or utility of the makerspace equipment outside of class purposes, the addition of the makerspace into classrooms may not be worth the added time commitment or financial cost.

Facilities Considerations

The use of the University of New Haven makerspace was both advantageous and potentially problematic. Many universities have large maker-facilities, or sometimes even dedicated maker-classrooms, with specific resources and space reserved for those students enrolled in the classes [5,12,17]. At our smaller institution, the makerspace is open to students of all majors and is not intended to serve as a classroom space. Special arrangements were made with the makerspace staff to reserve certain equipment during class periods that instructed and showcased the technology during class times. However, this may not be a long-term solution as the new curriculum is shared across all six expected sections of EASC1107 every fall semester. Additionally, while we informed the makerspace staff of expected deadlines during which we expected a large number of students to visit the makerspace, the timing coincided with other classes assigning their makerspace projects and thus there was often a wait for students to use the equipment. Universities looking to integrate a makerspace into coursework should have a conversation with makerspace staff or management to ensure that the physical space or equipment is not being commandeered by a new initiative and taking resources away from other groups on campus.

Conclusions

The faculty successfully implemented three class-periods of makerspace activities into a first-year engineering course, as well as modified a term-project to have a heavier reliance on the makerspace equipment. Class periods were hands-on in nature and taught the technology of the laser cutter, hand tools, 3D-printing, and Arduino while also teaching complementary skills of rapid prototyping, engineering design, modeling software, and thinking creatively. The implementation of the makerspace lessons and project were viewed as successful by both the faculty and the students, with many students reflecting positively in their end-of-course reflections on the makerspace activities and projects.

Specific gains or losses in course outcomes related to adding the makerspace were assessed via pre/post student surveys across both students in the makerspace sections and those in the traditional sections. Survey results indicated that all students showed an increase in identifying as an engineer and maker, but the changes were not statistically significant between the pre/post surveys or between the sections. Students in the makerspace sections visited the makerspace more for class-related work and also visited the makerspace more for non-class related work. Students in the makerspace sections were also more inclined to individually use more of the advanced technology available in the makerspace and practice new technical skill sets not often introduced to first-year students.

Last but not least, students in the makerspace sections were more likely to change their beliefs toward engineering to identify skills such as teamwork, problem solving abilities, and communication as being the most important part of being an engineer as opposed to characteristics related to personality traits like determination and the ability to adapt. This finding could link to the literature on developing student identity and thus helping with retention in engineering, but further studies are needed. A barrier to identity in the makerspace is often the sense of feeling like an “outsider” as a new visitor to the makerspace, but students who participated in class activities and assignments in the makerspace stated they were more likely to ask for help when unsure of the next step in a hands-on project. Using makerspaces in the classroom could be a key to breaking down the entry barrier for students to feel their sense of belonging to the maker community, even if it takes more than 8 weeks to develop. The authors will attempt a follow-up survey of all of the students to see how many continue to use the makerspace after the semester has ended and their coursework no longer requires it of them.

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