Making Improvements:
Pedagogical Iterations of Designing a Class Project in a Makerspace

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This research paper examines a professor's pedagogical adjustments over two semesters teaching a course that included a project in the university makerspace. This research used both qualitative and quantitative methods and was guided by the following research question:

- *What is the professor experience across two semesters teaching a course that incorporates a project in the makerspace?*

Observations of class presentations and final projects demonstrated a difference in project quality from the first semester to the second semester. Findings include that familiarity with the makerspace, prior experience with an open-ended project, and peer support for students seemed to produce superior student engagement and output without vast pedagogical shifts.

Keywords: makerspace, pedagogy, engineering education, student engagement, project

BACKGROUND

In recent years, substantial educational resources have been invested into makerspaces (Vossoughi, Hooper, & Escude, 2016). and the maker movement with the underlying assumption that these spaces generate experiences that ignite interest and engagement in engineering and entrepreneurship. University affiliated makerspaces have been shown to have a significant impact on the student experience by building students', innovation orientation, and sense of self-efficacy in multiple areas of engineering (Carbonell et al., 2019). As the body of literature on student impact develops, it joins the larger body of makerspace research. Predominantly, research examining the organization and operation of makerspaces (e.g. the design and layout, the type of equipment, the role of administration). Makerspace use has shown promise integrating the relationship between informal and formal learning; changing our methods for teaching, evaluation, and assessment; developing diversity, accessibility, and inclusion; and leading to new technologies and innovations (American Society for Engineering Education, 2016). These facilities are full of potential for the implementation of a variety of pedagogical techniques, but thus far there is a gap in makerspace literature exploring the pedagogy from a faculty perspective within the makerspace, specifically the decisions instructors make when planning and implementing class projects in the makerspaces.

In critical examinations of makerspaces within education, the findings are clear that these spaces can support opportunities to engage in STEM content as well as design, innovation, and identity. For example, in a study of a 10-week project in K-12 makerspace, Fosso and Knight (2019) situated design thinking "at the heart of makerspaces" (p.3). They found that the constant negotiation and collaboration required to complete a project within the makerspace provides a sociocultural space to support identity-building. In their literature review of K-12 makerspaces, Vossoughi and Bevan (2014) found that pedagogical structures were absent or minimal; or the methodological and conceptual approach of studies minimized the explicit attention to pedagogy in the makerspace. Specifically, when educators are mentioned in the studies of makerspaces they are described as "facilitators," "guides," or "coaches" with a deemphasis on the act of teaching (Vossoughi, et al., 2016).

In university makerspaces, educators and researchers are focused on student learning within university makerspaces. For example, Tomko and colleagues (2018), focus on exploring the complexity of makerspaces by asking questions like "What is going on in these spaces?" and "What are students learning?" and "What does learning look like ?"In a review of research on Academic Makerspaces, Rosenbaum and Hartmann (2017) identified only 5 studies that used qualitative methods, one of which used a case study approach to study student experiences in an extracurricular makerspace (O'Connell, 2015). This review also pointed out that while empirical research is focusing on student outcomes and curricular integration, many of the reports on academic makerspaces focus on the equipment and physical space of the makerspace itself (i.e., 18 out of 22 reports cited).

In engineering education, class projects in university makerspaces represent one pedagogical approach to encourage student participation in makerspaces, particularly within the first years of an undergraduate program (Dukart, Orser, & Guengerich, 2020). For example, in one makerspace over the course of two years, over 50% of students visiting the makerspace attended for a class project and 61% of student visiting the space for a first time did so for a class that required the use of a makerspace. Of the 72% of students that returned to the makerspace, 47% returned for class projects (Josiam, Patrick, Andrews, & Borrego, 2019). In an exploration of a faculty-designed project for students in junior and senior level engineering courses, she identified best practices for incorporating a class project which included instructor familiarity with the makerspace, prior-experience designing open-ended projects, and peer support (Carbonell, Boklage, Clayton, & Borrego, 2020). Despite this increase in a focus on what is happening in engineering classrooms, strategies to purposefully create inclusive classrooms that utilize the makerspace are largely missing from the literature, in part because of the theoretical framing of these studies. What is clear from the research is that supporting faculty and the individuals that design and guide these projects are essential components of their success (Vigeant et al., 2020).

Research has shown that assigning students a project that requires them to use the makerspace increases their likelihood of returning to the makerspace (Josiam et al., 2019). In a study that used quantitative methods to examine student outcomes over the course of an academic year when enrolled in a course which utilizes the makerspace, Brubaker and colleagues (2019) found students experienced significant gains in design, innovation, and engineering task-self efficacy and perceived closeness to a maker community in these courses. While research has reported on academic makerspace creation, development, and integration into engineering curricula, less research has used a qualitative approach to focus on instructor curricula and pedagogical decisions when using a makerspace for their course.

This previous research gives us some benchmarks, but it is important that pedagogical techniques and faculty experiences in higher education be studied in order to optimize the usefulness of makerspace projects for undergraduate engineers. This research addresses the gap in makerspace literature exploring the pedagogy from a faculty perspective within the makerspace, specifically the decisions instructors make when planning and implementing class projects in the makerspaces.

CONTEXT

This study was conducted at a large, public research university in the southwestern United States. This university boasts a large and respected engineering school with an undergraduate engineering population of approximately 6,000 students. The school of engineering is home to a recently redesigned makerspace that is available to all engineering students and faculty for coursework, research, and personal projects. The makerspace is over 30,000 square feet and is prominently located in the newest engineering building on campus. The space is highly visible with floor to ceiling windows giving it a powerful presence in the school of engineering, while providing a warm inviting atmosphere. As students contemplate projects and possibilities while walking to their engineering courses, they are reminded of the technology and support available to them in the makerspace.

The Space

In this university makerspace, students are given access to desktop additive manufacturing machines (3D printers), laser cutters, soldering stations, desktop CNCs, and a variety of hand tools to be used in the space. Laser cutters, soldering stations, and CNCs require safety trainings that are available throughout the semester. As an engineering school with a proud history of additive manufacturing research and development, the different 3D printers – and their respective filaments and resin - are free to use; however, other materials such as electronic components, acrylic sheets, and plywood are sold at cost in the space.

The makerspace is led by three knowledgeable fulltime employees who train a cohort of undergraduate student workers. These student employees are the primary face of the space and assist their peers by leading trainings, answering questions, and helping students troubleshoot project issues. One method of faculty assistance is a makerspace project grant given to selected engineering professors at the beginning of each semester. This funding is often a necessity for professors to explore the space and expose their students to the opportunity for projects that deviate from pencil to paper design projects that dominate engineering coursework by including the development of physical final products or prototype.

Participant

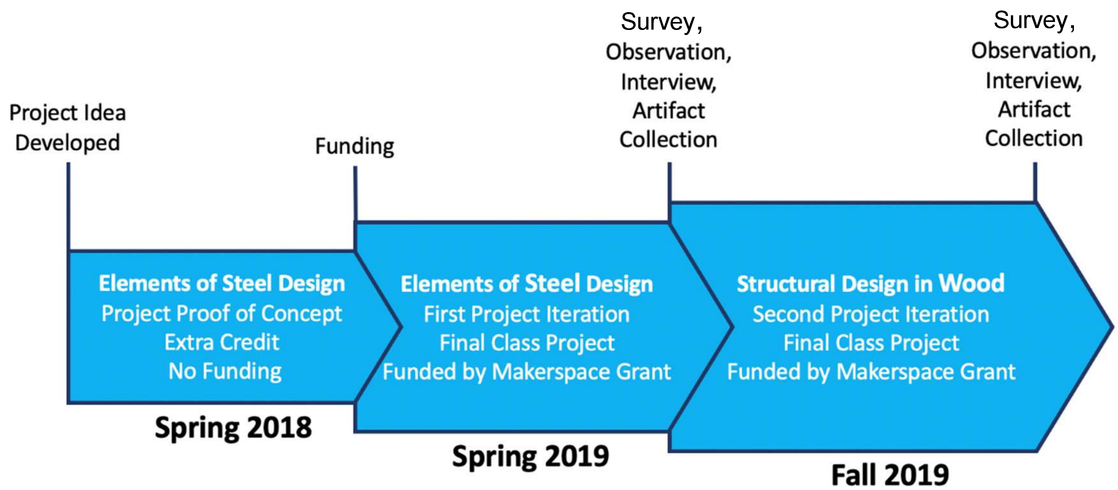
Dr. Cook is an assistant professor in the department of civil engineering and a recipient of the makerspace grant. Her expertise is in structural engineering and her research interests are in the design and testing of largescale steel structures. Observations of her class reflect a keen interest in students' growth, empathy for the student experience, and awareness surrounding the potential pitfalls that accompany the different projects engineering professors employ in their design courses. Her pedagogical leanings, developed through her close examination of engineering education, include a "firm belief" (Dr. Cook's words) in the use of physical models to improve students' understanding of new engineering concepts.

Project and Courses

Researchers followed Dr. Cook's classes over a period of two semesters. During these semesters Dr. Cook had received university funding to put towards adding a makerspace-based project to her course. Prior to receiving this grant, Dr. Cook had developed an idea to incorporate a project in her course that encouraged students to work in teams and develop a physical model based on a concept they had learned in class. Students would then reteach that concept to the class using the model in a five-minute presentation at the conclusion of the semester prior to final exams. The inspiration for this was her aforementioned belief in the importance of physical models. This created a desire to incorporate more physical models into her teaching practice; however, this objective was hindered by her own time constraints. A solution that would benefit her current and future students was to have students create models to illustrate the engineering concepts covered in her course. Additionally, she recognized that teaching a concept is an excellent way for students to further engage with content and review prior to a final exam.

In the spring of 2018 prior to receiving funding of any sort, Professor Cook offered this project in her course Elements of Steel Design – an elective open to juniors and seniors in civil engineering – as an extra credit project. Only 2 students took her up on the assignment, but this pilot run of the project showed enough promise that Dr. Cook decided to pursue funding for the following year. In the spring semester of 2019, she assigned the project to the entire class in Elements of Steel Design with funding from the makerspace grant. The following fall she ran this same project with funding from the makerspace grant in the course Structural Design in Wood, a class she was teaching for the first time. This course is organized very similar to Elements of Steel Design, and caters to the same population of upper classmen, the primary difference between the two courses is the change from steel to wood which leads to a shift in content and concepts.

FIGURE 1
TIMELINE OF PROJECT DEVELOPMENT AND RESEARCH



METHODS AND DATA ANALYSIS

This study used a descriptive, single case study design (Merriam, 1998). Dr. Cook's classes over the 2019 Spring and Fall semesters served as the bounded context with Dr. Cook serving as the unit of analysis, or case.

Qualitative Methods

This study employed the use of semi-structured interviews with Dr. Cook over the course of the 2019 Spring and Fall semesters. The purpose of these interviews was to understand what Dr. Cook described as the context of her class project as well as her planning and implementation for the project. The interviews lasted 60 minutes in length and were digitally recorded and transcribed.

Observations occurred at the beginning of each course, during class presentations, and at the University makerspaces. These observations were used as a way to triangulate data from interviews and artifacts collected throughout the study. In addition to observations, artifacts and interviews, researchers also collected data from an informal feedback survey Dr. Cook shared at the end of each semester. These surveys included open-ended responses such as, "How could the project be improved?" This approach in data gathering aligns with Merriam's guide for case study research in utilizing the three data collection techniques of conducting interviews, observations, and analyzing documents.

Data analysis began at the beginning of the study and continued throughout. This was intended as a process of "making sense of the data…[which] involves consolidating, reducing, and interpreting what people have said and what the researcher has seen and read- it is the process of making meaning" (Merriam, 1998, p.178

Following Merriam's (1998) guide to enhancing the internal reliability of this research, this study used triangulation, member checks through constant comparative analysis. First, the research team open coded the interviews. Open coding involved examining each piece of data and coding it as necessary. After open coding the research team entered a phase of focused coding. Focused codes then enabled the process of memo writing. This memo-ing step served as a space for making comparisons between data, codes, categories, and concepts with the purpose of articulating conjectures and new ideas about the data (Glaser & Strauss, 1967). These memos included raw data with the explicit purpose of keeping the participant's voice and meaning present in the theoretical outcome (Charmaz, 2014).The iterative process of writing and re-reading memos allowed the focused codes to become emergent categories through *constant comparative analysis*. As codes came in tandem with the memo-ing process, the researchers began organizing data in the form of charts and diagrams. This same process was used with the field notes from class and makerspace observations. The next phase of data analysis was *triangulation*, researchers used artifacts a triangulation method of a single case (Guba & Lincoln, 1994) as a method of enhancing internal reliability in our analysis (Merriam, 1998). The final step of the data analysis was *member checking*. In this phase, a summary of the findings was emailed with Dr. Cook asking for her input regarding researcher's findings with her perspectives. Her feedback was compared to the data and integrated into the findings.

Quantitative Methods

To supplement the qualitative data students were given a survey examining their attitudes towards engineering and the makerspace. The online survey, which took approximately fifteen minutes to complete, was administered to students in either the Spring 2019 semester or the Fall 2019 semester, at the beginning and end of the semester. The survey asked participants to respond to a series of Likert, multiple choice, and open-ended questions about their attitudes towards engineering, design and technology.

Survey Metrics

Drawing on prior literature, we compiled a survey instrument to measure five attitudes we hypothesized may be impacted by a student's participation in a makerspace. Students were asked to use a 5-point Likert scale to rate their confidence in their ability to perform a series of tasks in order to measure their *Design Self-Efficacy* and *Innovation Self-Efficacy*. Design self-efficacy, indicated by two items, has a Cronbach's alpha of 0.83 and innovation self-efficacy, indicated by 2 items has an alpha of 0.78. Students' *Technology Self-Efficacy* was measured through four 10-point, Likert scale items that asked students to rate their confidence in their ability to perform a skill at that time (Lucas, Cooper, Ward, & Cave, 2009). This scale has a Cronbach's alpha of 0.87.

Students' sense of belonging was measured through the adaptation of a previously validated 10-point, Likert scale that analyzed students' sense of belonging to their campus via 3 items (Hurtado & Carter, 1997); here, students evaluate their sense of belonging to the makerspace and the engineering community. *Sense of Belonging to the Makerspace* has a Cronbach's alpha of 0.96. *Sense of Belonging to the Engineering Community* has a Cronbach's alpha of 0.94.

Research Design

We conducted all data analyses using StataCorp. 2015 Stata Statistical Software: Release 17. Our sample includes all survey responses from students who had taken Dr. Cook's courses (n=64). Then, we removed respondents by listwise deletion if they were missing values for any of the 5 factors of interest. This left an analytical sample of n=48. Of these 48 students, only 12 took both surveys; a total of 18 took the "pre" survey and a total of 30 took the "post" survey. Subsequently, unmatched t-tests were conducted for each of the five factors of interest to measure differences between pre- and post- group means. We used a Bonferroni correction of p=0.01 to account for the five t-tests run and calculated effect sizes for each factor to further quantify the difference between pre- and post- groups

FINDINGS

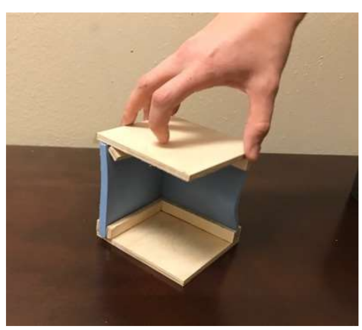
Semester One: Elements of Steel Design

Once Dr. Cook received a grant to do a makerspace-based project in her course, she used that funding to add a final project to Elements of Steel Design. The research team interviewed Dr. Cook after the final projects were presented. From this interview, Dr. Cook emphasized that funding was a necessity for running this project at scale. With funding, she was able to hire a TA to help with the organizational complexities and materials sourcing that the project required. This was a larger job than she or the TA had anticipated at the start of that semester, and it would have been unmanageable without TA assistance. Sourcing materials from outside vendors for the students was a cumbersome process taking hours of TA time and requiring the TA to play a different role than expected. However, Professor Cook saw that this was a necessity, telling interviewers: "There's a lot of stuff where having a TA or someone to help with material purchasing or stuff behind the scenes that I wouldn't necessarily have time for. So, without the funding, I wouldn't have done it."

Some of the original unique elements of the project involved breaking the assignment down into steps that required students to start before the end of the semester. Dr. Cook had been informed by makerspace staff that procrastination is a common problem with makerspace projects. Her attempt to mitigate this problem and avoid several teams finding themselves unable to complete the project during the end of semester rush, included several benchmarks. The benchmarks required students to get trained on one of the machines by the midpoint of the semester and report their project progress during multiple team meetings in Dr. Cook's office. During these meetings students and Dr. Cook went over incremental deliverables including a project plan, an initial design, and a proof of concept.

After observing presentations and collecting student surveys, Dr. Cook named other critical areas for improvement. She noticed that many students only explained their model and the construction process rather than actually teaching or explaining the concept the illustrated by the models. She saw this as an opportunity to incorporate a rubric or "some other method" to clarify what the presentations required. She also saw several projects where unsafe practices were used and felt eager to emphasize student safety in the next iteration of the project.

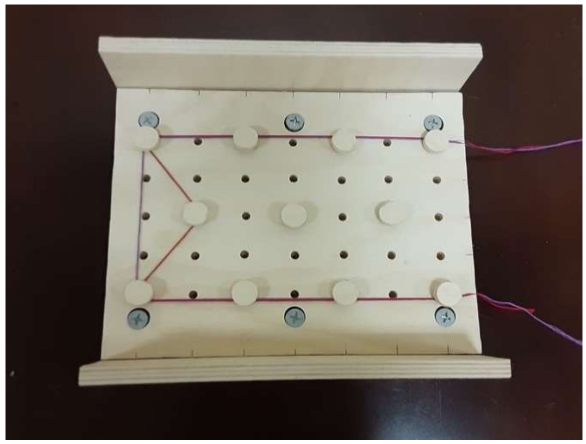
FIGURE 2
PROJECT FROM ELEMENTS OF STEEL DESIGN



While there were successful and impressive projects, many projects were poorly constructed, lacked effort, and fell apart quickly. Figure 2 shows a project that accurately demonstrates that a thinner steel plate will buckle before a thicker plate when a load is applied to them both, however the construction could use more thought and improvement. Dr. Cook told researchers that some of the best projects are incredibly simple, but for this simplicity to work they must be well thought out. An example of this from the following semester is shown in Figure 4.

Another issue was projects that required a great deal of teacher input and explanation rather than demonstrating the concept clearly without a large amount of explanation. There were also projects that entirely failed to physically demonstrate the intended concept. For example, in Figure 3, this peg board is meant to be wrapped with strings to show all possible failure paths around bolts; however, these strings are meant to be arranged by the teacher and if removed or rearranged they could inaccurately represent the concept without future students who are looking at the model accurately identifying the incorrect information being conveyed.

FIGURE 3
PROJECT FROM ELEMENTS OF STEEL DESIGN



Semester Two: Structural Design in Wood

The following semester Dr. Cook included the same project in her course Structural Design in Wood. Much of the project format was kept the same, but Dr. Cook's confidence and familiarity with the space led to improved project and presentation outcomes.

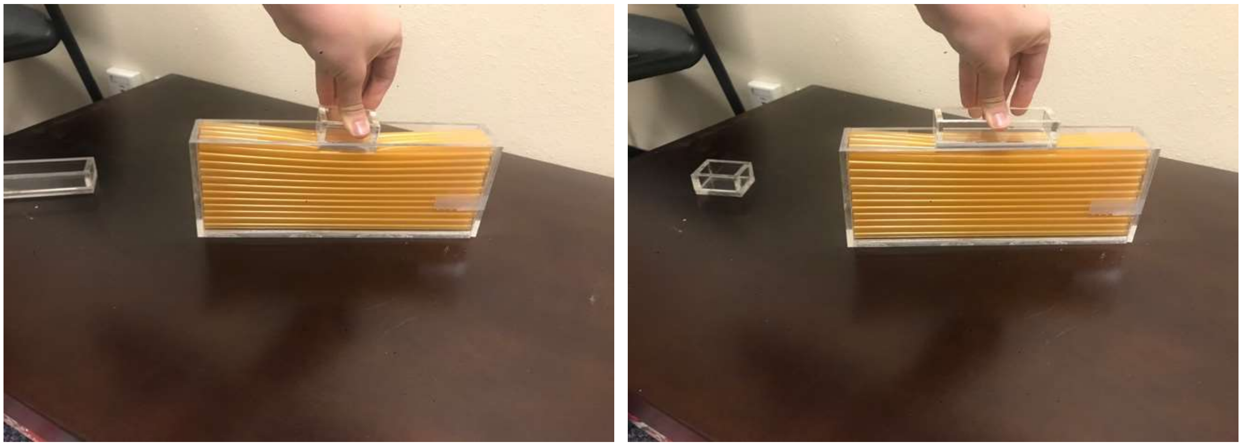
Dr. Cook was able to inform the TA of what to expect when sourcing materials and dealing with logistics. Early in the semester, the TA was able to use this information and speak to the students about prior difficulties sourcing materials. With the TA's previous experience and well-informed students, the same system for obtaining materials went from being cumbersome, and a time-consuming topic of discussion during team check-ins with Dr. Cook, to an inconvenience that students prepared for. This semester, Dr. Cook and the TA had actually dedicated less total time to the project. The students had fewer weeks to complete the project than students in Elements of Steel Design the prior semester.

Another piece of Dr. Cook's teaching that changed during this semester was her own frequent use of physical models to teach concepts. This was her first semester teaching this course and the previous professor had years of high-quality models to explain the concepts in the curriculum. Having these models as an example and watching Dr. Cook teach through the use of these models may have helped students form a better frame of reference for their presentations. Unlike the previous semester, many more students taught the concept they had selected using their model rather than presenting their model and only elaborating on the making process.

Dr. Cook expressed the gratitude she had for the "large impact" made by having a student makerspace employee in her class. This student's project actually did not require the makerspace, but her investment in the space led to her helping other students troubleshoot makerspace issues and ensure that other students were using safe practices. During the question portion of one presentation, this student raised her hand and expressed concerns about an image of the students using a piece of machinery outside of the space without proper eye protection. While this may seem small to someone less acquainted with the space, an employee of the makerspace knows the risks and was able to use that as a teaching moment reminding students that safety is of the utmost importance, even if they are outside of the space at the time.

Project outcomes in the second semester demonstrated more innovation and conceptual understanding. Figure 4 represents a project that is simple but well done with the clear illustration of the difference that bearing area makes in the deformation of wood structures. The stacked straws demonstrate how larger columns can lead to less deformation in a supporting member when a force is applied.

FIGURE 4
PROJECT FROM STRUCTURAL DESIGN IN WOOD



Projects in this semester illustrated ideas more clearly and allowed for more student interaction. For example, Figure 5 is a project that demonstrates the effect of sheathing to restrain lateral torsional buckling in a beam. The sheathing is made out of an acrylic material and the beams are made out of a relatively stiff plywood. The team realized that the plywood by itself did not demonstrate buckling on a scaled down model. These students started early and had time to iterate, they developed a better project by creating a living hinge that allowed the wood to show exaggerated out of plane buckling on a small scale. This pattern, laser cut into the wood, allows the wood to bend, compress, and buckle out of plane without breaking. In addition to the final project shown in Figure 5, the student provided Dr. Cook with 30 additional pieces of wood cut with this pattern (Figure 6) for future students to hold and explore the different deformations that come from applied loads on wood beams. Dr. Cook was "excited" to have these for upcoming semesters not only as an example of iteration while developing a final project, but as a way to allow many students to play with these physical models, easily demonstrating buckling to her future students.

FIGURE 5
PROJECT FROM STRUCTURAL DESIGN IN WOOD DEMONSTRATING HOW SHEATHING PREVENTS OUT OF PLANE BUCKLING

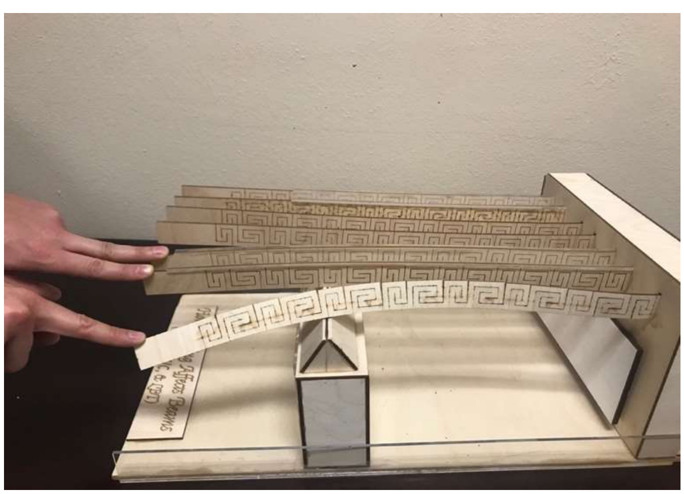


FIGURE 6
1 OF 30 ADDITIONAL BEAMS FEATURING THE LIVING HINGE PATTERN USED IN THE PROJECT FROM FIGURE 5

Survey Results from Courses

Table 1 provides a demographic overview of the analytical sample, generated from student responses to the survey.

TABLE 1
OVERVIEW OF STUDENT CHARACTERISTICS

Major	*n=48*	*%*
Architectural Engineering	22	45.8
Civil Engineering	23	48.0
Architecture	3	6.2
Gender		
Male		
Female		
Race		
White Only		
Asian Only		
Hispanic or Latino		
Foreign		
Multirace		
Black Only		
Prefer not to Answer		

Table 2 details the results of the unmatched t-tests, as well as the effect size, or standardized mean difference, for each factor. Following (Cohen, 2013), effect sizes from 0-0.05 indicate a small difference, effect sizes from 0.06-0.15 indicate a moderate difference and effect sizes above 0.25 indicate a large difference.

TABLE 2
MATCHED T-TEST RESULTS AND EFFECT SIZES

Factor	Pre	Post	Difference	P-Value	Effect Size
Design Self-Efficacy	2.94	3.96	+1.02	0.0000*	1.31
Innovation Self-Efficacy	3.31	4.02	+0.71	0.0001*	1.15

Technology Self-Efficacy[1]	5.44	7.41	+1.97	0.0003*	1.08
Belonging to Makerspace[1]	3.78	5.58	+1.80	0.0169	0.70
Belonging to Engineering[1]	7.41	7.12	-0.29	0.6648	0.12

**An asterisk indicates statistical significance at $p=0.01$*
[1]Indicates a response scale of 0-10. All others are 1-5

Three of the five factors showed statistically significant increases within persons over a one semester period: design self-efficacy, innovation self-efficacy, and technology self-efficacy. These measures of task-specific self-efficacy show very large gains over one semester, with effect sizes ranging from 1.08-1.31 standard deviations. While neither metric of belonging showed statistically significant gains, students' sense of belonging to the makerspace still increased by 0.70 standard deviations over the course of one semester. Sense of belonging to engineering actually decreased, but this change was far from significant.

DISCUSSION

Professor Support

During both interviews, Dr. Cook shared with researchers that she could not do this specific project without the aid of a TA. With the benefits of incorporating makerspace projects into courses in mind, institutions that aim to improve student outcomes through makerspace use should supply financial support. In Dr. Cook's case, sourcing supplies to a large university was the most complex logistical obstacle. The makerspace does not have the storage space necessary to have supplies delivered and stored for the entire engineering student population. Therefore, sourcing and storing materials required Dr. Cook to develop a system specifically for her class. In the first semester, this was an obstacle. This was something that wound up being the primary role of the TA in both the spring and the fall semester, but in the second semester the TA already had a system in place and had a much easier time assisting students with the sourcing process.

In the context of different makerspaces, the exact nature of professor support may vary. Regardless, it is evident that supporting professors who wish to incorporate makerspace projects into their courses is imperative, especially during the first run of a project when they are adjusting to the space and the logistics.

Familiarity

Learning the assets and limitations of the makerspace while incorporating a makerspace project into a course is a time-consuming task. In the first semester of Dr. Cook's funding, much of her time was spent handling logistics while developing benchmarks and support systems for her students. However, during the second semester Dr. Cook ran the project, she was surprised by how much less time consuming the project became. This was not due to any major overhaul, like Dr. Cook initially anticipated after the first semester of the project. Dr. Cook's experience suggests that persistence past the initial hurdles makes including a makerspace project substantially easier and well worth it for the potential benefits of makerspace use.

In addition to increased logistical ease, Dr. Cook found that the difference in quality of the projects between the classes was striking. Even though students in the wood design class had less time to spend on the projects, Dr. Cook was able to spend that time on the project concepts rather than the logistics. As previously mentioned, throughout the semester she told students several topics that would make for excellent projects as she taught. Additionally, she used more models to teach the class during Structural Design in Wood. Using these models may have helped students understand the quality of model that was expected. These models also illustrated the necessary ingenuity and design methodology to show large structural concepts on a small scale. These slight shifts in instruction and the drive to continue seeking the benefits of a makerspace project even after some difficulties during the first semester of her project led to a decreased professor workload and improved student output.

Student Staff

Dr. Cook recognized the importance of having a student on the makerspace staff in her class during the fall semester. This student consistently offered technical knowledge and support to help her peers. She was able to answer questions and had the authority to keep the space open late. She also assured that students took necessary safety measures. Many makerspaces use student workers. While the training and funding for these workers requires substantial resources, Dr. Cook's experience suggests that this resource allocation pays dividends by providing peer support that impacts project outcomes and student safety.

Development of Self-Efficacy

Measures of task-specific self-efficacy show very large effects over for both semesters of Dr. Cook's project, with effect sizes ranging from 1.08-1.31 standard deviations, indicating that exposure to the makerspace had vast positive impacts on students. The simplicity of these results makes them especially compelling – as students complete tasks associated with design, innovation and technology, they feel measurably more adept at doing so. These results echo findings from prior work (Andrews, Borrego, & Boklage, revisions in review; R. M. Carbonell, Andrews, Boklage, & Borrego, 2019) and affirm prototyping's direct benefits to students. Further, the long-proven links between self-efficacy and retention (Bandura, 1986; Brainard & Carlin, 1998; Marra, Rodgers, Shen, & Bogue, 2012; Sheppard et al., 2010) offer a strong motivation for the integration of skill-building in a makerspace into engineering classes, as seen here in Dr. Cook's course.

Students' sense of belonging to the makerspace increased over half a standard deviation over the course of one semester, however these gains were not statistically significant; nor were the slight losses in sense of belonging to engineering. These findings contradict prior work, which documented significant gains in both metrics for a broader sample of students (Andrews et al., revisions in review). However, these results are still important to consider, given that some have hypothesized that not all students feel welcome in makerspaces (Vossoughi, Hooper, & Escudé, 2016) and our prior work has indicated heterogenous effects of makerspace usage on sense of belonging by race (Andrews et al., revisions in review). Moreover, the impacts of sense of belonging on student outcomes such as persistence are well-documented (Good, Rattan, & Dweck, 2012; Hausmann, Schofield, & Woods, 2007; Seymour & Hewitt, 1997; Tate & Linn, 2005) and the impacts of interventions, such as makerspace usage, on belonging warrant further research.

LIMITATIONS

This is a single, descriptive case study and the findings of this study are limited by the context of a university class and makerspace. Therefore, the results should not be generalized to other populations (Firestone, 1993), without careful consideration of the participant and the context.

CONCLUSION AND FUTURE WORK

Researchers intend for this case study to be used to inform classroom and makerspace pedagogy as well as inform administrative and university policies to support hands-on learning in engineering classrooms. This research should be used to support and inform faculty members' engagement in using makerspaces to develop and evolve innovative instruction. Thus, while Dr. Cook is a single person, her lessons learned and the impact on her students can inform pedagogical decisions and support engineering educators looking to incorporate a makerspace project into their curriculum. These decisions may be especially important given the large gains in students' self-efficacy as a result of exposure to the makerspace.

Further research should be conducted to examine the student experiences over multiple semesters in courses that incorporate the makerspace. As surveys and observations continue, this research team plans on conducting further analysis to explore the student experience in these courses. In addition, future research should conduct in-depth interviews with students and TAs about their experiences to present a fuller image of project impact and experience. Finally, a comparative case study amongst faculty members would be useful in examining different approaches to iteration and pedagogy to further establish best practices.

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