



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

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Abstract

This research paper examines a professor's pedagogical adjustments over two semesters teaching a course that included a project in the university makerspace. In recent years, substantial resources have been invested into makerspaces in higher education with the underlying assumption that their creation will lead to experiences that ignite interest and engagement in engineering. In particular, university affiliated makerspaces have the potential to support innovation and design alongside the undergraduate engineering curriculum. the instructor's perspective is vital to support engineering students in their use of these spaces. To better understand these strategies, this paper uses a descriptive case-study approach to identify lessons learned to encourage student engagement in a university makerspace. This research used qualitative methods and was guided by the following research question:

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

During the Spring and Fall of 2019, researchers conducted two semi-structured interviews, 6 observations, and collected student artifacts from two civil engineering courses. A faculty member, Dr. Cook, at a large research university who received an institutional grant to support the design and implementation of a class project which utilized the makerspace, was the faculty participant. Dr. Cook's investment in project design and outcomes gave researchers the opportunity to observe the impact of iteration and intention in designing and implementing course projects that utilized the university makerspace.

Observations of class presentations and final projects demonstrated a difference in project quality from the first semester to the second semester. One of the essential institutional supports that encouraged both professor and student engagement in the project was the funding used to employ a teaching assistant (TA) familiar with the content of the course as well as the makerspace. From Spring 2019 to Fall 2019, Dr. Cook had thought that an overhaul of her project would be necessary to generate more engagement and output from students. Instead of these large changes, researchers alongside Dr. Cook found 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.

Background

In recent years, substantial educational resources have been invested into makerspaces 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' sense of engineering identity, 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 is building on a larger body of research on 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 [ASEE], 2016). These facilities are full of potential for various pedagogical practices to be implemented, 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.

The popularity of makerspaces is confounded by the lack of clarity in describing what constitutes the actual act of making which has been intentionally left vague (Tomko, Linsey, Nagel, Watkins, & Aleman, 2017). What is clear in the literature are the descriptions of where making occurs (i.e., makerspaces) and the subsequent *maker movement* and *maker mindset*. Maker Media, a company that publishes Make magazine and organizes Maker Fairs around the world, first coined the term *makerspaces* in 2005 and described it as “a place that enables making” rather than “a collection of tools”. Hlubinka and colleagues (2013) echo these broad depictions referring to a makerspace as a physical space in which individuals engage for the creative purpose of making artifacts.

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, Hooper, & Escude, 2016). They caution against a “fetishiz[ation] of tools” (Vossoughi & Bevan, 2014) and the reliance on the “act of making as the teacher within a self-directed process of learning” which can slip into a “meritocratic, pull yourself up by the bootstraps approach to education” (Vossoughi et al., 2016) that runs counter to the central concept of the maker movement: Do it With Others (DIWO) as opposed to Do It Yourself (DIY) (Wilczynski, 2015).

One approach to teaching in makerspaces is the emphasis and support of tinkering. Resnick and Rosenbaum (2013) describe tinkering as an approach “characterized by a playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities” (p.164). They specifically contrast tinkering with the engineer who “systematically develops a plan, then gathers the materials needed to execute it.” (p.165). Vossoughi and Bevan (2014) also found a tension between tinkering and engineering finding that making can sometimes be implemented as step-by-step, recipe like, construction activities, running counter to the inquiry-based exploration that the maker movement espouses. In order to encourage tinkering in makerspace settings, Resnick and Rosenblau (2013) recommend: emphasizing process over product; set themes, not challenges; highlight diverse examples; tinker with space; encourage engagement with people, not just materials, pose questions instead of giving answers, combine diving in with stepping back.

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?” It is important to recognize that while qualitative research is occurring in university makerspaces (e.g., Tomko et al., 2017; Tomko et al., 2018), quantitative methodologies, such as survey analysis dominate the research regarding experiences within makerspaces. 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). While qualitative methods are being used as a methodology to study experiences within makerspaces, reports on systems and space are still happening. For example, as recently as 2019 at the 2019 International Symposium on Academic Makerspaces, Wildbolz and colleagues (2019) shared best practices for managing access to space, tools and machines within makerspaces.

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. Furthermore, Carbonell and colleagues (2019) found that a semester long project which required the use of an engineering makerspace increased students’ technology and design self-efficacy, affect towards design, innovation orientation, as well as their sense of belonging in a makerspace. 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.

This new space predominantly houses machines commonly associated with rapid prototyping. 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 troubleshooting project issues as they arise. This new space aims to encourage students to go beyond their current capabilities in design projects, and to give faculty the necessary tools to develop creative hands on assignments. One way that this is done is through 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 standard pencil to paper design projects that dominate engineering coursework by including the development of some physical final prototype.

Participant

A recipient of the makerspace grant, Dr. Cook is an assistant professor in the department of civil engineering. Her expertise is in structural engineering and her research interests are the design process and testing the behavior 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 many types of projects engineering professors can

employ in their design courses. From interviews, it is clear that she is open to suggestions, curious about developing student proficiency, and searching for new and optimal ways to teach material. 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 these models illustrating 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 designing this project, her learning objectives were rather open-ended allowing students to pick anything they learned during the semester and demonstrate it in any way that involved a physical model. Her reasoning for this was based on her observation that her students are creative and may come up with unique designs for physical models that she “would not have ever considered.”

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 spring 2019, she assigned the project to the entire class in Elements of Steel Design for the first time with funding from the makerspace grant. The following fall she ran this same project with funding from the makerspace grant in Structural Design in Wood, a class she was teaching for the first time. This course is structurally 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 certain content and concepts.

Timeline

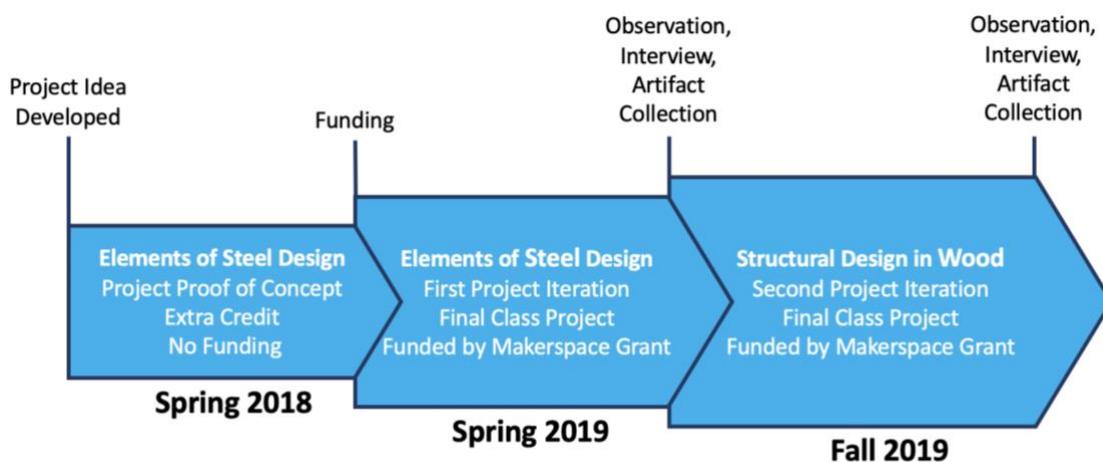


Figure 1: Timeline of Project Development and Research

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. Researchers used Merriam's (1998) approach to a descriptive case study in which researchers intended to provide a holistic description and analysis of a bounded phenomenon *“such as a person”* (p. xiii), in this case Dr. Cook. She served as the “what” of our research (Merriam, 1998, p.41), as researchers were interested in the insight and discoveries from her pedagogical moves over the course of a year of teaching upper-division engineering courses.

This study employed the use of semi-structured interviews with Dr. Cook over the course of the 2019 Spring and Fall semesters. Semi-structured interviews were chosen because of their ability to ask questions about specifics and provide the interviewer the freedom to ask follow-up questions if necessary (Thomas, 2011). 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. Artifacts for this study were collected through the research project with the purpose of supporting findings which emerged throughout the study through *triangulation*. Examples of artifacts included photos and videos of student projects. Observations were chosen as another data source for this study as they often heralded as the most unbiased form of data collection and allowed a clear look at what was actually happening during presentations. 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). The primary sources of data included the semi-structured interview transcripts, presentation observations, and artifacts which were used to triangulate the following findings. The first stages of data analysis involved recording and then transcribing the interviews. The researchers began transcribing interviews verbatim within 24 hours of concluding the interview. During transcription, researcher’s thoughts or questions were noted as comments within the document. Artifacts were also collected, organized and redacted if necessary throughout the process. Similar to the interview process, researcher thoughts, questions, and impressions were recorded within these field notes. This data was stored electronically on the researcher’s computer as well as saved on an external hard drive. Interviews and analyses took place in phases. 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, 2006). 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*, specifically with the purpose of “produc[ing] knowledge on different levels, which means [going] beyond the knowledge made possible by one approach [in this case, interviews] to promote quality in research” (Flick, 2008). 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.

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. As previously stated, she had tested this same project as extra credit the previous semester in this same course. This project was to design and build a physical model of any concept from the course and use it to teach the class the concept. The research team interviewed her 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. She had been informed by makerspace staff that this was a common problem with makerspace projects. Her initial 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. Among these were requiring students to get trained on one of the machines by the midpoint of the semester and holding multiple individual team meetings in her office. During these meetings students and Dr. Cook went over incremental deliverables such as a project plan, their initial design, and a proof of concept. In surveying her students about their project experiences, Dr. Cook had feedback saying that these deliverables were helpful. Students felt that, left to their own devices, they would have waited until the last minute. In spite of this feedback, she found that many students still did wait until the last minute, and students running out of time was one of the major factors mentioned when less successful projects were being presented.

One issue that she observed in the final projects, which may have been caused by this benchmark structure, was a lack of project diversity. An early deliverable was to meet with Dr. Cook and discuss the team’s project idea. She found that many teams picked the concept that had just been reviewed in class. Inevitably, there would be project overlap, Dr. Cook was well aware of this from the outset of her project. Still, she hoped that there would be a broader range of topics covered and noted this as something to try to improve in the following semester.

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.

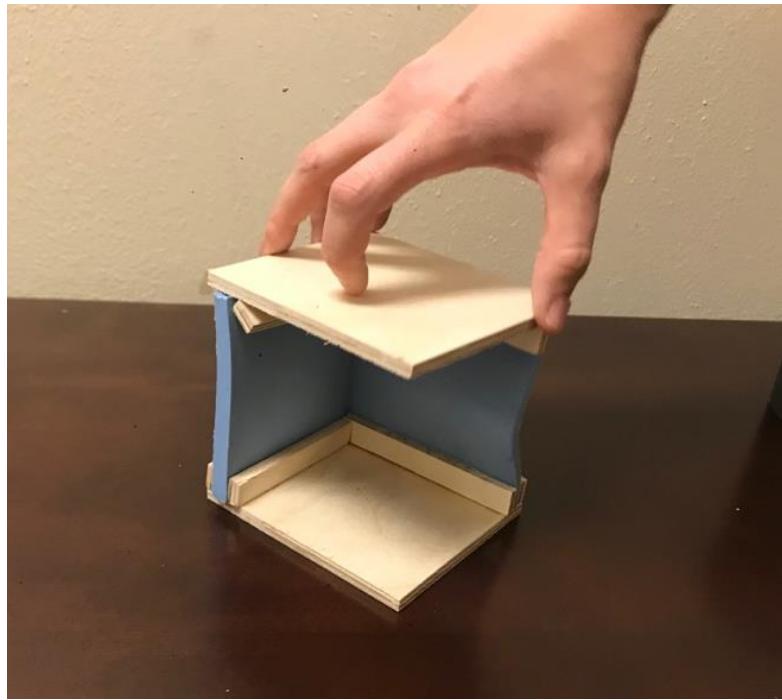


Figure 2: Project from *Elements of Steel Design*

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 common pitfall was that many projects 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.

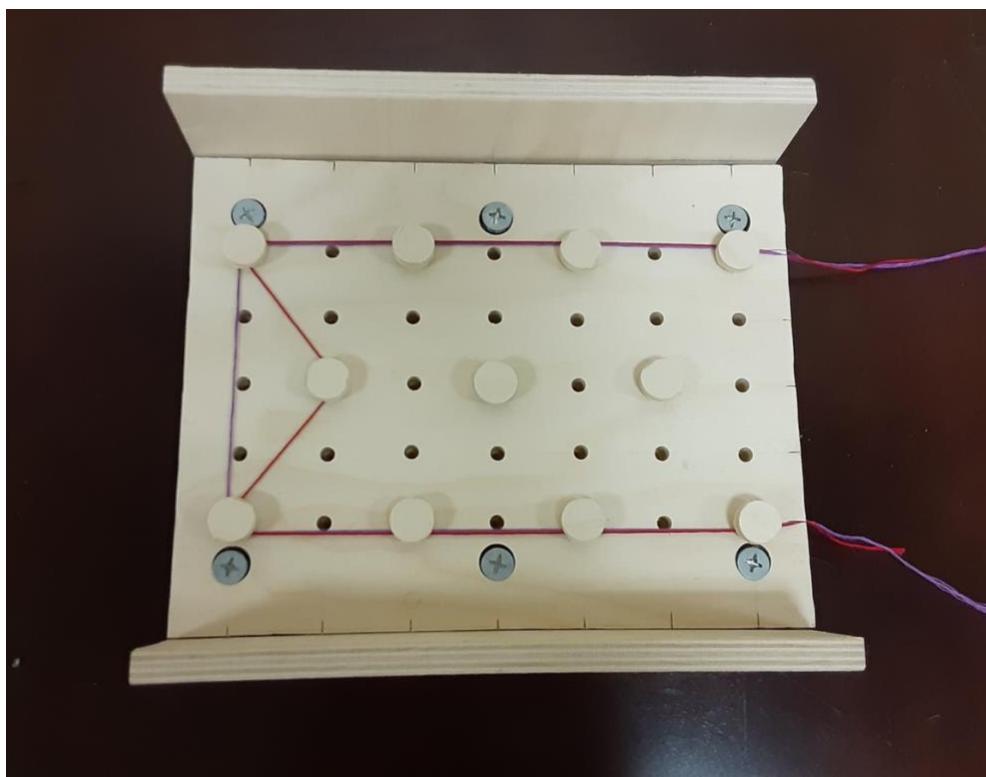


Figure 3: Project from Elements of Steel Design

Semester Two: Structural Design in Wood

The fall after the first full-scale run of the project, 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 common difficulties when sourcing materials. With their previous experience and well-informed students, the same system for obtaining materials went from being cumbersome, and a major topic of discussion during team check-ins with Dr. Cook, to relatively simplistic and a minor concern. This semester, Dr. Cook and the TA actually dedicated less total time to the project, and the students had fewer weeks than the students in Elements of Steel Design had. At the end of the semester, Dr. Cook emphasized that without the funding for the TA, the success of this project would still be hindered dramatically.

Thinking about the lack of diversity in the previous projects, compelled Dr. Cook to bring attention to potentially interesting projects throughout this second semester. While being interviewed, she stated that as she taught concepts she was “more aware”, informing students when a topic had potential to be an interesting final project.

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 just presenting their model and the making process at the end of the semester.

Finally, during her interview, 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. Furthermore, in spite of many warnings to not wait till the last minute, many students did. This makerspace employee had the authority to keep the space open for her classmates and allowed students with tight schedules a broader range of times to use the space and complete their projects.

In surveys, one striking theme was that students found this project to be relatively stress free. The students did not find this project to be a large burden, but instead saw it as something fun and educational. Given the rigor associated with engineering curriculum, being able to incorporate a makerspace project without increasing pressure on students may add to their education without significantly detracting from their academic bandwidth.

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 also 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 reasonably sized 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 even 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.

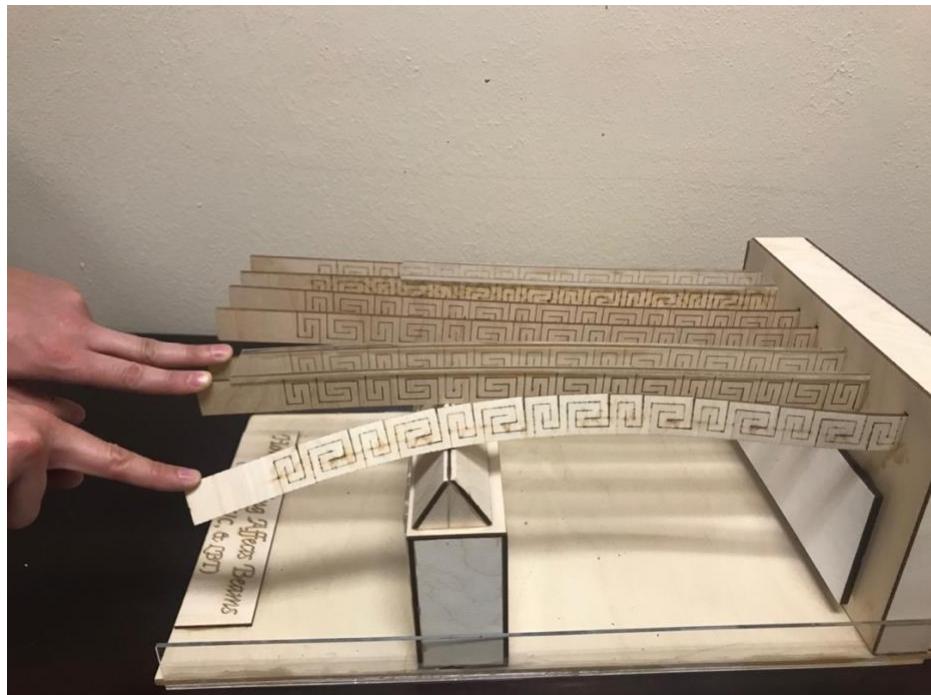


Figure 5: Project from Structural Design in Wood Demonstrating how sheathing prevents out of plane buckling



Figure 6: 1 of 30 additional beams featuring the living hinge pattern used in the project from Figure 5

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. That TA was funded with the grant she received from the makerspace. 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. There is a large quantity of funding and backing aimed at makerspaces as they gain popularity in engineering institutions across the country, but this is usually designated for equipment and the space itself. Giving professors the necessary support to be able to run makerspace-based projects in their classes is as important to incorporating these projects into engineering education as buying and maintaining equipment. If professors are unwilling to use the space due to their limited resources, these projects will not be able to continue, and the benefits of makerspace use and culture will be lost.

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. Discussing possibilities wound up taking away from meeting time with students and added an unforeseen layer of complexity to the project. 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. Additionally, the TA was able to inform students of this system early in the fall semester giving students more realistic expectations of lead time and when they could pick up materials from the TA.

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. Nothing about the issues Dr. Cook faced really changed (e.g. supply logistics), but familiarity with the process made a huge difference. She was more confident about continuing the project in future semesters knowing that initially adding a makerspace project to a course is a large task, but once professors put in that initial effort, the effort to continue the project

dramatically decreases. 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. This led students to choose from a more diverse pool of topics. She found that students were creative and made projects based on topics she had not even considered as possibilities. She believes that this was a result of leaving the project open-ended. She was opposed to assigning specific topics to each team because she saw that the creativity of her students led to more interesting and useful models. 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.

Additionally, with her increased familiarity, Dr. Cook has developed ways to run the project in the future without funding, if necessary. She told researchers that, if she does not have the funding for a TA, she will require students to use found/scrap materials, or materials free from the makerspace. This would be a creative alternative that would work well at this university. This suggests that, with increased familiarity with the makerspace, professors may be able to continue running projects with less outside support – as long as support exists while faculty are first developing projects and learning about the space. It is important to help professors overcome any initial barriers to entry when developing makerspace projects for their courses; however, in this study, researchers saw that initial challenges and need for assistance lessened over time.

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.

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 can inform pedagogical decisions and support engineering educators looking to incorporate a makerspace project into their curriculum.

Further research should be conducted to examine the student experiences over multiple semesters in courses that incorporate the makerspace. Students from each semester were surveyed using Likert scale questions that examine the following factors: affect towards design, technology self-efficacy, innovation orientation, design self-efficacy, and a sense of belonging to the makerspace. As these surveys continue, this research team plans on conducting further analysis to explore the student experience in these courses. In addition to these quantitative measures, future research should conduct in-depth interviews with students and TAs about their experiences. 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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