Board 32: The Impact of Integrating Making Activities Into Cornerstone Design Courses

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The Impact of Integrating Maker Curriculum into Cornerstone Design Courses

Abstract

This study explores how the integration of making activities into cornerstone engineering design courses affects students' design skills. A quasi-experimental design was used in the study, where 29 engineering students were interviewed and observed during their participation in a fourth-year mechanical engineering capstone design course. Students were interviewed in a team-based environment from weeks 2 to 11 in the fall term of the 2018–2019 academic year. Interviews ranged between 15 and 45 minutes per team every week. The study aimed to understand differences in the engineering design learning experience of two distinct groups of students based on the type of introductory engineering design courses students had taken in their first and second year of study. Students who had already attended design courses that had included making activities were found to have more confidence in their design skills, hold their work to higher standards, experience less stress throughout the course and perform better than their peers in the conceptual design phase.

Keywords: Engineering Design Education; Maker Movement; Making Activities; Maker Curriculum.

Introduction and Background:

In the post-industrial era, market demands have required that organizations design, develop and deliver products in ever-decreasing time frames [1]. To meet market demands, organizations have capitalized on teamwork, as it is ideally suited to spurring innovation and creativity, as well as generating and sharing knowledge [2]. These changes in industry have demanded that engineering graduates be trained in more than just technical skills [3]. For these reasons, engineering programs have worked to incorporate cornerstone and capstone design courses into the curriculum [4]. These engineering design courses generally aim to involve students in the design of a particular product or process while working in a team environment. They also usually include an individual component and advocate for the use of a particular design methodology [5]. Moreover, the introduction of cornerstone design courses in engineering programs' curriculum enhances students' interest in engineering, increases students' retention in engineering programs, motivate learning in upper division engineering science courses, enhances performance in design courses [6]. However, projects in cornerstone design courses are typically not based on authentic engineering practices or real-world problems [7]. The advent of the maker movement provides an opportunity to improve cornerstone design courses by exposing students to projects that can grant them access to authentic engineering practices. The Maker Movement is a relatively new trend that represents a community of enthusiasts who share an interest in working with their hands in interdisciplinary environments that incorporate various tools and technologies[8]. Together, the rise of rapid prototyping tools, the open source hardware culture and the dramatic growth in the number of makerspaces [9] have the potential to shift the future of manufacturing [10] and education [11].

This paper aims to investigate the impact that integrating making activities into cornerstone courses has on developing engineering students' design skills. Making activities are focused on designing, building, modifying and/or repurposing material objects, for playful or useful ends to make a product of some sort that can be used, interacted with or demonstrated [11]. For engineering schools, making activities also represent valuable learning activities that align well with their aspired learning outcomes and engage students in learning through the creation of physical or digital objects using sophisticated tools that promote new forms of thinking, support experimentation and enforce a growth mindset. Making activities also encourage persistence, challenge seeking and learning [12].

The courses considered for this study are cornerstone design courses: a first-year introduction to engineering design course and a second-year introduction to project development course. Both use a collaborative project-based-learning approach to teach engineering design while integrating making activities directly into their curriculum. Students work on an open-ended problem directly with a real-time client from the external community. Students in both courses are required to build a functional prototype by the end of the course with a $100 budget. The courses encourage students to follow design thinking methodology, an approach to learning that focuses on developing students' creative confidence through hands-on projects that train students on empathy, promote a bias toward action, encourage ideation and foster active problem-solving [13].

Moreover, both courses integrate making activities into the curriculum through weekly lab sessions that train students in various technologies, software and engineering tools, such as lathe and mill fabrication machines, Arduino programing, PCB design, soldering, programming of mobile apps, 3D printing, MatLab© and SolidWorks©. During the labs, students in the second-year course work to create a mini robotic chariot to demonstrate their ability to use these technologies and tools. A chariot racing event is held as a fun activity for students to demonstrate the functionality of their making project during the labs. Students who complete the chariot in time for the racing event receive a 1% bonus on their final mark.

The first-year course generally provides students with three project options. For the fall 2018 term, for example, these options were constructing an environmental robot, building a zero-net energy greenhouse or building a functional hydroponic system. Students in the second-year course worked with real clients to solve accessibility problems. Some of the projects offered to students in the fall term included creating a hand sanitizer for a client with limited motor control, a skating device to teach children with disabilities how to skate, a snow removal device that can be installed on a wheelchair for a client with cerebral palsy, a portable lightweight ramp, a portable wheelchair curtain, an assistive feeding device, a wheelchair robotic arm, and smart curtains for windows at long-term care residences. Throughout the semester, students participated in weekly lab sessions in the school's makerspace facility. In doing so, students were introduced to the makerspace environment and rapid prototyping tools.

The integration of making activities into engineering freshman year curriculum increases students' motivation and reduces their anxiety about performing design tasks [14]. Also, making activities are regarded as a promising way to engage students in the design and fabrication process, problem-solving and complex programming concepts by providing opportunities and resources to give them the opportunity to combine programming with physical fabrication [15]. Hence, this study seeks to verify if the integration of making activities into cornerstone design courses by exposing them to an authentic and iterative engineering design activity helps students increase their self-efficacy and confidence in relation to their design skills.

This paper addresses the research gap in the Maker Movement literature about the impact that the integration of making activities into cornerstone design courses has on engineering students. The existing literature lacks studies that aim to determine specific impacts of maker education on students' technical or soft skills [16]. This study follows fourth-year mechanical engineering students in their capstone design course and explores the effects of different students' learning experiences on the outcome of their capstone design project. Students who took one or both of the courses discussed above are compared with those who had not taken traditional engineering design courses in their first or second year of study. In this paper, traditional engineering design courses refer to capstone or cornerstone engineering design courses that use simulations in lieu of experiential and open-ended engineering projects, where students are required to create a functional prototype, to teach engineering design.

Capstone Course Structure

Participants interviewed for this study were recruited from a fourth-year mechanical engineering capstone design course offered at the University of Ottawa – Ontario. The course covers topics such as conceptual design, computer-aided drafting, stress and failure analysis, parametric design optimization, and the reporting of open-ended mechanical engineering design problems. Students had to submit several project deliverables during the course: a literature review report, a concepts report, a modelling report, a design dossier, an analysis dossier, an analysis report and a final capstone report. Students worked to design, analyze and draft CAD drawings for several engineering systems related to the automotive, aerospace and marine industries. The projects included:

- Baja SAE: design motion transfer systems and a chassis for an off-road Baja vehicle;
- Formula SAE: design motion transfer systems and a chassis for a small Formula-style race car;
- Shell Eco-Marathon: design motion transfer systems and an engine for an ultra-energy-efficient vehicle;
- Unmanned light aircraft: design a rapid off-loading mechanical cargo system to be used in conjunction with a light aircraft frame;
- two- to three-person submarine: design a submarine's hull, frame, hatch, seals and access mechanisms.

Students had to form teams by the second week of the term and sign a team contract. At the end of the semester, they had to present their final designs. Peer assessment was administered after each report was submitted to assess individual students' contribution to their team project. Reports were graded as a team, and peer assessment marks were then used to scale individual students' marks. Table I presents the reports that had to be submitted and the grades allocated for each report.

TABLE I. COURSE GRADING SCHEME

REPORT	MARKS
LITERATURE REVIEW REPORT	10
CONCEPTS REPORT	10
MODELLING REPORT	10
ANALYSIS REPORT	15
CAPSTONE REPORT	45
PROJECT RESENTATION	10

Students rated their peers five times during the course. Students rated their team members using a peer assessment and feedback tool developed by the Individual and Team Performance Lab at the University of Calgary. The tool — which is developed based on [17] Comprehensive Assessment of Team Member Effectiveness [18] dimensions: communication, commitment, knowledge, skills and abilities, standards, and keeping the team on track — invites students to rate each other on a five-point Likert scale and provide personal feedback. This feedback was used during team meetings mid-course as a team debrief to discuss each member's performance and possible areas of improvement.

Research Question

Given that the purpose of this study was to investigate the impact of integrating making activities into cornerstone engineering design curriculum on the development of students' design skills, the following question was considered:

1. How does integrating maker curriculum into cornerstone design courses affect the performance of engineering students in capstone design courses?

Methods:

Research design

This paper presents a non-equivalent quasi-experimental study on the learning experiences of mechanical engineering students in their final-year capstone design course. The study design was chosen to be non-equivalent quasi-experimental because the researchers had no control over students' introductory engineering design choices. Participants in this study had similar characteristics with the exception of one trait: the type of elective course they had taken in their first or second year of study. We compared students who had registered for a traditional introductory engineering design course in their first or second year of study performance in a fourth-year capstone course with those who had taken a cornerstone design course that had integrated a maker curriculum into the course.

A social constructivist stance was used by the researchers during the interviews [19] to explore students' learning experiences of engineering design. By following this epistemological stance used to understand the complex world of lived experiences to understand these experiences from the point of view of those who live it, the research process becomes an interactive process between the researcher and the research subjects [20, p.13-15]. Consistent with this stance, the methods used in this study are mainly qualitative. Qualitative methods aim to describe, provide an in-depth understanding, and capture and communicate someone's experiences of the world from his or her point of view [21]. The sampling methodology used in the study was purposive sampling, in which information-rich cases — student teams — were selected to provide the most insight about students' experience with making activities when learning about engineering design. Purposive sampling was used in this study to allow for an in-depth understanding of several student groups' learning experiences. Learning experiences were explored based on differences in design skills, academic achievement in a design course, stress level, project management skills and learning objectives.

Participants

The study followed six teams in their fourth-year capstone design course. There were a total of 29 student in the teams being followed. Table II presents information about each team, including the number of students that made up each group.

TABLE II. STUDENT TEAM DETAILS

Team No.	Project	No. of students	Student Group
A1	Aircraft	5	Group A
A2	Baja SAE – 1	5	Group A
A3	Formula SAE	5	Group A
B1	Shell Eco-Marathon Motion Transfer	4	Group B
C1	Baja SAE – 2	5	Group C
C2	Shell Eco-Marathon Engine	5	Group C

Teams were selected based on a pre-course survey that asked about their engineering design course history and their participation in engineering design competition teams. Teams were then classified as part of one of the following three groups:

A- Student-teams where the members had taken traditional introductory engineering design courses

B- Student-teams where the members had taken design courses into which making activities were successfully integrated as a fundamental part of the teaching method

C- Student-teams where the members claimed they hadn't taken any previous design courses

Pre-survey results showed that some of the students who registered for the capstone design course indicated they hadn't taken any introductory design courses as part of their program at the university. Of course, these responses contradict the Department of Mechanical Engineering's course structure, as students have to register for mandatory design courses in all years of the program. Follow-up interviews concluded that these students did not consider prior courses to be design courses, as they found them to be overly structured and lacked the open-endedness of typical design problems that would give the freedom to come up with their own designs. This surprising result forced the study to include a third group of teams, group C, to understand more about the learning experience of students in this group.

Semi-structured interviews were held with students during their weekly lab hours. Each team was interviewed eight times over the term. Interviews ranged in length from 15 minutes to 45 minutes. Interviews were then transcribed verbatim and analyzed using grounded theory [22] to identify patterns and themes in students' learning experiences. Participation in the study was optional, and students were not compensated for participating in the study. Students were free to refuse participation without any negative consequences for their success in the course.

Early interviews looked at student learning objectives, how they chose their project, and how the scope of work and success criteria had been set by their team. As the course evolved, interviews explored how the students were managing their project, how many times they were meeting during the week, how their tasks were being split up, and how they were planning for each design phase. Appendix A provides the questions for each interview. Interviews were transcribed and analyzed by the primary author of this study.

Results & Discussion

Results of the pre-survey are summarized as follows. Teams in group A were mechanical engineering students who identified as makers and had taken a traditional engineering design course. One of the students in team A2 (which belonged to group A teams) had prior experience with the faculty's design competition teams that were similar to his team's capstone project. Teams in group B were students who identified as makers and participated in engineering design courses that had implemented making activities and provided experiential learning opportunities. These students had also previously volunteered in engineering design competition teams that were similar to their capstone project. Teams in group C were students who also identified as makers but felt that they hadn't had any training in engineering design. Project reports marks and final marks for each team and descriptive statistics are presented in Table III below.

TABLE III. STUDENT TEAMS' MARKS

Team Name	Lit. Review / 10	Concept Report / 10	Modelling Report / 10	Analysis Report / 15	Capstone Report / 45	Final Presentation / 10	Final Mark / 100
A1	6	6	8	10	26	8.5	64.5
A2	8	7	9	14	39	10	87
A3	9	7.5	8	11	35	9	79.5
B1	7	10	9	15	42	10	92
C1	7	6	6.5	10	33	8	70.5
C2	8	6	4.5	11	35	10	74.5

Students were questioned about their learning objectives at the beginning of the course. Most students in groups A and C noted they wouldn't have registered for the course if it wasn't mandatory to graduate and explained their feelings stemmed from what they had heard about the heavy workload of the course from previous students who had already taken the course. Students in group B, on the other hand, noted that they were excited about the course because it was a fun project and a great way to end their university degree. Here is a selection of responses from students in teams **A1**, **A2**, **A3**, **C1**, and **C2** to the interview questions, “What is your objective from taking this class?” and “Would you register for this course if it was not mandatory?”:

- *“I don’t think anybody will take this course for fun.”*
- *“Like, I will be honest: if I had a choice to take this class or not, I would probably just won’t just because of the time, and it’s so stressful.”*
- *“I am more a fan of regular coursework, and these design courses are not for me, I probably wouldn’t take it.”*

Two students out of the 25 students in groups A and C, however, expressed excitement about the course and noted that for them, it resembled a challenge similar to the environment they would expect from a real engineering job with tight deadlines, a challenging project and an opportunity to work in a team environment. One of the members of team **A1** responded this way to the interview question “Would you register for this course if it wasn’t mandatory?”:

- *“[Obscenity] yeah — it shows if you are ready to work as an engineer and if you are able to implement all the stuff you had learned before into one single course.”*

One of the members of team **A3** responded with the following to the interview question “Would you register for this course if it wasn’t mandatory?”:

- *“For me, the objective is to learn as much as possible. Basically, they put us in this very uncomfortable situation, where we always have something due, and we had 10 days to do this report, we are going to have seven days to do the next two, and then we have two weeks to do the sixth and the seventh reports. So basically,* [the objective is] *to work under pressure and learn.”*

Students generally felt challenged by their projects because of the amount of time and workload involved in completing their project deliverables. Group A and C respondents indicated that they felt the course was hard and that their main challenges were planning and organizing the team and project requirements, unclear expectations and guidelines, exhaustion and high stress levels caused by the heavy workload, and lack of time to gather and apply new information and engineering skills related to the project. Group B students indicated that they didn’t feel that the project was hard but that they felt challenged by the time constraints involved and the level of detail they aspired to. Team members from teams **A1**, **A3** and **C1** responded with the following to the interview question about challenges faced by students in the course:

- *“The other thing is basically knowing what the hell to do … That’s like most of the time what we are trying to figure out, and once we know it, then we get into it … Time — we barely sleep.”*
- *“Time, prioritizing what’s important stuff, trying to get that done first, but that is going to take a while.”*

Differences in design skills and performance were especially clear between groups in the conceptual design phase. Student teams in groups A and C received negative feedback about the lack of detail and clarity in their sketches and conceptual designs, while students in group B received the highest mark in the course. Members of team **A3** responded with the following to the interview question about the feedback they received about their concept report:

- *"We are doing OK. We just got back from our meeting with the professor about the last report we handed it in … and not quite as good as the first one … It was supposed to be the concept stage, so we do a bunch of sketches and drawings of possible designs we could be doing, but the thing is we had to do concepts for every single mechanical component, and we didn't include everything, so we had a lot of components missing. So we got a lot of marks deducted because of that … And the ones we did do, it didn't show enough detail."*

Members of team **B1** responded with the following to the interview question about the feedback they received about their concept report:

- *"The feedback was really positive. We still haven't received our grade, but the feedback was positive."*

How each team distributed work on mechanical systems between its team members was tracked. Teams in groups A and C distributed the mechanical systems they were tasked with designing between team members based on each students' preference and ability to contribute to the project, while group B students distributed systems between team members based on prior experience with the systems in their volunteering experience with the university's competition teams. Members of team **A2** responded with the following to the interview question about their task distribution structure:

- *"I think at first we were all together and figuring the dimensions, and once that was figured out, we split tasks. One person was doing most of the external forces, another was doing kinematics, some were focusing on suspension — nothing specifically, just to divide all the tasks."*

The general strategy for decision-making adopted by all groups was consensus, and each student had a final opinion on their respective systems. Students in groups A and B met almost five days per week, while students in group C teams started by meeting only two or three times during the week and then increased the frequency of their meetings after receiving negative feedback from the course's teaching staff in consecutive sessions. Members of team **C2** responded with the following to the interview question about the frequency of their meetings:

- *"Saturday, Monday, Wednesday, Sunday sometimes, yeah … But now I feel like it should be whenever … so I am trying to get a little bit more of that. We are having more meetings."*

Only one of the two teams in group C, **C2**, adopted a task distribution system as the course progressed and changed how they were planning and organizing their project. Their changes included creating a weekly work breakdown structure and assigning two members to work on each task. The other team in group C struggled throughout the course with finishing their project deliverables on time, with creating a regular meeting schedule and agenda and with outlining weekly tasks for preparing deliverables. Members of team **C2** responded in the following way to the interview question about the changes they made to how they were managing their project after receiving negative feedback from the course's instruction team:

- *"What we did now is that we wrote everything that we can think of right now that had to be analyzed, drawn, whatever it needs to be done, then put it on a list. But this time, it's not just one person doing it; two people are doing it. Even if one person takes the lead, there would be another person that would be checking up on what they are doing and give them feedback."*

The leadership model of each team varied. Teams in group A and C with the exception of team **A2** had no leader, and each student worked independently on their system. Team **B1** and team **A2**, on the other hand, assigned the role of leader at the beginning of the term to a student who would follow up with the project tasks. It is interesting to note that team **A2** chose as their leader a teammate with prior volunteering experience with the faculty's design competition teams. Members of team **A1** responded with the following to the interview question about their leadership model:

- *"We try to have consensus ... If we had a leader, like, giving someone that role makes — it's like big headache ... Let's say I have a problem, and he has a problem, we are going to come to him, and he will be overwhelmed because of that."*

Dealing with the ambiguity of the design process was a huge challenge especially for group A and C students. Students in these groups indicated they lacked understanding of the level of detail required from them. Students in group C also struggled with researching and finding the right resources to perform analysis and modelling calculations and gain insight on part drawings and on how their designs would be manufactured. In both groups, students felt their strategy to succeed was to communicate frequently with the professor to try to extract as much information as possible from him. Members of teams **A2**, **C1** and **C2** responded with the following to the interview question about how they were dealing with the uncertainty of the design process:

- *"The professor was busy giving feedback to groups, so he wasn't really available for us to ask questions about the deliverable, and we were confused about what we have to hand in. And it's the same with last time, but we thought we did really good last time, but they tore us to shreds because apparently we were missing a lot of stuff that they didn't really tell us about…"*
- *"Bother the TAs as much as possible … basically, hounding the profs and TAs. Sometimes when we talk to the TAs, they give us a different answer than what the prof gives us, so it ends up being really misleading, in terms of research, but in the end we end up trying to do both. But we usually try to focus on what the prof says and maybe add in some insight on what the TA has said before."*

Moreover, students from both groups A and C expressed frustration with their inability to solve problems they had not been exposed to in their previous courses and felt that they should have been trained on how to analyze and solve unfamiliar problems. Students in both groups relied on the teaching staff heavily to help navigate their design project. Members of team **C2** responded with the following to a question about their attempt to increase the frequency of their meetings with the professor after receiving negative feedback:

- *"I feel like we should keep going, but as well not just ask them questions, but show him stuff we have done, and ask him what you think the next step should be, where are we going from here, is this good, you know… Even meeting with him, things we weren't thinking of, by asking him, popped up during the meeting, and that really helped, like when he recommended the textbook, like, really helped to lay out how analysis is going to go."*

In contrast, group B team was more comfortable producing detailed sketches of subsystems and knowing where to find resources to develop their concepts. Students also indicated they had utilized the literature review phase to prepare for the conceptual design phase and to investigate how each part was manufactured or assembled. A student on team **B1** commented the following about how their prior knowledge in these systems had helped them make decisions in their conceptual design phase:

- "*Since we do have a little bit of experience on the team,* [pointing at teammate] *he knows what kind of steering system that should work, and* [student name omitted] *knows about everything. And if our transmission is heading the wrong way, he would say that's not going to work — we should probably focus on this one."*

Students from team **B1** indicated they felt they had an advantage over other teams because they walked into the capstone course with prior experiential knowledge of the systems they were about to design. Although they lacked scientific knowledge about these systems, they felt they were more prepared for the conceptual design phase. A student on team **B1** commented the following about how fortunate they felt to have prior experience with the systems they had to design:

- *"We are lucky because we all knew what we wanted to do, and the design part is the easy part… For some groups that doesn't have the design in their heads, they get to the design part and they have seven days to actually design and they don't have time to get a proper design, or they pick something and they discover that it's not going to work."*

It should also be noted that students in teams **B1** and **C2** who had prior experience with volunteering in the faculty's design competition teams didn't think their experience helped them very much, because they thought what was required in the capstone course was different from what they did with the design competition team. On the other hand, a member of team **B1** said the following about how being part of the faculty's design competition team has helped them in the early stages of the design process:

- *“Drawings are mostly new concepts that we came up with this semester, so that doesn’t help us much* [as] *like, to know what forces and what’s important for the super mileage car. We are in a competition, and we know what’s the worst-case scenario, we know all the tests that the vehicle has to go through.”*

Another major setback for students in groups A and C was their need to learn, in a very short span of time, a programming language and mathematical modelling software they felt they were not adequately exposed to previously. A member of team **C2** said the following about their need for training on programming languages:

- *“I think another thing that we will have a problem with, and we do now, is that we are not really strong programmers, which would mean whoever is among us will get most of the work, and it might be, like— but hopefully it doesn’t stress anyone out depending on what their strength* [is]. *But that would be one problem we might face.”*

Students in group B had two team members who were experienced with modelling software in mechanical design projects, and this helped them tremendously in navigating the last phase of the design process. On the other hand, students in groups A and C had to relearn modelling software and improve their programming skills in a span of two weeks and then apply what they had learned to a complex mechanical design project. This contributed to a significant increase in the huge amount of stress that students were already facing. Team **A1** commented the following on their challenges with learning and using MatLab in a short span of time at the end of the semester:

- *“For the truth, everybody, ... we don’t know how to use MatLab, so now we are trying to learn all the stuff related to MatLab…. It’s a challenge for me — at least for me it’s a challenge because the four years I think we — at least a course of just MatLab, it should be OK for us. Like, in the first year we took GNG1106; if that GNG course we can learn MatLab instead of C, it should be good for mechanical engineering students…*
  Interviewer: “So none of you have used MatLab before?”
  “Not really. We had one assignment for a control loop exercise, and we somehow managed to find instructions to do that, and it was three lines of code for the whole course.”

Students in all three groups struggled with high levels of stress over the term, although the factors and timing that contributed to the stress were different. Table 3 presents a summary of the factors that contributed to increasing student stress levels during the course. Students in team **B1** felt less stress at the conceptual and modelling phase of the design process. A student from team **B1** responded with the following to the interviewer’s question about the level and sources of stress the team members were experiencing in their fourth week of the course:

- *“We have Volleyball tonight, so we are not stressed at all.”*

- "*Time and personal expectations… More to do with we want to do — a project that is good — and we want to analyze everything. Sure, we can submit something tomorrow that would probably be fast, but we want to do something that is good and get a good grade. And to do that, you gotta to analyze every part in three different ways. Like the steering wheel — I have seven or eight pages of analysis for it; it's just a steering wheel. So there's a lot of things to do, and it takes a lot of time.*"

TABLE IV. STUDENTS' SOURCES OF STRESS

Group	Sources of Stress
A	- Time management - Unclear expectations from the teaching staff - Conflicting advice from teaching assistants - Problem-solving
B	- High expectations set by the students for themselves - Time management
C	- Negative feedback - Lack of information and resources - Time management - Ambiguity of the design process - Problem-solving

The purpose of this study was to explore how maker education affects specific students' learning outcomes related to their engineering design skills.

Results of this study found that students who participated in maker engineering design cornerstone courses and were part of the faculty's design competition teams were more confident in their skills, held their designs to higher standards and performed better in the conceptual design phase. Although the study design prevents us from attributing these benefits to the courses alone, students indicated their experience in the design competition teams had helped them only by exposing them to the systems they were tasked with designing and how the systems are interconnected.

Consistent with studies on digital fabrication literature [23], we found that cornerstone design courses that included maker curricula had contributed to students' having a higher self-efficacy in their design competencies. We also noticed that students who had participated in these cornerstone design courses with making activities were more prepared to deal with the ambiguity of the design process and felt less stressed throughout the course. The value of integrating a maker curriculum into the cornerstone design courses is that it provides opportunities for experiential learning, which give students the freedom and responsibility to engage in authentic engineering practice, make decisions and realize their ideas for physical or digital prototypes [24]. Moreover, it provides students with valuable lessons in design and manufacturing [25].

Student projects considered in this study were very similar, with the exception of team **C2** project, which was a new project that was introduced this academic year for the first time. Students in team C2 were tasked with designing an engine, something they found to be a hard project as compared with other teams included in this study that were designing a motion-transfer system for different vehicles. This difference in project should be noted, as it might explain the difficulty students had in finding resources.

Another observation from the study is that students who had taken cornerstone design courses that had included a maker curriculum were more adept at project management and solving problems that were not familiar to them, something that can be attributed to the benefits of going through project-based learning environments, such as improving students' problem-solving skills, creativity, responsibility, communication and self-direction [26].

There are four aspects to engineering design education that are necessary for engineering students to acquire: 1) Thinking about a system's approach; 2) Looking at risk management and uncertainty; 3) Estimation; 4) Physical modeling and experimentation [6]. The cornerstone design courses under study that integrated a maker curriculum were found to better prepare students to deal with the engineering design process that often deals with uncertainties, relies on incomplete data and unclear constraints and objectives. The courses has also awarded students an opportunity to build and experiment with physical models which helps students to understand and practice the experimental approach to engineering design.

Conclusion

This paper presents preliminary analysis of data collected by investigating the impact on students' design skills of integrating making activities into cornerstone engineering design courses. Students who had previously taken an introductory engineering courses that had provided them with an authentic engineering experience through making activities were more prepared to execute an engineering design project. We found that students who were exposed to making activities and a making project in their first few years of engineering school were better able to manage and organize their projects. Students who had previously been involved in making activities performed better in the conceptual design phase than the other groups studied in the sample. They were also more capable of dealing with the ambiguity of the design process and perform research tasks much more comfortably. The study hypothesized that being exposed to working on an open-ended authentic engineering problem with a real client and constructing a functional prototype would better prepare students for the complex, ambiguous, iterative and research-intensive process of finding a solution to an engineering design problem. Students who attended the courses under study that had an emphasis on making activities were exposed to the process of solving an open-ended problem and were trained on defining an engineering problem, using ideation strategies and prototyping. They were also exposed to the challenges of the iterative process of engineering design and to the practice of striving to find answers to questions that arise through the design process.

These characteristics of the learning environments of the cornerstone design courses under study, which are aided by the availability of the resources in the makerspace on campus, together with a student-makers' community of practice, helped the students who had taken these courses to be more confident in their design and problem-solving skills. The courses also helped students to be less stressed than those who hadn't taken the courses when working through a complex engineering design problem. The implications of these findings are that the integration of making activities into cornerstone courses provides a great resource to expose students to authentic engineering experiences that can help them be more prepared for their senior years in engineering school and for their future engineering careers.

A limitation of this study is that there was only one team in group B. The interventions under study were initiated in 2015, and a handful of students had registered for them as an elective at the time. Hence, team **B1** was the only team that was available to study whose members had taken the design courses under study in their first or second year of study. Still, **B1** was the source of a wealth of qualitative data.

Another potential explanation for team **B1**'s performance is their participation in the faculty's design competition teams, which would have granted them access to experiential learning experience that might have contributed to their achievement in the conceptual design phase. However, the impact of this volunteering experience is limited to the level of participation and activities that the students were a part of, as indicated by the leader of team **A2**, who had a similar experience as that of team **B1** members and noted that it didn't provide him much help during the project. From this preliminary analysis, it can be observed that participating in making projects whether in a guided environment such as an engineering design course or through participating in a design competition team, where students are required to work in an authentic engineering environment and deal with a client's constraints and specifications, and where students are exposed to unfamiliar engineering problems, allows students to be better prepared to answer today's highly technical demands. Another intriguing question could be the extent of the impact these cornerstone courses had on encouraging students to participate in design competition teams at the faculty and whether this had any effect on their performance.

Other observations stemming from this study include the requirement to update the engineering curriculum in universities to provide students with more practical exposure to modelling software and programming languages that are related to their discipline. Moreover, a review of engineering problem analysis in engineering courses in the mechanical engineering department is necessary to assess how students can be better prepared to solve unfamiliar or ill-defined engineering problems. Finally, it is recommended that more making activities be included in engineering courses because they clearly have a direct impact on student design skills.

References

[1] R. M. Crowder, M. A. Robinson, H. P. N. Hughes, and Y.-W. Sim, “The Development of an Agent-Based Modeling Framework for Simulating Engineering Team Work,” *IEEE Trans. Syst. Man, Cybern. - Part A Syst. Humans*, vol. 42, no. 6, pp. 1425–1439, Nov. 2012.

[2] A. Buch and V. Andersen, “Team and Project Work in Engineering Practices,” *Nord. J. Work. Life Stud.*, vol. 5, no. 3a, p. 27, Nov. 2015.

[3] E. Seat, J. R. Parsons, and W. A. Poppen, “Enabling Engineering Performance Skills: A Program to Teach Communication, Leadership, and Teamwork*,” *J. Eng. Educ.*, vol. 90, no. 1, pp. 7–12, Jan. 2001.

[4] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, “Engineering Design Thinking, Teaching, and Learning,” *J. Eng. Educ.*, vol. 94, no. 1, pp. 103–120, Jan. 2005.

[5] A. J. Dutson, R. H. Todd, S. P. Magleby, and C. D. Sorensen, “A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses,” *J. Eng. Educ.*, vol. 86, no. 1, pp. 17–28, Jan. 1997.

[6] W. Akili, “Perspectives on engineering design learning: Realities, challenges, and recommendations,” in *2015 IEEE Frontiers in Education Conference (FIE)*, 2015, pp. 1–7.

[7] G. Arastoopour, D. W. Shaffer, Z. Swiecki, and A. Ruis, “Teaching and Assessing Engineering Design Thinking with Virtual Internships and Epistemic Network Analysis,” *International J. Eng. Educ.* , vol. 32, no. 3, pp. 1492–1501, 2016.

[8] E. P. Clapp and R. L. Jimenez, “Implementing STEAM in maker-centered learning,” *Psychol. Aesthetics, Creat. Arts*, vol. 10, no. 4, pp. 481–491, Nov. 2016.

[9] D. Dougherty, *Free to Make: How the Maker Movement is Changing Our Schools, Our Jobs, and Our Minds*. North Atlantic Books, 2016.

[10] C. Anderson, *Makers: The new industrial revolution*. 2012.

[11] L. Martin, “The Promise of the Maker Movement for Education,” *J. Pre-College Eng. Educ. Res.*, vol. 5, no. 1, Apr. 2015.

[12] A. M. Thomas and D. Besser, “The Maker Movement and Engineering,” *Bridg.*, vol. Volume 47, no. 3, pp. 32–36, 2017.

[13] M. Carroll, S. Goldman, L. Britos, J. Koh, A. Royalty, and M. Hornstein, “Destination, Imagination and the Fires Within: Design Thinking in a Middle School Classroom,” *Int. J. Art Des. Educ.*, vol. 29, no. 1, pp. 37–53, Mar. 2010.

[14] R. Morocz, B. D. Levy, C. R. Forest, R. L. Nagel, W. C. Newstetter, K. G. Talley, and J. S. Linsey, “University Maker Spaces: Discovery, Optimization and Measurement of Impacts.”

[15] S. Papavlasopoulou, M. N. Giannakos, and L. Jaccheri, “Empirical studies on the Maker Movement, a promising approach to learning: A literature review,” *Entertain. Comput.*, vol. 18, pp. 57–78, Jan. 2017.

[16] “What Have We "Learned" from Maker Education Research? A Learning Sciences-base Review of ASEE Literature on the Maker Movement,” *Rev. Dir. - Am. Soc. Eng. Educ.*, 2018.

[17] M. W. Ohland, M. L. Loughry, D. J. Woehr, L. G. Bullard, R. M. Felder, C. J. Finelli, R. A. Layton, H. R. Pomeranz, and D. G. Schmucker, “The Comprehensive Assessment of Team Member Effectiveness: Development of a Behaviorally Anchored Rating Scale for

Self- and Peer Evaluation," *Acad. Manag. Learn. Educ.*, vol. 11, no. 4, pp. 609–630, Dec. 2012.
[18] T. O'Neill, S. Park, N. L. Larson, A. Deacon, G. Hoffart, B. Brennan, M. Eggermont, and W. Rosehart, "Peer Ratings and Intentions to Change: Adopting the CATME to Explore Outcomes of Peer Ratings: American Society for Engineering Education," in *ASEE Annual Conference and Exposition, Conference Proceedings.* , 2015.
[19] P. L. Berger and T. Luckmann, *The social construction of reality : a treatise in the sociology of knowledge - University of Ottawa*. Garden City, N.Y. , 1967.
[20] D. M. Mertens, *Research and evaluation in education and psychology : integrating diversity with quantitative, qualitative, and mixed methods*, 2nd ed. Sage Publications, 2005.
[21] M. Q. Patton and M. Q. Patton, *Qualitative research and evaluation methods*. Sage Publications, 2002.
[22] K. Charmaz and L. L. Belgrave, "Qualitative interviewing and grounded theory analysis," in *The SAGE Handbook of Interview Research: The Complexity of the Craft*, 2455 Teller Road, Thousand Oaks California 91320 United States: SAGE Publications, Inc., 2012, pp. 347–366.
[23] E.-S. Katterfeldt, N. Dittert, and H. Schelhowe, "Designing digital fabrication learning environments for Bildung: Implications from ten years of physical computing workshops," *Int. J. Child-Computer Interact.*, vol. 5, pp. 3–10, Sep. 2015.
[24] L. Pittaway and J. Cope, "Simulating Entrepreneurial Learning: Integrating Experiential and Collaborative Approaches to Learning," *Manag. Learn.*, vol. 38, no. 2, pp. 211–233, Apr. 2007.
[25] R. Carrick, A. Czekanski, and M. R. Ha, "BUILDING A MORE COMPLETE DESIGN EXPERIENCE: PHILOSOPHIES AND REFLECTIONS FROM A SECOND YEAR MECHANICAL ENGINEERING DESIGN PROJECT COURSE," in *Proceedings of the Canadian Engineering Education Association (CEEA)*, 2017.
[26] S. Wurdinger and M. Qureshi, "Enhancing College Students' Life Skills through Project Based Learning," *Innov. High. Educ.*, vol. 40, no. 3, pp. 279–286, Jun. 2015.

Appendix A

Interview Protocol

Week 1

- Can you please introduce yourself?
- Can you please describe your project for me?
- How did you select the project?
- How did you specify the criteria for the project?
- How did you distribute the tasks between each other?
- Do you have a long-term plan for the next stages of the project?
- Do you know what information you are missing to finalize your design?
- Do you find that there is uncertainty with your project? And if yes, how are you dealing with it?
- How many times have you met?
- What is your objective from taking this class?

Week 2

- How are you doing with your design project so far?
- How did the last deliverable go?
- What did everyone contribute to the work?
- What have you learned this week?
- What engineering concepts have you used from the past three years at the school?
- How do you feel about your progress?
- What are you doing this week?
- What step of the design process do you think you are at now?
- What are the challenges that you are facing?
- What's the plan?
- What information are you missing up to now?

Week 3

- How are you guys doing this week?
- That you missed on the concept report?
- How are you splitting the work?
- What about the modelling report: did you learn new concepts then?
- What do you think of your progress this week?
- How did the feedback from last week’s report go?

- What challenges are you facing this week?
- Are you feeling less stress this week?
- So what's your plan moving forward?
- Do you know the concept you need in the analysis dossier?

Week 4

- What was the feedback you received on the design dossier?
- What are you doing this week?
- What resources are you using to make your calculations?
- Are you facing any challenges?
- How are you planning to finish the analysis report?
- How are you splitting the work?

Week 5

- What was the feedback from the last report you had submitted?
- How many times did you meet last week?
- Did you outline the tasks you need to do for this dossier, and have you finished those tasks?
- How much have you finished of the work required for this week’s report?
- How did you split the work?
- What challenges are you facing?
- What are the steps that you take when you are trying to solve a problem?
- Are you learning new concepts?
- Are you following a task allocation system?
- Are you guys planning to change anything about how you are managing your project?
- Where in the design process are you now?
- How are you dealing with uncertainty?
- What is the plan moving forward?

Week 6

- How are you guys doing this week?
- Are you guys stressed this week?
- Individual question: What were your learning goals when you signed up for the course and what have you learned so far?

Week 7:

Group questions:

- How much do you like the project?
- How enthusiastic are you for the project? Would you call yourself excited when you are working on it? Does it feel like a burden or joy?
- If the project had a making component to it, would it have made you more excited about it?

Individual questions:

- Do you have any engineering job experience (co-op, internship, summer jobs as technician)?

**** Verify the students' answer on their Maker Identity (What was their response)

- Can you please explain to me, why did you respond like that?
- If they are a maker: Can you give me an example of when you have fixed something, created something, or tinkered on something?
- Have you participated in any hands-on engineering projects outside of school?

Week 8:

- How was the feedback you received for the analysis report?
- What are the lessons learned from the analysis report/phase?
- Have you learned anything new in the past three weeks?
- Did you struggle with time management in the final week for the analysis report?
- Do you feel less or more stressed out now that you have finished that phase?
- What are your next steps?
- What have you learned from the course?
- What would you change about it? (I am sure they are going to say make it an eight-month project, but I will ask for other options.)
- In your opinion, was this course a good representation for a career as a mechanical design engineer?
- Do you think you want a career in engineering design based on your experience in this course?