Implementing an Entrepreneurial Mindset Design Project in an Introductory Engineering Course

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Abstract

At Florida Institute of Technology (FIT), freshman students begin their studies within their chosen major, typically taking an introductory engineering course specific to their discipline. For undecided engineering students, they have the option to start in a general engineering program to help them select a major. FIT has had great success using this general engineering model to improve student retention and time to graduation; however, improvement can be made in preparing students to be innovative, entrepreneurial-minded professionals. The purpose of this paper is to describe the activities focused on exposing students to the entrepreneurial mindset and preparing them for engineering careers. An introductory course in the General Engineering program comprises both a lecture and a lab component and includes a traditional project-based learning experience that spans the semester. The group project requires application of fundamental engineering skills to construct a mini-golf hole. Students are given a theme and a modest budget from which to build the product. While several variations of this project have been used in prior years, this year's project is modified to incorporate components of entrepreneurial-minded learning. Students were tasked with interviewing potential mini-golf customers to create a valued entertainment experience within the budgetary, design, and manufacturing requirements. Students submitted a final project report, wherein they discussed the impact the entrepreneurial components had on their learning process. Overall, the mini golf freshman design project has been a large success. The students regularly mention it as one of the best experiences in the class on course evaluations. When surveyed at the end of the project, students reported exploring more than one engineering discipline during the project with exposure to Civil, Mechanical, and Electrical the most common majors stated. The students found communicating with their group members as one of the largest project challenges, but also one of the most important to ensure the success of the project. They also found the interview process very helpful during the early stages of their design process; however, rather than using the interview assignment to discover a market opportunity, students used interviews as a means for verifying design themes, aesthetics, and/or obstacles.

Section 1: Introduction

Academic engineering institutions strive to prepare students for the engineering profession. Typical engineering curriculum builds strong foundational skills in mathematics and science during the first two years of engineering education. Institutions vary on when students can elect to study an engineering discipline. Students often begin their engineering education in a specified a discipline. Other institutions offer an introduction to engineering fundamentals or general engineering course with students choosing a specific discipline after their first year. At Florida Institute of Technology (FIT), most students elect a discipline before matriculating. However, students are also given the option to enroll in an Introduction to General Engineering EGN 1000 course designed to expose students to various career disciplines, introduce fundamental engineering approaches, and create an awareness of the responsibilities of engineers to their profession and society[1]. EGN 1000 replaces many of the discipline specific Introduction courses offered by the various engineering departments. The varied timing of when students choose an engineering discipline and the foundational focus on "core" curriculum of mathematics and science tend to limit freshman curricular opportunities introducing engineering concepts. First year courses that incorporate projects to build fundamental engineering skills while initiating students to the multidisciplinary nature of engineering offer excellent opportunities for entrepreneurial minded learning (EML).

The Kern Entrepreneurial Engineering Network (KEEN) comprises over 1200 faculty members practicing entrepreneurial-minded learning. KEEN's purpose is to graduate engineers who create personal, economic, and societal value through a lifetime of meaningful work. KEEN's framework couples an entrepreneurial mindset with engineering skill set to accomplish this mission. Within the network, entrepreneurial mindset is often described as 3 C's –curiosity, connections, and creating value. It is also demonstrated as a set of attitudes, motivations, expectations, and dispositions[2]. Additionally, entrepreneurial-minded learning has also been described through three learning domains – affective factors, thinking patterns, and content knowledge and skills[3].

While first year projects may not fully develop an entrepreneurial mindset, it is important to introduce students to these thinking patterns as early as possible in their academic engineering experience. First year projects incorporating making and value creation can be useful EML frameworks for shaping the necessary affective traits such as interests, motivation and values to develop an entrepreneurial mindset[4].

EGN 1000 Intro to General Engineering is a unique course, comprised of undecided engineering students, with a variety of interests and career goals. The course is broken up into two lectures and one lab per week, covering a variety of engineering topics. The course has three learning objectives, with this paper focused on the second one:

- To introduce you to various career disciplines in engineering and applied sciences.
- **To introduce you to fundamental approaches in engineering**.
- To create an awareness of the responsibilities of engineers to their profession.

This objective is achieved through a semester-long group design and making project called MiniGolf at Panther Links. The mini-golf project serves as a first year curricular driven project requiring students to design and make a mini-golf hole. Students are introduced to fundamental engineering skills such as virtual design and microcontroller programming in the laboratory environment and the engineering design process in lectures, but then use these skills in a project that requires the design and manufacturing of their golf hole. The following sections describe this effort in greater detail. Section 2 covers a brief review of previous literature. Section 3 describes the methodologies used in this study. Discussions of the study's results are included in Section 4, with conclusions presented in Section 5.

Section 2: Literature Review

<u>Entrepreneurial-Minded Learning</u>

Active and collaborative instruction that encourages student engagement has shown to improve learning outcomes in all academic disciplines[5, 6] including engineering[7]. Entrepreneurial-minded learning (EML) is an extension of proven active and collaborative learning techniques that further emphasizes discovery, opportunity identification, and value creation for others[8]. Founded on a framework of 3C's – curiosity, connections, and creating value - student learning outcomes include demonstrating a constant curiosity about the changing world and exploring a contrarian view of accepted solutions, integrating information from many sources to gain insight and assess and manage risk, and identifying unexpected opportunities to create value and persist through and learn from failure[2]. In 2004, the National Academy of Engineering published "The Engineer of 2020: Visions of Engineering in the New Century" putting forth aspirations for the profession and a call for engineering educators to prepare students with both a strong foundation and a new knowledge that advances society and creatively applies technology with broad consideration[9]. Many of the attributes used to describe the engineer of the future include qualities associated with creativity, innovation, and entrepreneurship. Relevant entrepreneurial skills include developing judgment to deal with novel and complex problems and pursuing opportunities of compelling value.

Efforts to connect EML to educational assessment literature suggests considering three entrepreneurial learning domains -- affective factors, thinking patterns, and content knowledge/skills[3]. Affective factors such as self-efficacy – a belief that students can succeed in a value creating activity, an orientation or predisposition toward value creation (a desire to participate in creating new value), and habitual curiosity, a drive to understand how things work and how to make them work better[3]. Thinking patterns derived from effectual logic can strengthen an entrepreneurial mindset by helping students leverage current knowledge resources and move through uncertainty by developing connections with other people and information in the pursuit of value creation[10]. Common learning outcomes that demonstrate entrepreneurial knowledge include opportunity recognition, design iteration and prototyping, project management, strategic and financial planning, communication and presentation, leadership and ethics[3].

Maker Movement

The Maker Movement in education is broadly characterized by three components – *making* as a set of activities, *makerspaces* as communities of practice, and *makers* as identities[11]. Three prevailing thought leaders in the maker movement include Chris Anderson, editor of Wired Magazine and author of Makers: The New Industrial Revolution, Mark Hatch, CEO and founder of TechShop and author of The Maker Movement Manifesto, and Dale Dougherty, founder and CEO of Maker Media and Chairman of Maker Education Initiative. Common themes of the maker movement include use of digital desktop tools, fabrication of physical artifacts, physical and digital collaboration, iterative design and fabrication, community of like-minded individuals, and democratized access to knowledge, tools, and spaces. From the December 2013 Maker Impact Summit a report developed by the Delotitte Center for the Edge and Maker Media leaders explored how the maker movement might have an impact on education, manufacturing, government and public policy, citizen science, and retail. Educational impacts included the conclusion that making encourages a learning disposition by nurturing curiosity, exploration and collaboration, and that making emphasizes hands on learning and transforms consumers into creators. This report also cited a lack of educators to champion making based education and difficulty creating scalable, personalized, and effective curriculum. Lack of educator champions and scalable, effective curriculum has also been identified as a barrier to general STEM education reform[12, 13]. In 2014 during the first ever White House Maker Faire, over 150 universities and colleges composed a joint letter to the President committed to expanding opportunities for making on their campuses and in their communities[14]. Additionally, universities across the globe are investing significant financial resources developing campus makerspaces.

While making encompasses a wide range of activities, the primary focus of a making project features the use of computational tools-both hardware and software-that have become increasingly affordable and accessible to the public[15, 16]. This includes open source virtual design software, desktop fabrication, 3D printers, and microcontroller kits such as Arduino's and Raspberry Pi's, all combined to realize a physical artifact. A making project goes beyond assembly of a kit and engages a student in combining existing knowledge with new skills to create a physical artifact that is first virtually designed and then physically constructed.

Entrepreneurial-Minded Learning and Maker Movement

Table 1 describes a model for creating curriculum driven experiences from project based learning, where projects are fundamentally making activities (or projects) that take place in makerspaces. The purpose of creating curriculum experiences requiring project based making activities within campus makerspaces is to provide a catalyst to establish the student's identity as a maker. The combined making activity, makerspace interaction, and identity formation can be a foundation for developing an entrepreneurial mindset – essentially transforming a student maker into a student value creator. This model provides a framework for creating student experiences and learning outcomes to develop an entrepreneurial mindset as defined by attitude, motivation, expectation, and disposition. Ideally, the initial experience occurs within first year curriculum.

Table 1: Model for curriculum development using an EML framework

Entrepreneurial Mindset Demonstrated by:	**Before Making Resource Interaction**	**After Making Resource Interaction**	**Entrepreneurial Minded Learning Outcome**
Attitude	Ambivalent to creating/making	Positive feeling about their ability to learn by doing	Validate technical knowledge learned in courses by creating a model/prototype
Motivation	Extrinsic curricular requirement	Convert extrinsic motivation of course work to an intrinsic motivation based on value of making	Quickly test concepts learned in courses to validate functional understanding and further learning as a creator vice consumer

Expectation	Low expectancy of being able to complete assignment.	Increased confidence and expectations of being able to make and create.	Create a model/prototype and develop skills for self-directed learning
Disposition	Potentially Fixed Mindset	Growth Mindset; discovery of learning by doing/building; greater confidence in ability to learn.	Develop curiosity. Persist through and learn from failure. Identify personal passion and plan for professional development.

Section 3: Methodology

Due to the unique nature of the General Engineering program at FIT discussed earlier, a multi-disciplinary approach is a natural fit to the course activities, assignments and learning objectives. Class lectures cover a variety of broad engineering topics and weekly labs are used to introduce a number of common engineering skills and computer applications. These activities support a semester-long group design and build project. This design and build project serves as a making activity that requires students to interact with campus makerspaces and fits the framework for curriculum driven making experiences that begin to develop a student's entrepreneurial mindset.

Over the semester, students engage in a group project where they design and make their own mini golf hole. Students are assigned to groups of 3 by the professor. Groups are chosen to be as diverse as possible, having both male and female members (when possible) and include a diversity of engineering discipline interest, since students in this course are undecided engineering majors. Towards the end of the semester, each mini golf hole comprises a MiniGolf course that is open to the campus and community to play. This golf course is often a feature during campus Discovery Days to introduce potential engineering undergraduates to unique educational experiences. The students' grades are based on several aspects, including the construction quality, the design aesthetics, accuracy of the CAD drawing, two separate design reports and a final design presentation. By completing the project, students will be expected to demonstrate:

- Working in an interdisciplinary group
- Verbal and written communication skills
- Design-related problem solving skills including innovation and an entrepreneurial mindset
- Knowledge of many engineering majors
- Hands-on making skills including woodworking, machining, 3D printing, and microcontroller programming

The MiniGolf course has an overall theme, which the groups must align their designs around, as well as several other design requirements. For the Fall 2016 semester, the course theme was Florida, leading students to design their holes around any theme related to the state of Florida. Some examples were theme parks, beaches and other natural attractions. The other design requirements were:

- Include one 4” golf hole cup (provided)
- Fit within a 3’ x 8’ footprint (basic frame materials were provided)
- Have a specified par less than or equal to six – meaning six golf strokes to complete the hole
- Be easily transportable by two or more students
- Include at least one 3D printed part of at minimum 1 cubic inch in size
- Include a microcontroller that performs at least 1 task
- Incorporate at least one feature from three different major related categories
    - Mechanical/Aerospace Engineering
    - Civil Engineering/Construction Management
    - Electrical/Computer Engineering
    - Ocean Engineering/Environmental Sciences
    - Chemical Engineering
    - Biomedical Engineering

Each group was required to submit four deliverables. The first was a preliminary design report, which was due approximately one month after the project was assigned. The preliminary design report served as an opportunity for the students to tell the faculty member what they planned to do and how they planned to do it. If groups did not sufficiently answer those two questions, their preliminary design was not approved and they did not receive their building materials until their design was approved. More specific guidelines were provided to the students to aid in the creation of their preliminary report. The second deliverable, due towards the end of November, was the finished mini golf hole, which was arranged with the other holes to form a complete MiniGolf course that was open for people to play over a period of three days. Over 100 people, including a group of over 50 middle school children played the course over those three days. The third deliverable was a final design report. This report was due at the very end of the semester and included the students design overview, budget, discussion on what was learned through the benchmarking/interview activities, and lessons learned among other required topics. Finally, during the final exam time, each group gave a presentation based on the group’s final report to the entire class and the paper authors.

The Intro to Engineering course meets twice a week for 50 minutes during the entire 16-week semester. Throughout the semester guest speakers from each department or program in the College of Engineering provide a brief but thorough introduction to their respective program. A number of lectures also covered topics such as the Engineering Design Process, Teamwork and Problem Solving. These lectures happened after the project was assigned, but prior to when any project deliverables were due. The intent is that students start the project on their own using the lectures to guide them through uncertainty and the design of their golf hole. This design and value creation phase is generally a new experience for student teams. Lectures are strategically framed to empower students to find resources (faculty, peer mentors, university staff, etc.) that enable them to complete the design and value creation phase. This structure also encourages students to develop thinking patterns necessary for an entrepreneurial mindset.

The course also met once a week in smaller lab sections (14 students or fewer) in various engineering computer labs. Labs covered a range of engineering topics and skills including: Microsoft Excel (2 lab sessions), Machine Shop tour/intro (0.5 lab sessions), Arduino microcontroller basics (1 lab session), engineering drawing (2 lab sessions), Computer-Aided Drawing/design (4 lab sessions), 3D printing basics (1 lab session), Matlab basics (2 lab sessions), and drone/UAV basics (1 lab session). Most of these topics were covered at an introductory level over the course of one 50-minute session. Those topics were specifically added to support the students in their making activity.

Both the machine shop tour and the 3D printing labs took place outside the computer lab within our campus makerspaces. The machine shop tour introduces students to our machine shop equipment, staff, and general procedures. Students were highly encouraged to take the optional Machine Shop Certification 1 course taught by the shop's director. This certification course is a zero credit, 8 hour long course required for students to use basic power equipment. Completing this course allows students to manufacture components of their project, rather than relying on the shop staff resources.

The 3D printing lab was taught in our newest campus makerspace supporting electronic and 3D printing activities. This makerspace is equipped with 5 operational 3D printers of varying models and sizes and a variety of microcontrollers, cameras, power equipment, and circuitry for use in curriculum, research, or personal projects. This makerspace is open to all students on campus.

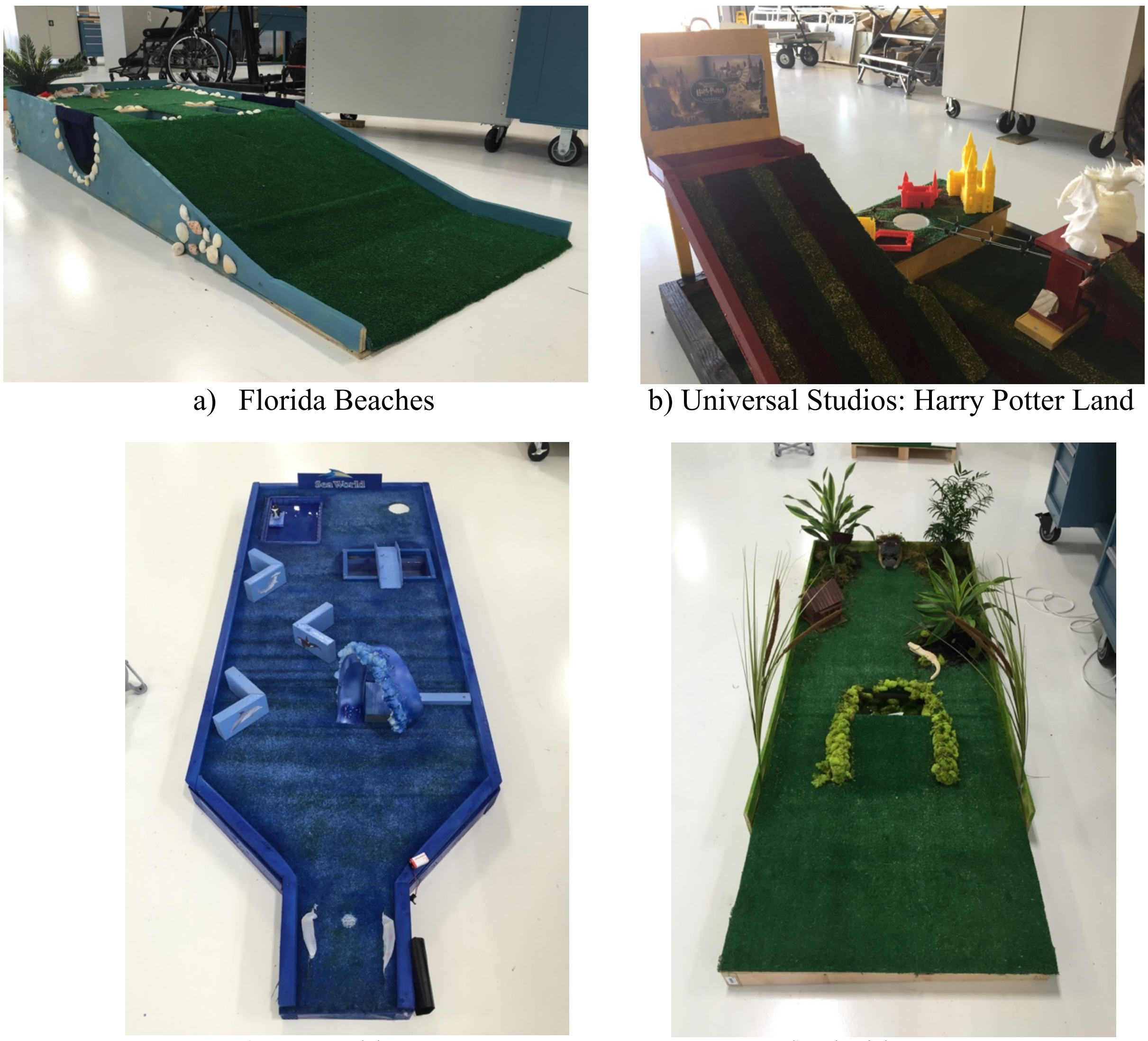
A third makerspace, our student design center (SDC), was not used for any lab session, but served as the construction site for the mini-golf course. Each group was allocated supplies and a workstation to complete their mini-golf hole. The SDC is conveniently located across the street from the machine shop facilitating the transition from manufacturing (machine shop) to assembly (SDC). Finally, the library's Digital Scholarship Lab (DSL) is considered the fourth makerspace on campus. The DSL is housed on one floor of the library, and loans electronic equipment (cameras, drones, VR equipment, etc.), as well as computers with a wide variety of software packages for photo and video editing, GIS, CAD, 3D scanning, and 3D printing. While not a required space for the design project, many students used this space to help them complete various aspects of the project when resources in other makerspaces were unavailable or over-loaded.

The mini-golf project allows engineering students to explore the design process with the goal of making a mini-golf hole. This semester the making project was augmented with an assignment to interview potential customers. The purpose of the assignment was to build communication skills, spur curiosity about why people play mini-golf, and what they seek from the experience. This requirement also introduced the students to the concept of a market and how to design a product/experience that benefits society (i.e. value creation). Students were surveyed about how the project and making experience affected their motivation and interest in pursuing an engineering education. Survey results are discussed in the following section.

Section 4: Results

Students' performance and learning were evaluated using a variety of methods. Measured deliverables included the finished product, reports and presentations throughout the semester. Additionally, student peer evaluations were conducted, along with a brief questionnaire regarding the student's experience related to making and entrepreneurial mindset.

The most visible deliverable of the group project was the finished mini golf hole. For many students, their mini-golf hole was the largest product they had ever made and for some students it served as their first experience with designing and making a finished artifact. A sense of pride was evident in many students during the display and open play to the campus and community. In fact, some students were able to bring their family to campus to show off their accomplishments to parents and siblings. Figures 1a-d highlight some of the mini golf holes that were created.



a) Florida Beaches
b) Universal Studios: Harry Potter Land
c) Seaworld
d) Florida Swamp

Figures 1a-d: Sample mini golf holes

Twelve mini golf holes were made as part of the overall MiniGolf course. For three days, the course was open to both the campus and community for play. Over 100 faculty, staff, students and community members completed the entire course, including a group of nearly 50 middle school students and teachers that coincidentally happened to be visiting campus. Every hole was expected to maintain playability over the course of the three days. While some minor breakdowns (mostly microcontroller wiring failures and power failures) did occur, every hole was playable for the full time requirement. Additionally, over 300 prospective students and family members were given a tour of the student design center (including the MiniGolf course) during a large admissions recruitment event on the last day of the course being open for play.

While the physical hole was the most entertaining deliverable, each group had to complete a preliminary report roughly one month into the project, a final report at the end of the semester, and provide a 5-10-minute presentation during the course's final exam time. The preliminary report was used by the instructor to gauge each group's preparedness for the construction portion of the project. Students were expected to state what they planned to do and how they were going to do it. Only 2 of the 12 groups received an approved preliminary report upon first submission, but groups were allowed to revise and resubmit without grade penalty. Each group received feedback from two other groups via peer review, as well as from the faculty member. Groups were able to resubmit their preliminary reports based on the feedback and once approved, they were given the basic building materials and assembly space in the design center so as to begin constructing their design. The majority of groups received approval upon resubmission, with only two groups requiring multiple resubmissions prior to approval. The benefit to the preliminary report feedback is helping groups make manageable design considerations and better understand how they will implement those designs prior to beginning work. Because these are freshman students with little design/manufacturing experience, many hadn't fully grasped the necessity of planning ahead.

The final design report and presentation were used as the final exam for the course. The final report was based on the preliminary report, but needed to include: an introduction, design overview, final budget, discussion of the steps in the design process and how the group followed them, discussion of the benchmarking and interviewing activities and the impact they had on the design, CAD drawings of the hole or several of the hole's features, and the lessons learned from the project. Little guidance was given for the final presentation, short of the expected time and the need to incorporate visuals of the finished product. The groups were told this presentation should be used as a way to "sell" their design to the professor.

As would be expected, the quality of final reports varied, with some groups merely using the report requirements as different sections in the report. A couple groups were able to put together a more cohesive report that told the story of their design and how they went about creating it. The overwhelming consensus on lessons learned is to not procrastinate and do a better job communicating. Another common lesson learned was to have a formal team leader who would take charge of the scheduling and team activities.

A peer evaluation was used to determine each group members overall contribution to the project, as well as to better understand how well the group functioned. Recall, the groups were assigned at the beginning of the semester so there was no previous connection between the students prior to starting the project (unless they happened to meet during an orientation event before the semester started). In general, the teams functioned reasonably well. A few groups had significant issues with communication, namely a single team member was not fully participating or engaging with the other members. When it was clear there was a team member that was significantly under or over-performing compared to the rest of the team, adjustments were made to that individual's project grade.

Overall the project encouraged exploration of more than one engineering discipline – an important outcome for an introductory general engineering course helping freshman to inform their discipline choice. The project proved to be an excellent introduction to the several making resources available to students on campus, as every team utilized several different spaces with most teams using all the available spaces. By completing this assignment, students were introduced to our machine shop, makerspace, library, and student design center. Students reported an increase in learning through interactions with the making space staff and other students (often upperclassman student workers).

A survey was administered to the students after they had completed the project, but before they gave their final presentations. A summery of four of the closed answer questions is shown in Tables 2 and 3. Overall, the students strongly agreed that the project stressed the importance of engineering drawings and the need for planning their design before beginning construction. Additionally, the students appeared to be very satisfied with the making project and felt the project increased their motivation for related course assignments.

Table 2: Directed response questions of mini golf project survey

Question	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Average
This project helped me better understand the importance of engineering drawings.	0	0	1	9	15	4.56
This project helped me better understand the importance of balancing project design with the financial aspects of a project budget	0	0	4	9	9	4.23

Table 3: Additional directed response questions from mini golf project survey

Question	Yes	No	Neutral
Did this project increase your interest in related course work and assignments?	19	3	2
Were you satisfied with your exposure to hands-on making experience during this project?	15	1	8

Based on the student's answers to the open response survey questions, the customer interviews were mostly used to determine how difficult to make a hole or what kind of obstacles a person enjoys most. Rather than using the interview assignment to discover a market opportunity, students used the interviews as a means for verifying their design themes, aesthetics, or obstacles. In other words, most teams had a design in mind during the interview process and used the interviews to select features and functionality rather than discovering opportunities for desired features/functionality and creating a unique valued entertainment experience. However, one team did learn that customers do not enjoy crowded courses. They responded to this information by simplifying their design of obstacles to achieving par on the course enabling rapid completion times.

One aspect of the interview process that caught the authors off guard was that students only interviewed other people available on campus, typically their friends. In this case, the mini-golf course was being designed for campus and would likely be used by people on campus. However, an improvement could be made to challenge students to interview people that are more representative of an intended "market". Generally mini-golf courses are a form of family entertainment, ideally being equally fun for people of all ages and skill levels. Additionally, the authors intended on having the interviews force the students to better understand how to create a valued experience for a diverse set of people.

Significant outcomes of the project were students stating that the project helped them understand the value and purpose of engineering drawings and the importance of planning the design before diving into the making process. Similarly, most students agreed the project exposed them to the challenge of balancing project design with financial aspects of a budget.
Most students reported that the making project increased their interest in related engineering courses and valued "using the design process in practice" over simply learning about it in a lecture. Students also reported discovering the possibilities of what could be accomplished with their new engineering skills such as programming the Arduino micro-controller processer. Overall students reported an increased satisfaction through the realization of a making activity.

However, students did report during the final presentation that the teamwork component of the project was often the most frustrating aspect. Students reported that they did not learn skills to help them better interact with others on the project. In fact, a survey question of whether the project increased or decreased an interest in the related course work – one student responded that discovering other students did not share their commitment to success caused great unwanted stress. This student reported they did not learn skills to manage the stress of working with difficult teammates.

Students were surveyed on their primary communications method used within their team. Overwhelmingly every student reported text messaging as the primary communication method. Very few students employed email, phone conversations, or regular weekly meetings. In fact, one team reported during their final project presentation that they were "shocked" by how much work the team could accomplish when they met face to face in the makerspaces.

Section 5: Conclusions

Overall, the mini golf freshman making project has been a large success. Students regularly cite it as the best class experience in course evaluations further confirming student preference for active, engaged learning experiences. All teams were able to complete a product in time (mostly through a large push right up until the deadline). Additionally, students documented and communicated their experiences through a written final report and presentation. Both requirements allow students to reflect on the project, making activity, and better understand where there was room for improvement. Unsurprisingly, the largest point of reflection is to avoid procrastination.

In the surveys, students reported exploring more than one engineering discipline during the project with exposure to Civil, Mechanical, and Electrical being the most common majors reported. The students found communicating with their group members as one of the largest challenges of the making project, but also one of the most important to ensuring the success.

The authors intend to continue this making project in future years, assuming sufficient financial support is found. Funding for teams to build the physical golf hole each year has proved to be the largest hurdle to adopting this making project, although the total cost is typically under $2,000 for a class size of approximately 30 students.

Some modifications are planned for next year's version of this making project with further improvements in entrepreneurial minded learning. Additional guidance on customer interviews will be provided so that students can strengthen their content knowledge regarding opportunity discovery and value creation. Further curriculum modification is needed to incorporate additional knowledge content regarding market identification and analysis within the context of the engineering design process. A second peer evaluation will also be added to provide earlier feedback and reflection on team communication and functioning so that skills for resolving teamwork issues can be explored and developed.

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