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A First-Year Design Project That Encourages Motivation, Curiosity, Connections, and Making

Dr. Haolin Zhu, Arizona State University

Dr. Haolin Zhu earned her BEng in Engineering Mechanics from Shanghai Jiao Tong University and her Ph.D. in Theoretical and Applied Mechanics from Cornell University, with a focus on computational solid mechanics. Dr. Zhu is an Associate Teaching Professor of the freshman engineering education team in the Ira A. Fulton Schools of Engineering at Arizona State University (ASU). In this role, she focuses on designing the curriculum and teaching in the freshman engineering program and the mechanical engineering program. She is also the Co-Director of the Grand Challenges Scholars Program (GCSP) at ASU. In this role, she focuses on student support and tracking, curriculum, program requirements, as well as programming for current students in GCSP. Dr. Zhu was also involved in the ASU ProMod project, the Engineering Projects in Community Service program, the Engineering Futures program, the Global Freshman Academy/Earned Admission/Universal Learner Courses Program, and the ASU Kern Project. She was a part of the team that designed a largely team and activity based online Introduction to Engineering course. She has also co-developed two unique MOOCs, Introduction to Engineering and Perspectives on Grand Challenges for Engineering for the Global Freshman Academy/ASU Earned Admission/Universal Learner Courses Program. Her Ph.D. research focuses on multi-scale multiphase modeling and numerical analysis of coupled large viscoelastic deformation and fluid transport in swelling porous materials, but she is currently interested in various topics in the field of engineering education, such as innovative teaching pedagogies for increased retention and student motivation; innovations in non-traditional delivery methods, incorporation of the Entrepreneurial Mindset in the engineering curriculum and its impact. She has published over 30 papers and presented at various conferences about her work. She is recognized as the Engineering Unleashed Fellow and won the Fulton Outstanding Lecturer Award for her contributions in Engineering Education.

Amy Trowbridge, Arizona State University

Amy Trowbridge is an Associate Teaching Professor in the Ira A. Fulton Schools of Engineering at Arizona State University and is co-Director of the Grand Challenges Scholars Program (GCSP) at ASU. Amy is a member of the current interim Executive Committee for the international GCSP Network, and mentors schools to develop GCSPs as part of the GCSP New Programs committee. She is also actively involved in the ASU Kern project and Kern Entrepreneurial Engineering Network (KEEN), focused on students' development of entrepreneurial mindset. Amy received the 2019 KEEN Rising Star award from KEEN for her efforts in encouraging students in developing an entrepreneurial mindset. She is interested in curricular and co-curricular experiences that broaden students' perspectives and enhance students' development, and the use of digital portfolios for students to showcase and reflect on their experiences.

A First Year Design Project that Encourages Motivation, Curiosity, Connections, and Making

Abstract

This paper describes a design project, the Mars in the Making project, that was developed to encourage more motivation, curiosity, and connections in first year engineering students, while also enhancing opportunities for making. The motivation behind the Mars in the Making project is to use the future establishment of a Mars colony and automation as the context and to allow students to choose an opportunity/need area to focus on based on their interests and passions, while still ensuring consistency in the amount of effort and complexity of the designs produced. The design project was implemented in 3 sections of the Introduction to Engineering course at Arizona State University in Fall 2021, 2 sections of the course in Spring 2022, and 7 sections of the course in Fall 2022, with approximately 40 students in each section.

To assess the impact of this design project on student motivation, curiosity, connections, and their making skills, a survey instrument was administered to students enrolled in 7 sections of the course and a written individual reflection about their course experience was assigned to students enrolled in 4 sections of the course, both at the end of the Fall 2022 semester. Quantitative analyses of the 163 survey responses to the Likert scale questions show that students 1) corresponded mostly with the self-determined types of motivation, i.e., they were mostly motivated to do this project for their own benefits and chose to do this project themselves because of the value it provided; 2) were curious, actively seeking out new information and knowledge while working on the project, and enjoyed the personal growth and learning they gained from their project experience; and 3) improved various types of making skills through the project experience. These analyses also show that the project provided a good opportunity for students to make connections in different ways and a good yet fun learning and making experience. Qualitative analyses of the 112 individual reflections further confirm that students demonstrated the self-determined types of motivation, were curious while working on the project through demonstrating positive emotions from learning new information and skills, made connections to diverse viewpoints and alternative solutions, and acquired valuable making skills from their project experience. Suggestions offered by students to improve the project include more time for project prototype construction, more guidance on Arduino coding, more clarity about the scope of the project, and more encouragement for creativity in the designs produced.

In the paper, the design project and its implementation will be described, and the assessment results will be presented and discussed.

Introduction and Motivation

At Arizona State University, the Introduction to Engineering course is a 2-credit team-based, hands-on course taught in a studio format over a 15-week semester. Each section of the course has approximately 40 students from multiple majors and meets twice a week for 2 hours each in a makerspace. This course introduces students to the engineering design process as well as technical and non-technical skills that are essential for their success in college and future careers. Students in the course have opportunities to apply the engineering design process and the technical and non-technical skills in a team-based design project that is demonstrated with a functional physical prototype. In the past, the authors have implemented different design projects in this course, ranging from projects that require all teams to design a version of something according to a set of design specifications, e.g., a solar-powered vehicle, to projects that are completely open-ended. Due to the restrictions set in place for the former, students often do not have the opportunity to exercise their entrepreneurial mindset, a mindset that focuses on the three C's: curiosity, connections, and creating value, according to the KEEN framework for Entrepreneurial Mindset [1-3]. In these projects, students often focus more on the technical details of their designs without considering why the design should be created and what value it creates for the relevant stakeholders and target customers. On the other hand, with the latter, when a project is completely open-ended, it provides better opportunities for students to exercise their entrepreneurial mindset by observing their surrounding world with curiosity to identify opportunities and making connections to create value through design. However, it is sometimes difficult for first year students to properly scope their project when it is completely open-ended, and the complexity of the designs produced often vary a lot across teams, resulting in consistency issues for student learning, effort, and assessment purposes.

To address the weaknesses of both types of projects, the authors found a middle ground and developed a design project, the Mars in the Making project, which is open-ended but within a real-world context to both allow students to be creative and maintain a somewhat consistent level of complexity and effort. This project uses the future establishment of a Mars colony and automation as the context within which each student team has the freedom to identify an opportunity/need area to focus on based on their interests and the needs of the stakeholders. The goal in implementing this project is to encourage more motivation, curiosity, connections, and making. According to self-determination theory, the highest level of self-determination, intrinsic motivation, i.e., doing something for one's own sake, is achieved when there is a true sense of choice, i.e., a sense of freedom to do something one has chosen to do [4]. Because of this, the authors hope that students would be more intrinsically motivated to work on the project and learn from their project experience by making the project open-ended. Providing an open-ended, real-world context and allowing students to identify opportunities has also been found to inspire students' development of an entrepreneurial mindset, including curiosity and connections [5]. By setting the context on Mars and in the future, the authors aim to push students out of what they may already be familiar with, encouraging them to exercise their curiosity more to gather, learn, and integrate new information in order to create effective and successful designs. Requiring students to include automation in their designs is done to ensure a level of technical complexity and provide a better making experience, enabling students to learn and apply important modern making skills, including CAD modeling, 3D printing, laser cutting, using hand and powered tools, and Arduino [6].

Project Description

The fictional context provided for the project involves a National Aeronautics and Space Administration (NASA) mission in the year 2050. In this fictional scenario, NASA has successfully sent a small number of human astronauts to Mars to set up the first habitat and is planning to send another 100 astronauts very soon to set up a large scale habitat, conduct experiments and research, identify and establish sustainable food, energy, and water sources, identify and mine other resources, and set up other necessary facilities/processes for a Mars colony. Each student team's goal is to identify an opportunity/need area important for establishing the Mars Colony and sustaining life on mars that could benefit from hands-free automation, and to create a design to fulfill the opportunity/need identified. Each team demonstrates their design's function by creating a small scale physical prototype on a $100 budget using an Arduino uno board, various sensors and actuators, and common construction materials with costs based on their market prices. The physical prototype can be constructed using hand tools, powered tools, 3D printing, laser cutting, or a combination of these methods. The physical prototypes are assessed based on a set of criteria including ones that measure functionality, performance, ability to address customer needs, cost effectiveness, creativity, aesthetics, and craftsmanship. Students first learn and apply the engineering design process in a small-scale two-week conceptual design challenge prior to the start of the Mars in the Making project. The Mars in the Making project starts in Week 4 of the course and lasts until the end of the semester for this 15-week course. More specifically, during the first half of these 12 weeks of the project, students work on 2 intermediate project deliverables that are designed to help them identify an opportunity, perform customer discovery, define the problem, and propose a well thought out conceptual design solution before construction of the functional physical prototype begins, and actively participate in hands-on skills sessions to learn and practice various technical skills that are useful for their project. Physical prototype construction and testing occurs during the remainder of these weeks. Final deliverables of the project include an oral presentation about their designs and a final written project report. A complete example weekly schedule for the Mars in the Making project can be found in Table 1 in the Appendix.

Examples of designs created for this project range from rovers for various purposes such as weather monitoring, resources identification and transportation, and ice detection, to devices that help with waste management, getting access to sustainable food sources, and mental health of the astronauts and future Mars colonists. Below are a few examples of design prototypes for this project.

Fig. 1. Examples of design prototypes for the Mars in the Making project (top example: an astronaut companion robot; middle left example: a greenhouse assistant robot; middle right example: a rover to detect and harvest ice; bottom example: a rover to explore and document findings using images)

Research Aims and Methodology

This study aims to address the following questions:

- Why did students participate in the project and to what extent were they intrinsically and extrinsically motivated to work on the project?
- Were students curious and did they exercise their curiosity while working on the project?
- Did the project provide students with opportunities to make connections?
- How much did the project impact students' making skills?

To address these questions, data was analyzed from two sources: a survey with both Likert scale questions and a free response question and student written individual reflections about their course experience. The survey instrument that was administered to students enrolled in 7 sections of the course at the end of the Fall 2022 semester collected information about the participants, including their academic level, biological sex, and major, and measured student motivation based on the Situational Motivation Scale (SIMS) [7-8], student curiosity that relates to joyous exploration based on the five-dimensional curiosity scale [9] and curiosity involvement [10], connections based on the connections rubric [11] adapted from the VALUE (Valid Assessment of Learning in Undergraduate Education) Rubrics [12], and their making skills. The survey also measured students' opinion about the project and collected their suggestions to improve the project. Students enrolled in 4 sections of the course in the Fall 2022 semester also submitted written individual reflections at the end of the semester about their course experience based on a generic prompt provided. The prompt asked students to summarize their course experience, describing what they have learned from the course, what they found interesting, and what they would take away from the course, and to reflect on the value of their course experience, discussing what specific skills, mindset, and experiences they have gained from their course experience and how these skills would benefit them in the future. Only data collected from participants who gave informed written consent is included in the study. This study is based on survey data from 163 participants and individual reflections from 112 participants.

Results and Discussion

<u>Survey Results</u>

Demographics of Survey Participants

A total of 163 valid survey responses from those who provided informed written consent were received. Out of these survey participants, 80.4% are males and 19.6% are females. The majority (96.1%) of these survey participants are freshmen and they represent six majors (42.3%

Mechanical Engineering, 23.3% Aerospace Engineering, 17.2% Electrical Engineering, 16.0% Chemical Engineering, and 0.6% Other).

Motivation

The survey asked the participants to rate how much they agreed with each of a series of statements from the Situational Motivation Scale (SIMS) [7-8] that represent their reasons for participating in the Mars in the Making project on a Likert scale of 1 to 7 (1=corresponds not at all; 7=corresponds exactly). These statements represent the SIMS subscales of Intrinsic Motivation, Identified Regulation, External Regulation, and Amotivation, where Intrinsic Motivation refers to doing something for one's own sake, Identified Regulation means choosing to do something oneself as it is being valued, External Regulation corresponds to doing something as regulated externally, e.g., by rewards or demands, and Amotivation means there is no sense of purpose for doing something [7]. The statements for each of these four SIMS subscales can be found in Table 2. These survey responses were analyzed quantitatively, and the results are displayed in Fig. 2. In Fig. 2., bars in each motivation subscale correspond to the statements in the order as shown in Table 2. The last row in Table 2 shows the overall average score for each motivation subscale. Based on the results, Intrinsic Motivation and Identified Regulation scored higher than the other two subscales, which indicates that the participants corresponded mostly with the self-determined types of motivation, which are often associated with positive outcomes and thus are more desirable than the other two non-self-determined types of motivation [7]. This means that these participants did the project for their own benefits and felt that they chose to do it themselves, even though the project is a required component that is worth over 30% of their grade for the course.

Table 2. Situational Motivation Scale statements and average score for each subscale

	Intrinsic Motivation	**Identified Regulation**	**External Regulation**	**Amotivation**
1st Statement	Because I think that it is interesting.	Because I am doing it for my own good.	Because I am supposed to do it.	There may be good reasons to do it, but personally I don't see any.
2nd Statement	Because I think that it is pleasant.	Because I think that it is good for me.	Because it is something that I have to do.	I do it but I am not sure if it is worth it.
3rd Statement	Because this activity is fun.	By personal decision.	Because I don't have any choice.	I don't know, I don't see what it brings me.
4th Statement	Because I feel good when doing it.	Because I believe that it is important for me.	Because I feel that I have to do it.	I do it, but I am not sure it is a good thing to pursue it.
Overall Subscale Mean	**5.34**	**5.42**	4.93	2.36

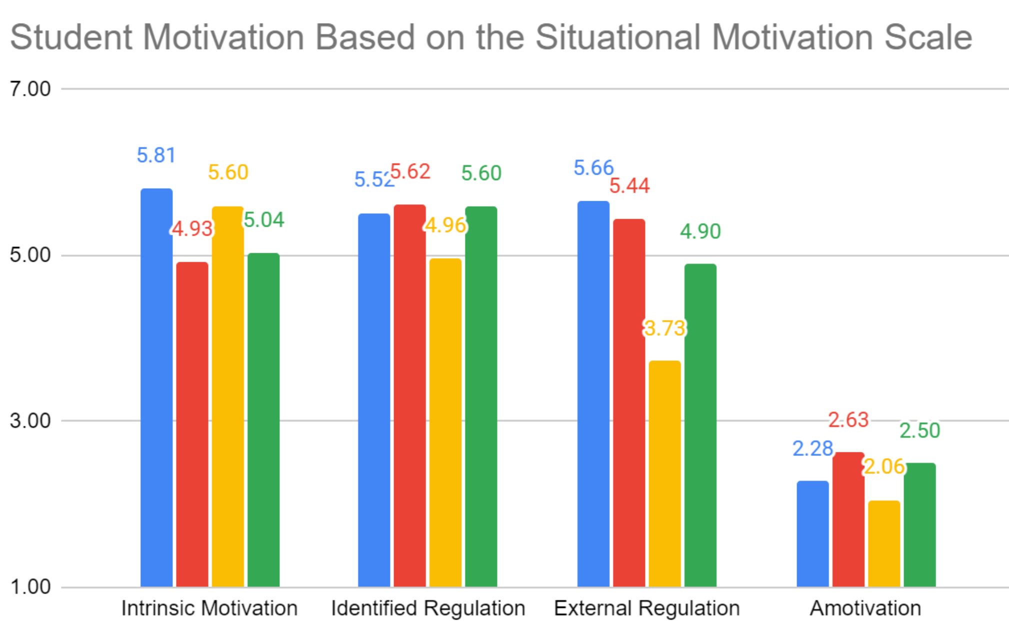

Fig. 2. Student motivation based on the Situational Motivation Scale (bars in each motivation subscale correspond to the statements in the order as shown in Table 2)

The survey participants also rated how much they agreed with other reasons for participating in the Mars in the Making project on a Likert scale of 1 to 7 (1=corresponds not at all; 7=corresponds exactly) and the results are shown in Fig. 3. These results suggest that students were mostly motivated to participate in the project because of the value it provides, as opposed to external factors.

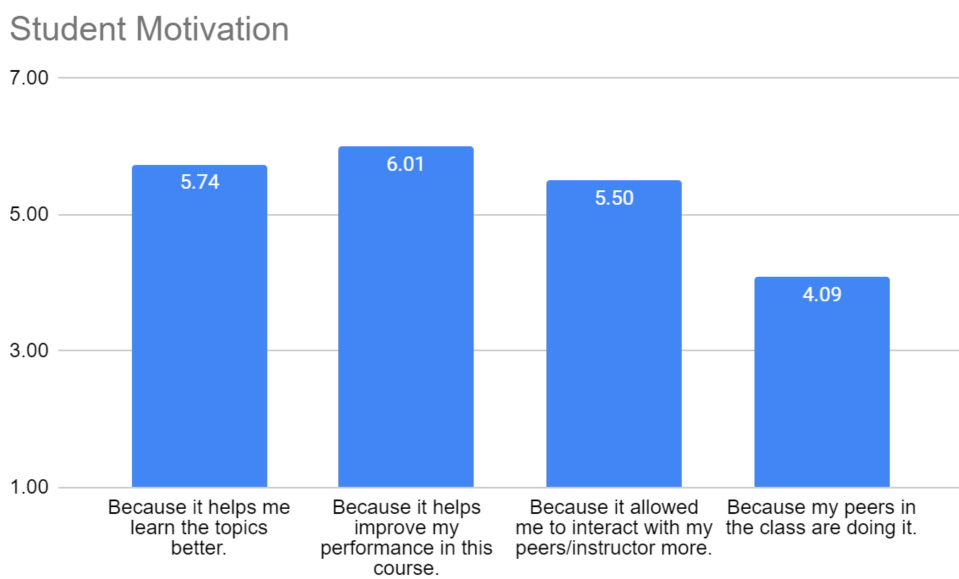

Fig. 3. Student motivation - other reasons

Curiosity

To assess impacts of the project on curiosity, survey participants rated how much each of the statements listed in Table 3 described them on a Likert scale of 1 to 7 (1=does not describe me at all; 7=completely describes me). The first five items in Table 3 characterize one of the five dimensions of curiosity, joyous exploration [9]. According to Kashdan [9], joyous exploration is the measure that most strongly corresponds to the motivation for seeking out new information and experiences and thus is the most relevant dimension of curiosity for this study. The last four statements in Table 3 are measures of curiosity involvement, curiosity that correlates to acquiring knowledge and learning new ideas without being constrained by time and specific problems [10]. The participants scored very high on both joyous exploration and curiosity involvement. This indicates that they were curious, enjoying the learning and personal growth that occurred from their project experience.

Table 3. Items of the five dimensions of curiosity - joyous exploration & measures of curiosity involvement

Statement	**Mean Score**
I view challenging situations, such as working on the Mars in the Making project, as an opportunity to grow and learn.	6.27
I am always looking for experiences, such as working on the Mars in the Making project, that challenge how I think about myself and the world.	5.94
I seek out situations, such as working on the Mars in the Making project, where it is likely that I will have to think in depth about something.	5.83
I enjoy learning about subjects, such as those I learned while working on the Mars in the Making project, that are unfamiliar to me.	6.10
I find it fascinating to learn new information, such as the new information I learned while working on the Mars in the Making project.	6.21
I enjoy exploring new ideas.	6.31
When I learn something new, such as the new things I learned while working on the Mars in the Making project, I'd like to find out more about it.	6.01

The survey also asked how many external sources the participants referred to while working on the project. This survey question aims to gauge how much the participants actively sought out new information when not being required to (but encouraged to), another indicator of curiosity. According to the results, almost all of the survey participants referred to external sources while working on the project and over 40% of them referred to at least five external sources.

Making Connections

Survey participants rated how well they agreed with each of the statements that measure the opportunities that the Mars in the Making project provided to make connections, on a Likert scale of 1 to 5 (1=not at all; 5=extremely). These statements were adapted from the connections rubric [11]. The responses to this survey question were analyzed quantitatively and the results are shown in Table 4. Based on these results, the project provided great opportunities for students to make connections in several different ways.

Table 4. Connections – The Mars in the Making project provided an opportunity for me to

Statement	**Mean Score**	**Standard Deviation**
Connect information from more than one discipline in order to create an effective solution.	4.35	0.71
Consider multiple viewpoints in order to create an effective solution.	4.42	0.72
Connect with and use my existing knowledge in order to create an effective solution.	4.42	0.75
Consider multiple solution paths in order to create an effective solution.	4.52	0.63
Explore the context of the problem in order to create an effective solution.	4.40	0.70

Making Skills

Survey participants were asked to rate their level of familiarity with various making skills before and after the course, on a Likert scale of 0 to 5 (0=never used/learned; 5=very familiar), and the results are compared in Fig. 4. Out of these making skills, laser cutting had the largest gains from before to after the course, followed by building circuits, CAD modeling, and 3D printing. It is interesting to note that the participants' familiarity with Arduino coding decreased slightly (by 4.41%). During the two Arduino based skills sessions, students were taught how to code common sensors and actuators that most groups may find useful for their designs. But due to the open-endedness of the project, almost all groups used at least one sensor that was not taught in these two skills sessions and the complexity of the designs required the groups to integrate multiple sensors and actuators which resulted in complicated circuits and codes. Some of these groups had difficulty working with the new sensors and/or integrating all the sensors and actuators, which may have led to their lack of confidence in this making skill after the course. This hypothesis is supported by the fact that 24 survey participants suggested that more teaching and guidance be provided to help them with Arduino and sensors in their responses to the free response survey question "What suggestions do you have to improve the Mars in the Making project in this course?" (more details are discussed later).

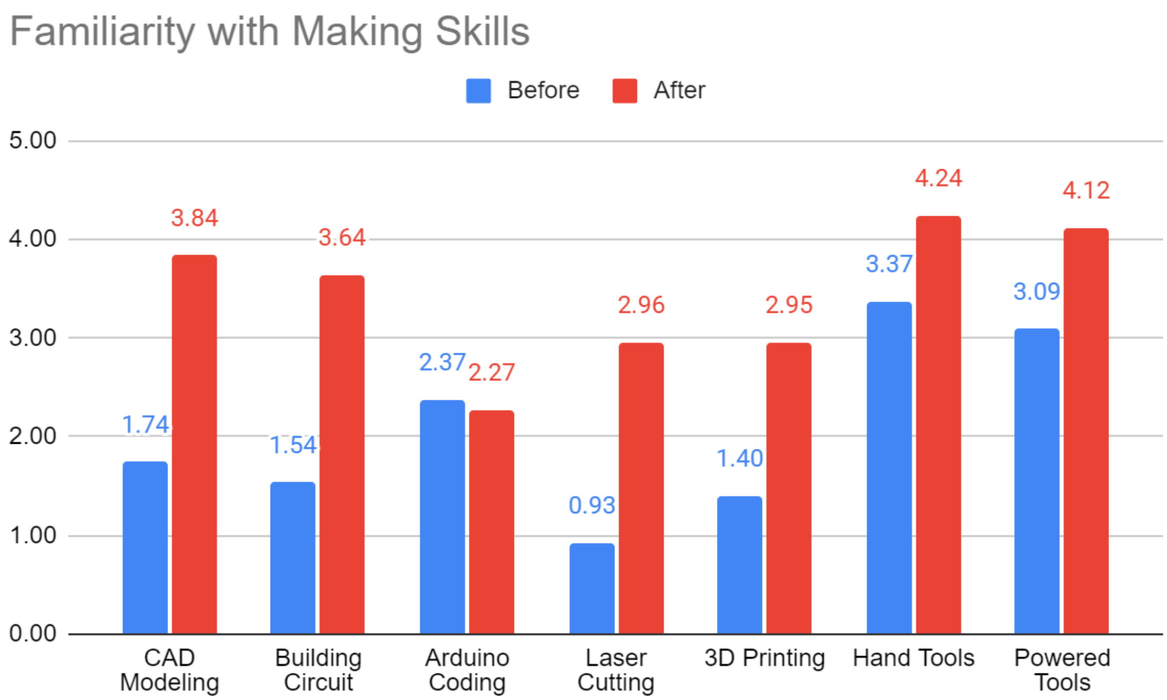

Fig. 4. Student familiarity with making skills before and after the course

Overall Opinion

The survey asked participants to share their overall opinion about the Mars in the Making project by selecting all statements that they agreed with. Fig. 5 shows the percentage of participants that agreed with each statement. Overall, the project provided a good learning and making experience that was also fun and enjoyable.

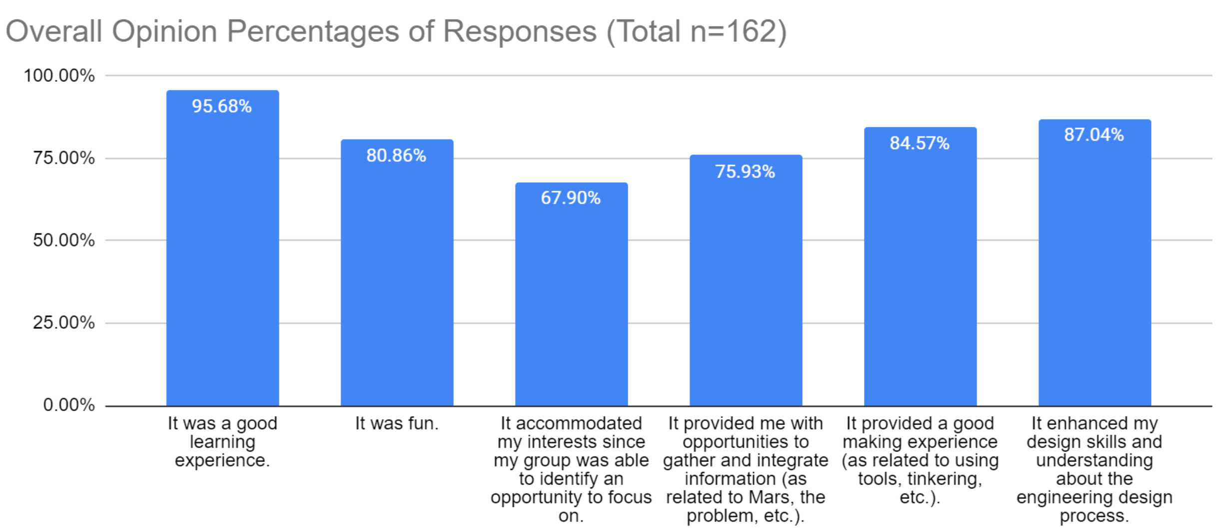

Fig. 5. Student opinion about the Mars in the Making project

Suggestions for Improvements

Out of 163 survey participants, 98 offered suggestions to improve the project in their responses to the free response survey question "What suggestions do you have to improve the Mars in the Making project in this course?". These responses were analyzed qualitatively using thematic analysis [13] and common themes were identified. Overall, the participants thought that the project was great, but they wished to have more time for project prototype building, more guidance and help with Arduino coding and prototype building, more budget, more examples of designs to help them better understand the scope of the project when it was introduced, and more encouragement for creativity. More details about the common themes that emerged, the number of responses that showed each theme, and example comments can be found in Table 5 in the Appendix. The suggestions offered by the participants are very valuable and will be incorporated into the project and its implementation in the future.

<u>Individual Reflections Results</u>

The individual reflections from the 112 participants were analyzed following the process for thematic analysis described by Braun and Clark [13]. Two researchers independently reviewed the data to become familiar with it and then identified themes based on the literature to use as the framework for the thematic analysis to measure student motivation, curiosity, connections, and making skills. The two researchers then independently coded the data by labeling excerpt(s) from each reflection that reflected a theme and recording it in a spreadsheet. The analysis results from both researchers were compared and any discrepancies were discussed until agreement was reached for inter-rater reliability. The number of reflections in which a theme was found was counted and example excerpts for each theme were recorded. The results and discussions are presented below.

Motivation

Two themes were identified for motivation based on the self-determined types of motivation from the Situational Motivation Scale [7-8]:

1. Engage in the project experience because it is interesting (Intrinsic Motivation)
2. Engage in the project experience because it is valued (Identified Regulation)

One or both themes for motivation were found in 61 out of the 112 reflections (54.5%). Many students described their project experience to be fun, demonstrating intrinsic motivation, while others discussed the value the project experience provided, indicating that they demonstrated identified regulation. Below are example excerpts that align with one or both themes:

"The most enjoyable part, however, was the actual building of the design. This took place in class almost entirely within the Mars in the Making Project, which took up almost the entire semester of the class. This was easily the most memorable part of the course, as well as being the most useful and enjoyable. It helped me learn skills such as working with power tools, workplace safety, and generally granted me experience in craftsmanship. Should I be able to do something similar like this again, I would definitely perform better than I had before because of this class. I have learned the do's and don'ts of designing, and I really enjoyed the process as well."

"The component of this course that I enjoyed and valued the most was when we began working on our "Mars in the Making" project. I enjoyed and valued this project the most because it allowed us to gather all the skills and knowledge we picked up throughout the class and incorporate them into our very own machine, providing us with a taste of how engineering work would work in the real world."

"The Mars in the Making project was awesome as well. As an Aerospace Engineer who is really interested in space exploration, doing a sample project and making technology that down the line, if I find myself in the right situation, could be pitched to actually be put on Mars, was such a fun experience. It allowed for the creative side of my brain to really be opened up in school and explore some crazy topics which eventually lead to our final design."

Curiosity

The themes identified for curiosity are:

1. Value personal growth from experience
2. Demonstrate positive emotions from learning new information and skills
3. Seek out new information actively outside of classes

The first two themes were identified based on the characteristics of people who scored high on the Joyous Exploration dimension of the five dimensions of curiosity [9]. According to Kashdan, these people "*were shown to be open to experiences, in possession of a strong personal growth initiative, show tenacity when pursuing opportunities to learn and grow, and derive positive emotions and meaning from learning new information and experiences*." [9]. The third theme appeared when the researchers coded the data and it is clearly an indicator that one is being curious.

One or more of these three themes appeared in 63 out of the 112 reflections (56.3%). Out of the three themes, the second one was found to be most prevalent. Those whose reflections showed this theme described their experiences learning new information and skills as being fun, interesting, enjoyable and overall a good experience, and/or that they were grateful for such experiences. Below are example quotes representing demonstration of positive emotions from learning:

> *"One of my favorite topics to learn about was circuits and coding. At first it was hard to understand but I kept learning and trying until I got the hang of it. As I learned more and gained a deeper knowledge I began really enjoying how codes and circuits worked."*

> *"Another big thing that I learned and found the most interesting was Arduino coding and circuitry. I had never worked with a coding language before, and certainly not one that could be used for real life automation. I already had some circuit practice coming in, but applying those skills to automation was a huge learning curve and one I really enjoyed. Being able to watch your code/project "come to life" was super great to see and rewarding of all the hard work that went into it. This was mainly evident in the Mars Project, but was also great to work with in the assignments leading up to that which refined those skills even more."*

> *"The most fun I had during the semester in FSE 100 was my experience with the 3D printer and laser cutter! While I was never able to use the laser cutter, learning how to use the Inkscape software was really fun and informative, and I already plan on using what I learned in the near future when I cut the fins for my project rocket for my club! This was also the first time I was able to use a 3D printer, and I still have the object I made for the assignment as I loved it so much, and I can personally see myself using the printer throughout college, if it may be for other classes or clubs or for my own ventures into a variety of engineering projects."*

Although not as prevalent, several students mentioned taking the initiative to spend extra time outside of class to further their learning of what was introduced in the class though not being asked to. For example, one student noted that:

> *"I was able to learn from my team members how to use screwdrivers and cut wood as I have never worked with these tools before. I even took the time outside of class to get familiar with them, as they are valuable skills that I can use at home and in my career."*

Connections

According to the connections rubric [11] that was adapted from the VALUE (Valid Assessment of Learning in Undergraduate Education) Rubrics [12], there are seven aspects for making connections, including connections to diverse disciplines, diverse viewpoints, global context, existing knowledge, personal experiences, problem contexts, and alternative solutions [11]. Instead of using each one as a separate theme, researchers looked for evidence for making connections from any of these aspects and used this as the overall theme for connections.

This theme was found in 32 reflections (28.6%). In most instances, students mentioned how they connected diverse viewpoints among the team members when working on the project and/or how they considered alternative solutions and explored how they connected to the context for the project. One student mentioned connections to the problem contexts:

> *"We spent months working on this project, initially beginning with the brainstorming session in which we worked to understand what type of self-automated robot would be best to create for Mars based on NASA's and its astronaut's needs. For this, we initially began by identifying a number of problems that we could solve for astronauts that could also bring value, such as the fact that there would be limits on food and water sources since none are found to be there, variations in weather conditions that could be hazardous, and providing a method that could assist astronauts in their building of machines and other areas."*

Making Skills

The following three themes were identified for making skills where making skills refer to one or more of the modern skills including CAD modeling, 3D printing, laser cutting, using hand and powered tools, and Arduino [6]:

1. Acknowledge acquisition of making skills
2. Express confidence in making skills
3. Value making skills

Making skills showed up in 95.5% of the reflections (107 out of the 112 reflections). In most of these reflections, the students mentioned learning more than one type of making skills and/or how these skills will be useful and valuable in their future classes and careers. Examples of excerpts that showed these themes are:

> *"It is my first time building something from scratch, I have never touched any woodcutter or drill before. This was a once-in-a-lifetime learning experience for me, I picked up a lot of building and designing skills from this part of the project."*

> *"I recently started an internship during this class and it was amazing because of the skills we were learning I was putting into use at my job. At my job I am a systems engineer meaning I have been working on many different areas. Specifically CAD modeling, I was able to transfer into work. Even though at my job we used a different software, just having the prior knowledge of what CAD modeling is has helped me a lot."*

Some students also commented on how they were confident in their ability to apply making skills in the future as a result of their course experience. For example, some mentioned that:

> *"Circuitry and coding is also going to follow me wherever I go in the engineering world, so being able to feel capable of doing both effectively was a huge boost to my own confidence and will translate very well into internships, club work, and a real career when the time comes."*

Other Themes

During the thematic analysis, several other themes that do not fit into the framework mentioned above also emerged. Though not all of these themes are relevant to this study, there are two that relate to the student's development of an entrepreneurial mindset and thus are worth mentioning.

The first additional theme identified is *Recognize the importance of a customer-centric approach to design* (appeared in 16 reflections). This theme is important to note because the inclusion of a stakeholder or customer is the key element that differentiates entrepreneurially minded learning from project-based learning [3] and customer awareness is an important attribute of an entrepreneurially minded engineer [14]. The excerpts below show examples of how students recognized the importance of focusing on the customer when designing solutions:

> *"Specifically, I learned to identify the three clients: the decision-maker, the payer, and the end-user. I then learned how to formulate a problem statement that addresses client needs. Most of my previous experience was focused on technical skills, so learning to design for a client was an important enhancement to my knowledge."*

> *"Another interesting thing I learned with working within criteria and requirements was doing it for someone else. There may be cases where I want to build a cool or exciting project because I think it's interesting, but would that project be valuable to someone else. Would that product sell if it's something that only I care about? I learned that it's not just about what I want to design and build, but what the stakeholder, customer, user, etc, wants. It gives me a new take on engineering."*

The second additional theme that emerged is *Persist through failure* (appeared in 25 reflections). This theme aligns with the KEEN framework for Entrepreneurial Mindset [1], more specifically, it fits under the third C of the framework, creating value [1]. For this theme, several students mentioned how they faced failure while working on the project but were positive about it and worked through the failure:

> *"During our mars in the making project, we faced failure as sometimes our prototype was not working as we desired and the many things were not going as expected. It taught us a real-life scenario that everything does not always go well. But still we did not give up and tried our best to fix the problems and keep up our spirits and give our best."*

> *"FSE100 also showed me how to better approach problems that can happen in the engineering process, as in the past I might get frustrated if something did not work the first time, and that it was the computer's fault that the code was wrong. And, as shocking as it may be, the computer is very often not wrong. These failures throughout the semester enlightened me to the fact that coding and engineering are full of failure, and it is important to remember that very rarely things*

will be perfect from the jump, or ever be perfect, so take everything in stride and keep working hard."

"Toward the end of the project, I learned the significance of having a determined and motivated mindset especially when my group fell behind. We spent a lot of time outside of class working and testing perseverance, but it paid off when we were able to present a great project that met all requirements and deadlines. Overall this class showed me that hard work, and consistency pay off."

Conclusion

In this work, the authors implemented a new open-ended design project, Mars in the Making, in a first year Introduction to Engineering course to motivate students to develop an entrepreneurial mindset and making skills. Students' motivation, curiosity, connections, and making skills (acquisition and confidence) were assessed via a survey based on existing validated instruments and qualitative analysis of an individual reflection assignment. Results from this study indicate that students were motivated to complete the project, expressed curiosity and made connections during the project, acquired new making skills and gained confidence in those making skills. Students overall indicated they enjoyed the project, but also provided great suggestions for improvement in the future. Future work may include implementing some of the suggested changes to improve the project, and conducting a pre- and post-assessment to help better assess the impact the project has on student motivation, entrepreneurial mindset, and making skills.

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Appendix

Table 1. Mars in the Making project schedule

Week	Class	Topic
4	1	Project Opportunity Identification and Problem Definition Work Time (*Students are introduced to the project and start to identify an opportunity to create value for relevant stakeholders and target customers.*)
	2	Project Opportunity Identification and Problem Definition Work Time (*Students continue with opportunity identification and also work on problem definition, i.e., write problem statement and POVs, define design requirements and criteria.*)
5	1	Hands-on Skills Session: Electrical Fundamental and Circuits (*Students acquire and practice the skills of building circuits.*)
	2	Hands-on Skills Session: Arduino, Sensors, and Actuators (*Students learn to work with Arduino and a few commonly used sensors and actuators*.)
6	1	Hands-on Skills Session: Engineering Models, Visual Models, Technical Drawing, 3D Modeling (*Students acquire and practice 3D modeling skills*.)
	2	Hands-on Skills Session: 3D Modeling (*Students continue to practice 3D modeling skills*.)
7	1	Project Ideation and Proposal Work Time (*Students start to brainstorm possible solutions to fulfill the opportunity identified*.)
	2	Hands-on Skills Session: Advanced Arduino Topics

		(*Students continue to practice skills working with Arduino and more sensors*.)
8	1	Project Ideation and Proposal Work Time (*Students continue to brainstorm possible solutions, formulate at least 3 complete, competitive, and well defined conceptual solutions, compare these solutions, and select their proposed solution, i.e., the 'best' solution according to the weighted design criteria*.)
	2	Project Proposal Work Time (*Students further design their proposed design solution, create a 3D CAD model to help visualize the form of the solution and an activity diagram to help describe the logic of the automated features, and prepare for the project proposal presentation*.)
9	1	Project Proposal Presentations (*Students deliver their oral presentations for the project proposal to describe the proposed design solution, make justifications for the decisions made, and describe the timeline for the prototype building and testing work days. They receive feedback on their proposed design from the teaching staff and peers.*)
	2	Hands-on Skills Session Laser Cutting, 3D Printing, and Tools (*Students prepare a file for laser cutting and another one for 3D printing, learn about the process for laser cutting and 3d printing, and practice doing laser cutting and 3D printing. Students also learn about various hand and powered tools such as drills, hand saws, table saws, jigsaws, etc*.)
11-14	1 & 2	Project Prototype Building and Testing Work Time (*Student teams work on the creation, testing, and refinement of a functional physical prototype of their design*.)
15		Project Showcase (Presentation + Project Demonstration) (*Student teams present their final design solutions and demonstrate the functionality of their design prototypes.*)

Table 5. Suggestions offered by survey participants to improve the project

Theme	Number of responses	Example comment(s)
Everything was good/great/amazing/interesting/ fun	36	*"There is really nothing to improve on it. This project was amazing and if I ever got the chance to do it again, I definitely would."* *"...I thought it was a perfect project compared to other students that had different projects. It went over everything that we reviewed in the length of the course and tested our knowledge of it. It allowed us to feel what it is like to be in an engineering environment, as it effectively compared to my experience in the manufacturing industry. I thoroughly enjoyed the project and would encourage that it stays the way it is for the most part. ..."* *"I really loved this project! I think it challenged students to think about the future, and what type of technology could be incorporated into that future. I really liked how this project was open ended and we did not have to conform to any set guidelines like building an RC car - instead we thought outside the box to build a weather prediction system. I originally went to an entirely project based middle/high-school, and I believe that this is a better teaching format since it allows the students to make discoveries for themselves. ..."*
More guidance/resources/lessons (related to the process, arduino, sensors, tools, prototype building, etc.)	24	*"Give more lessons about how to use and code for the sensors available to be used in the project."* *"...it is easy for one or two members to dominate building, so having skill sessions in between the project in the same way we had skill sessions for coding and requiring everyone in the group to specifically use the hand/power tools in building something small can help everyone gain equal experience."*
More time to work on the project prototype	11	*"I found that by the end of the project, my team was rushing to complete our prototype. While this is somewhat normal for most projects, I did find out that some other classes had a week or two longer to be working on their projects. While the amount of time given to work on a project does not severely impact what the students learn from it, it still would have been nice to have a bit more time."*
Better intro at beginning of project	3	*"When we first started the project we had no ideas what to do as the topic is way too broad. Maybe giving some samples of the project from previous class can help us narrow down what to focus on."*
Increase budget	2	*"Possibly to slightly increase the budget of the project so that it can be showcased properly and it functions well"*
Encourage creativity more	2	*"I think it would be cool to reward or encourage creativity more. It seems throughout almost every single class that 80*

		percent of the teams were making mars rovers. Yes it's a cool project but I feel this class could really showcase students diversity. Our group took a huge risk and did something out of the box which paid off and we had so much fun. Maybe forcing groups to choose different topics or even lessening the consequences for failure in terms of grading to allow for freedom of creativity."
More limitations	2	*"I think that there should be more restrictions on the final product to increase the difficulty of the project."*
Less limitations	2	*"Perhaps allow a larger amount of creations - having restrictors in this project made it difficult for my group to do what we wanted."*