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Understanding Student Experiences in a First-Year Engineering Online Project-Based Learning (OPjBL) Course

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For several years after earning my engineering degree in 2001, my professional duties included working full-time as a process engineer at a chemical company and teaching engineering courses as an adjunct instructor. In 2009 I left a seven-year long career in industry—interrupted only by my time abroad earning a master's in engineering—to become a full-time faculty member, mostly in pursuit of one goal: professional and personal fulfillment. To be sure, the most gratifying experience I have had in my career is participating in the intellectual development of students and earning their gratitude. Propelled by this motivation, I chose an academic life focused on quality engineering teaching, which ultimately led me to pursue a Ph.D degree in Engineering Education. Teaching engineering and scholarly exploring ways to excel at the job are my professional passions.

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Introduction and Background

Project-based learning (PjBL) is a widely adopted active learning pedagogical approach, which promotes student critical thinking and problem-solving skills [1]. In a higher education context, this gives students an opportunity to learn while engaging actively in a collaborative environment under the context of a challenging, open-ended problem [2]. PjBL is effective in helping engineering students, especially in the first year, develop both technical and professional competencies as they progress through their undergraduate studies.

Due to the current pandemic, many classes in higher education institutions shifted online in the 2020-2021 academic year, where teaching and learning were undertaken remotely and on digital platforms [3]. Similarly, the Foundations of Engineering II course, which promotes PjBL for first-year engineering students at a Mid-Atlantic R1 institution, was recently adapted into an online format. This was the first time that the course had been offered in an online format at the institution. The transition from in-person to online PjBL required some significant changes for the course, though many aspects of the existing infrastructure and program coordination remained the same [4]

Prior studies have explored the adoption of an online project-based learning (OPjBL) approach in various educational contexts [5]–[7]. However, there are few studies which report the use of online PjBL in engineering, or more specifically in first-year engineering courses. Hence, this study focuses on the implementation of an OPjBL first-year engineering course and its success in achieving an effective learning environment. The purpose of this study is to better understand the PjBL experience of students working in a first-year engineering foundation course in an online format. One of the major learning outcomes of this course is that students should demonstrate proficiency in implementing the engineering design process. For that reason, we focused on exploring students' perceptions of engineering design through the online experience. Accordingly, the following research question guided this study: *What are students' perceptions of engineering and design after taking an online PjBL First-Year Engineering class?*

Literature Review

Prior studies have observed active learning strategies like Project-based Learning (PjBL) in first-year engineering classes and highlighted mostly positive experiences from the students' perspective. Abdulaal et al. [8] introduced the PjBL approach in a first-year engineering introductory course for two semesters. The course introduced engineering design practices to students and provided opportunities to collaborate in teams, practice communication skills, and create global awareness of current domestic and global challenges in engineering. The course had several positive outcomes, including an increase in students' exposure to real world engineering design attributes and higher levels of learning compared to other learning classrooms. Other authors discuss similar implementations of PjBL with positive outcomes including strong interpersonal relationships among students for working in teams, acquiring new technical and professional skills in engineering through instructor support, and increased motivation and engagement for engineering design [9]–[11].

In addition to PjBL implementation in the aforementioned studies, several studies have discussed the implementation of online PjBL strategies in various educational contexts [5]–[7]. Some studies have focused on supportive online learning tools and community building strategies to enhance student learning in an online environment. For example, Wang et al. [3] encouraged the use of social media tools that helped students acquire required knowledge and new information to promote collaborative learning and communication in the PjBL setting. The strategies used provided richer cognitive experiences and fostered the development of interpersonal skills among students. There were, however, some challenges mentioned while conducting online PjBL classes. Andersson [12] reported that students faced time constraints while trying to adapt to the new learning environment because of limited prior experience with PjBL. In addition, there are more studies which compared the effectiveness of Online PjBL with face-to-face PjBL in terms of learning effectiveness but found inconsistency in different PjBL contexts [13].

Collectively, these studies suggest that the transition to online PjBL was mostly positive, as students reported experiences similar to those gathered from in-class learning environments in several educational contexts. However, there is little to no existing literature on online PjBL in first-year engineering class. Hence, this study is aimed at exploring students' interest in and perceptions of learning about engineering design after the online experience in a first-year engineering PjBL course. Results of this exploration could help determine whether there were shortcomings related to the format of our course as it was adapted for online learning.

Theoretical Framework

Project based learning (PjBL) is a type of situated learning based on the constructivist finding that students gain a deeper understanding when they are actively exposed to real and meaningful problems. According to Krajcik et al. [14], project based learning is an overall approach to the design of learning environments. These learning environments have five key features: *starting with an overarching question, exploring the question by participating in authentic, situated inquiry, collaborative activities with teachers, students and community to find solutions, challenging beyond students' ability by participating in active learning and creating a set of tangible products that address the overarching question*. Ultimately, these features applied in the classroom allow students to learn by engaging in real-world activities and applying new ideas [15].

The PjBL course discussed in this paper was structured using an approach that encompasses the five key features mentioned above. First, students are presented with an authentic problem in the form of the following overarching statement: *Given certain needs, constraints, and a realistic context, ideate and design something to address those needs* (for the purpose of this manuscript, the language is intentionally kept very general because instructors have a pool of different problems to choose from, ranging from drones to solar ovens, to campus-related problems). Students team up and are required to transform this general problem statement into a more scoped version, where they identify and define the specific stakeholders and needs of their project and start establishing criteria for success. Students are then encouraged to generate and prototype design concepts, first individually and then in their teams, with increasing levels of complexity and fidelity. Design concepts are iterated through discussions with the instructors and facilitators from a maker space lab dedicated for the course. In addition to providing feedback, instructors help students acquire the specific skills and knowledge relevant to their project, like the use of CAD and decision-making tools, and the calculation of the power extracted from sunlight or wind. At the end of the semester, student teams must present and defend one solution to the problem stated and scoped, explicitly addressing the engineering design process that allowed them to arrive at such a solution.

Foundations of Engineering Class

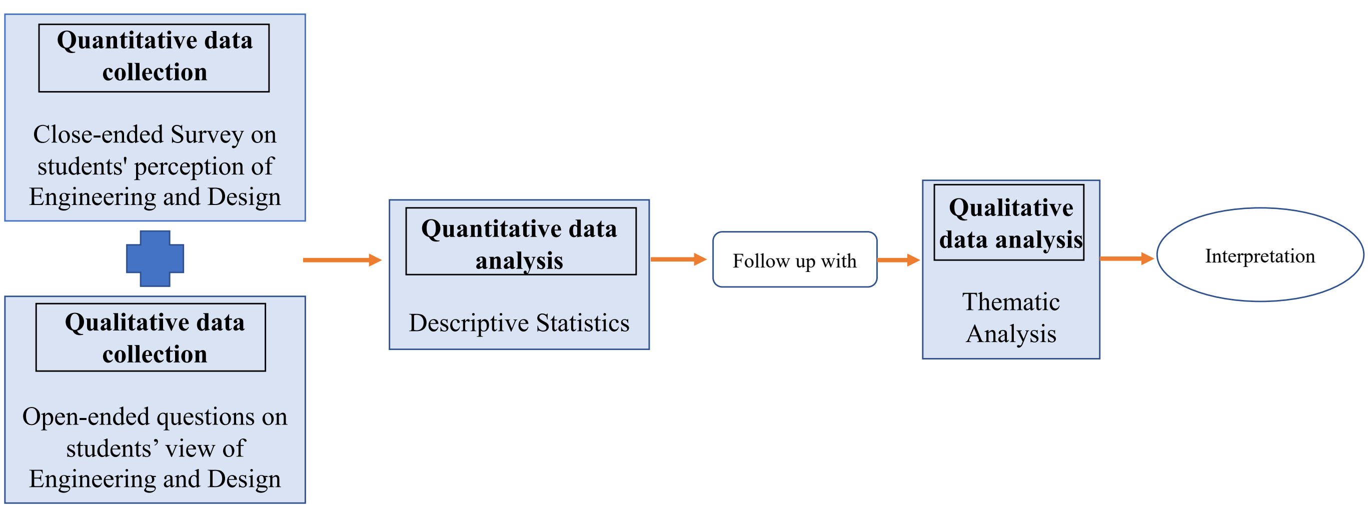
Foundations of Engineering II is the second course in a two-course sequence required of all entering general engineering students before transferring to an engineering major. This class is centered around a semester-long team project and is divided into two design iterations, each featuring a single design/build/test phase, carried out in teams of 5-6 students per team. In this class, our approach to PjBL was student-centered and driven by a team-teaching approach. Our collective goal was to facilitate students' achievement of the course learning outcomes, namely: *applying an engineering design process, working effectively in a team, working with, and interpreting data, applying critical thinking skills to articulate how ethical principles apply to engineering, and practicing effective communication.*

Due to the COVID-19 pandemic, in Fall 2020 the entirety of the preceding course in the sequence was offered online for the first time, and several changes to teaching and learning strategies were introduced. In Spring 2021, the Foundations of Engineering II followed suit drawing from some of the lessons learned previously, with the additional challenge of being a PjBL course. During this semester, students were required to attend class, check-in with the instructor, and work with their teams via online platforms (e.g., Zoom), although most of them were living on-campus. Other strategies used for OPjBL, and lessons learned from implementing them are discussed elsewhere [4].

Methodology

To answer our research question, this study used a mixed methods design approach, with a caveat. According to Creswell [16], a mixed methods design sequentially combines and integrates both quantitative and qualitative data in a single study. During the first step, we used a quantitative approach to collect the data and analyze students' interest in engineering and perception of engineering and design after taking the class. In the next step, we collected qualitative responses using open-ended questions to understand their view of engineering and design to further probe the quantitative findings. For instance, we wanted to see whether students' positive perceptions of their learning were supported by an observable understanding of design concepts seen in class. The caveat mentioned deals with the fact that our quantitative and qualitative data were gathered in the same phase of the study, instead of allowing the results of the quantitative analysis to inform the data collection for the qualitative phase. Figure 1 shows the overall design of the study.

Figure 1
Sequential Explanatory Mixed Methods



Data Collection

Data for this study was collected from a large R1 university in the Mid-Atlantic region. The participants were primarily first-year engineering students in their second semester who were part of the general first-year engineering program at the university. Our study sample involves students who enrolled in the ENGE 1216 class during Spring 2021. Data was collected from 11 course sections with a maximum of 72 students each, taught by three instructors. While these sections do not comprise the entirety of students in the first-year program, they are a representative sample that responded to the survey used for the purpose of this study. There was a total of 686 students enrolled in the 11 sections.

The survey was administered at the end of the semester as a part of the final check-in assignment and asked students to complete a questionnaire. This is a common practice implemented among the authors for the purpose of checking in with the students at the end of the semester and collecting insights conducive to course improvement. Regular check-ins were part of most classes, so the students were used to this format of gathering information. The final check-in was important to understand students' experience of the class given that it was online, and how the course impacted their interest in and perceived learning of engineering and design. For this study, the close-ended (quantitative) part of the survey included two items that asked students to rate their level of agreement with two specific prompts:

- Item 1: My ENGE 1216 design project increased my interest in engineering
- Item 2: My ENGE 1216 design project helped me better understand how to engage in doing design

Students were asked to rate their level of agreement with these two statements using a Likert scale from a score of 1 ("Strongly Disagree") to 5 ("Strongly Agree"). In addition, with the purpose of gathering qualitative insights, students were asked to respond to a set of open-ended prompts. Responses to the following prompt were examined in this study:

- Elaborate on how your project affected your view of engineering and the design process

There was a total of 682 student responses, which represents around 93% of the total number of students enrolled in the participating sections. The study protocol was submitted to the IRB, and it was determined as *not human subject research* considering recent changes to federal regulations on the matter. Each instructor was responsible for introducing the survey questionnaire to the class and collecting the responses online. Students received credit on the final check-in assignment based on completion, but they were at liberty to respond "N/A". After data collection, the data was de-identified and unlinked from the demographic information.

Data Analysis

To answer the research question, the quantitative data was first analyzed using descriptive statistics. We used Likert-type survey items to gauge whether students' perception of their interest in engineering and ability to engage in design after taking the course were positive. Specifically, we used descriptive statistics to look at the two closed-ended items included in the survey with higher scores indicating a more positive perception.

To further understand the rationale behind the quantitative results, we analyzed the survey responses qualitatively. Specifically, we used thematic analysis methods on students' responses to the open-ended item about how the project affected their view of engineering and the design process. Thematic analysis is defined as a method of *'identifying, analyzing, and reporting patterns within qualitative data'* [17]. In addition, Robson & McCartan (2016) define thematic analysis as a generic qualitative method that allows patterns to emerge from data after implementing open coding of the qualitative data. We used Saldaña's [18] procedures to conduct a coding process to discern themes relevant to our research question. Initially, one of the authors carried out open coding and several themes emerged. A codebook was established and negotiated with a second author who looked at randomly selected entries in the data set. The two authors discussed categories that could encompass all the themes found, and the data were examined again considering these categories. The resulting revised codebook is shown in Table 1.

Table 1
Codebook and description from the Thematic Analysis

Code	**Description**
Data-driven Design	Collecting and testing, coding, or modeling data to make meaningful information during the design process that can be directly applied to the project for design improvement or demonstration of technical performance.
Prototyping with a Purpose	Understands development of a prototype using an approach that builds from information gathered in multiple iterations.
Considering Stakeholders	Project stakeholders are clearly identified and taken in consideration to support engineering decisions in real world situations.
Communication	Relevant information is presented concisely through reports, assignments, presentations etc. in an organized manner
Iterating with Peer Feedback	Project iterations create opportunity to provide constructive feedback that team members can use to improve their team contributions, attitudes, and behaviors

Managing Projects	Ability to create and apply project management documents and tools and learn to implement projects step by step.
Working in Teams	Ability to work effectively as a team member and contribute to the team goals which includes the ability to productively coordinate among team members, solve conflicts and communicate effectively.

Research Quality and Limitation

We took several measures striving for validity and trustworthiness. First, several authors participated in the creation of the data collection instrument and in the analysis to ensure the validity of our mixed methods design [19]. For the quantitative part, we ensured external validity by collecting data from a large sample size (n=682). In addition, construct validity was ensured by following proper documentation, reporting, and cross-checking by the research team. We ensured inferential consistency by connecting the theory of project-based learning in the study with our final results and considering this connection when illustrating our findings and providing recommendations [20].

However, our study had several limitations. Data was used from only one institution in the United States which might not be representative of the student population. In addition, our study was conducted for just one particular year during the pandemic and online learning might be different as we move forward with this course. Regarding our methods, we did not ask students explicitly to address the online format of the class. While this was an intentional decision to look at the class outcomes in general, it might have prevented us from eliciting insights directly related to the online learning experience. In terms of the study design, we collected quantitative and qualitative data at the same time, which prevented us from using the results of the first phase to inform data collection instruments for the second one.

Results

Quantitative Results

As mentioned before, we used Likert-type items to gauge students' perceptions of engineering and design after taking the course. Descriptive statistics representing the median scores and interquartile range for the two specific items are shown in Table 2. In general, both items reflect positive perceptions, with the majority of students agreeing or strongly agreeing with the prompts. The interquartile range for item 2 *"My ENGE 1216 design project helped me better understand how to engage in doing design"* is shifted a level higher than the one for item 1 *"My ENGE 1216 design project increased my interest in engineering"*. While there is no difference between the two medians, the displacement of the interquartile range (Figure 2) prompted us to probe this difference.

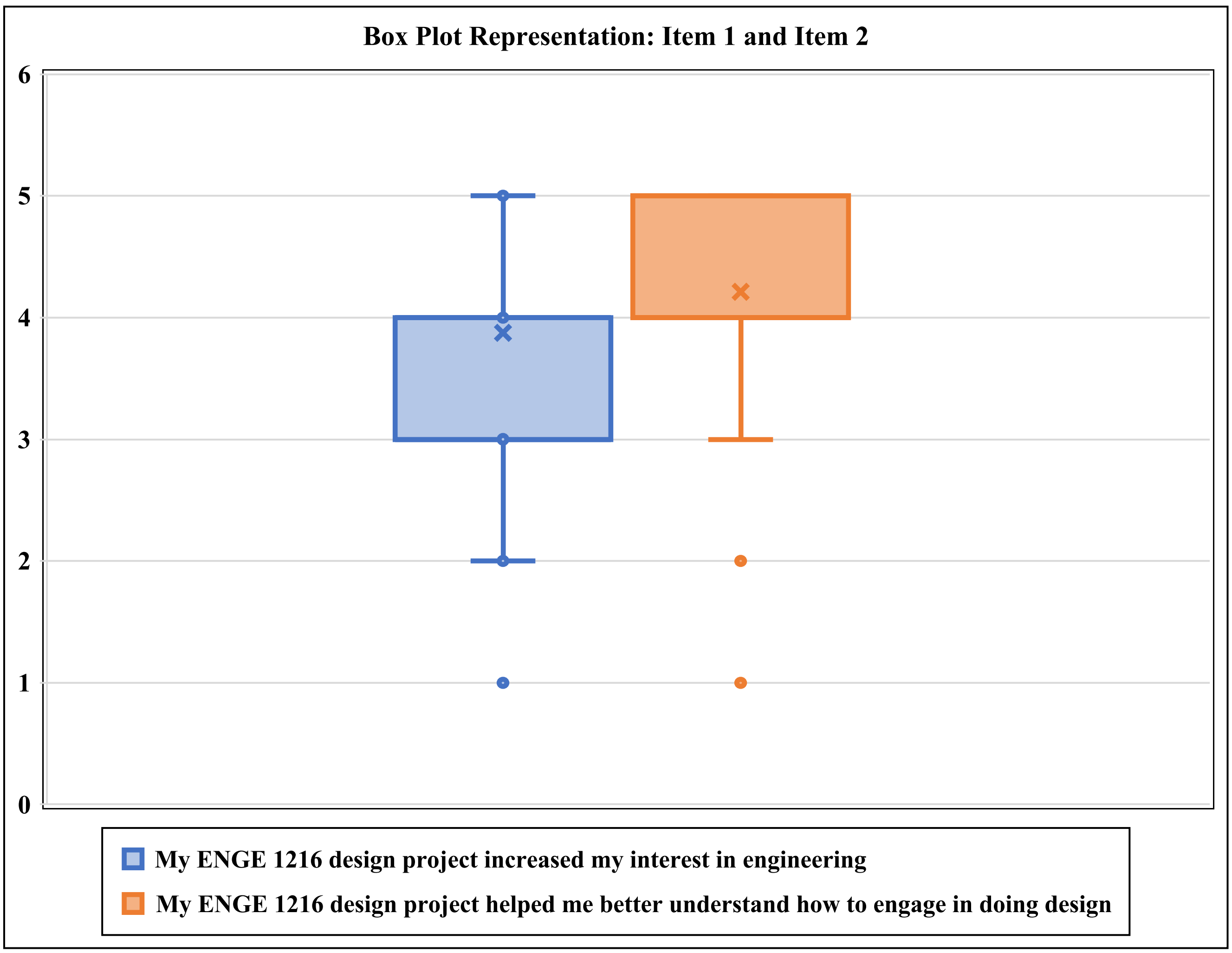
Table 2

Descriptive statistics from the survey response

Item	Median	Q1	Q3
1. My ENGE 1216 design project increased my interest in engineering.	4	3	4
2. My ENGE 1216 design project helped me better understand how to engage in doing design.	4	4	5

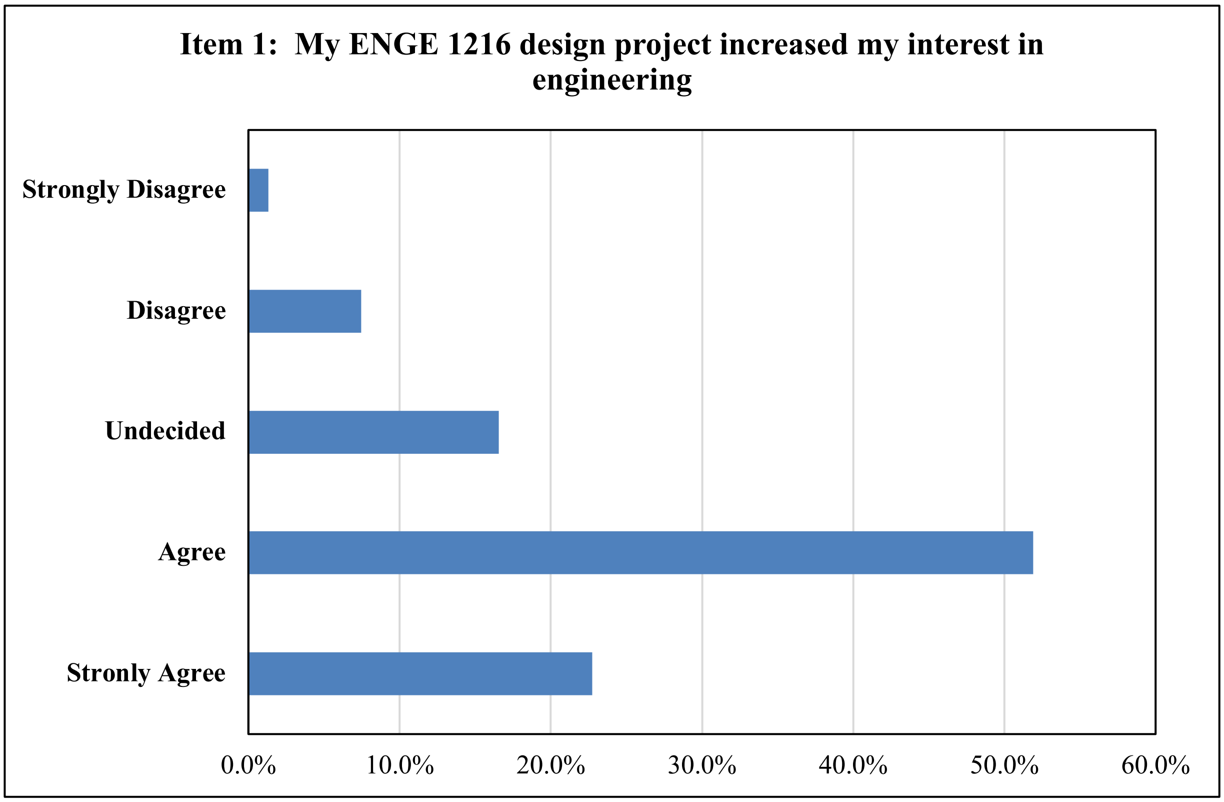
Figure 2

Boxplot Representation from the survey response



To further understand and probe the difference in the scores, we analyzed the distribution of all responses to both items. For item 1, 92% of students responded with either ‘agree’ or ‘strongly agree’ when asked whether their design project helped them better understand how to engage in doing design. There were a few students who reported to be undecided (4.5%) in relation to this question. Figure 3 shows the distribution of student responses from the survey question.

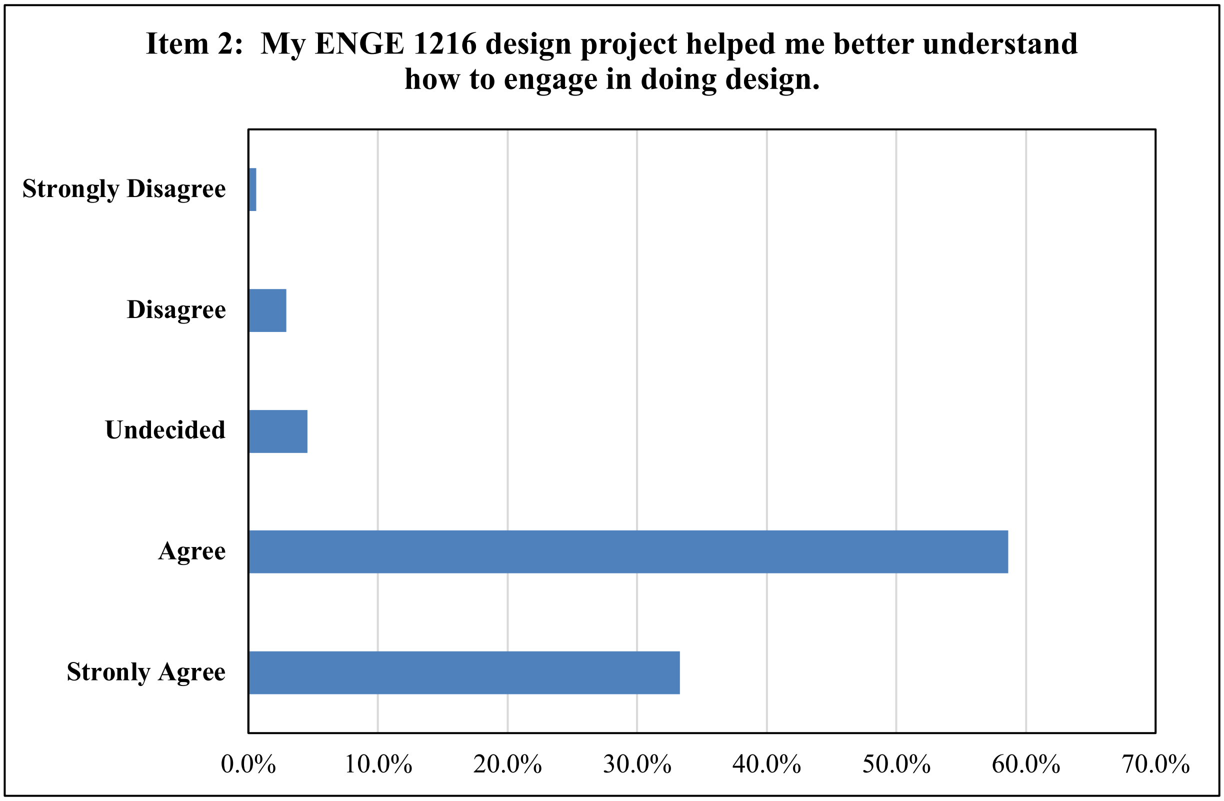
Figure 3
Student Survey Response: Item 1



For item 2, when asked about whether their course project helped them better understand how to engage in doing design, 74.6% students responded with either agree or strongly agree (figure 4). However, 16.6% of students were undecided on this question. Also, 8.8% of students who either disagreed or strongly disagreed with the survey question. After comparing both the survey questions, it was found that majority of students were positive about their experiences in projects that helped them engage in engineering design (item 2). However, there is a decline in agreement of students when asking students whether their design projects had positive perceptions on their interest in engineering overall (item 1).

Figure 4

Student Survey Response: Item 2



Qualitative Results

To follow up on the quantitative results, we further analyzed students' responses to the open-ended question in the survey, as described in the Data Analysis section. Our results yielded several key patterns across the participants' responses with mostly positive experiences and a few challenges in terms of their overall perception of engineering and the design process. As mentioned in the Data Analysis section, we carried out a thematic analysis and established a codebook by creating categories for the emerging themes. In the following subsections, we will present a more detailed look at the qualitative responses which were mapped into the different themes from our results.

Data-driven design

When students were asked to elaborate on their perceptions of their view of engineering and the design process, they highlighted how the use of data collection and analysis through testing, coding, or modeling has helped them through the engineering design process and has proven to be a significant factor that fosters their interest in engineering. These responses are exemplified by the two quotes below:

> This project has significantly excelled my interest in engineering and my overall view of the design process because it allowed me to see that there are many different and interesting parts of the process. I like to code the best but this project forced me to go outside of my comfort zone and try to model with [CAD Software] or even make my own physical model. -2057

> This project positively affected my view of engineering because we started from a concept then turned it into a physical model and designed other prototypes. We wrote code given our data values to see what our [prototype name] could accomplish and the distance it could travel. The design process was interesting to me that as a team we made a concept into a drone then ran simulations with it. -2191

Note that as students elaborated on how the class project affected their views of engineering, they are also providing accurate descriptions of different steps and tools pertaining to engineering design.

Prototyping with a purpose

Students learned to develop prototypes through multiple iterations and understand the purpose of the prototyping process and its significance in real world engineering. Some students highlighted the complexity involved with prototyping during their project experience and provided examples of implementing multiple iterations before making final decisions on their project. This theme is further exemplified by the two quotes below:

> After going through the prototyping and testing process, and creating the decision matrix, I now more clearly understand the process that engineers go through when refining an idea and preparing it for a commercial market. Even though I had some idea before, now I understand the detailed process of how to create prototypes and make design decisions during the engineering process. -2013

> The project provided me some insight as to how much more complicated a design process can be. Not only were we each tasked with creating prototypes, but we also had to judge each one on specific criteria. Ultimately, we chose one, improved its flaws, and then had to test it. It was an interesting process. It's fascinating to think about how involved this process could be on a larger scale, such as for a massive [project] to generate electricity. -1143

Beyond being a "cool" hands-on activity, students seem to have built an understanding of the purpose of prototyping and the role of prototypes in the entire design process.

Considering Stakeholders

Students often mentioned considering stakeholders during their design process. Specifically, students highlighted the importance of stakeholder involvement in the engineering design process that had direct impacts on their project. Students identified real stakeholders of their project, which helped them get exposure to real-world situations. The three quotes below exemplify students' views on stakeholders in their engineering design process:

> The [name] project affected my view of engineering and the design process by taking me through the steps of the process. This project was my first experience designing something on my own and going through different things like looking at the stakeholders, limitations, scope, etc. for a large project individually and with a team. -1182

> "It made me see how small details in the design process can affect numerous stakeholders." -3025

> It was interesting to see the alternate side of engineering. Everyone knows about the fun stuff of engineering, but the reality of the situation is that is not always the case. Being exposed to the stakeholders and other such real-world situations was interesting and helped me grasp an understanding that I might not have had otherwise. -1040

Communication

Students have discussed how important 'communication' can be to the design process. Communication happens both internally (within the team) and externally (from the team to an external audience). While this code focuses on external communication, it was sometimes impossible to split one from the other, as represented in the following excerpt:

> I think that it showed me just how important team communication can be, completely changing our design and ability just from how cohesive we were. I think I can better see how to evaluate our project and better showcase it in presentation as well. -1153

In the previous excerpt, the student discussed the importance of communicating effectively within the team, but then being also able to convey the information to an external audience through presentations. The following quote focuses solely on external communication:

> "The project gave me new insight as to how the engineering process works. Writing reports is still relatively new to me, and this class definitely helped improve that aspect." -1117

There were some challenges related to communication that students faced during their projects. Some students have discussed writing reports as being overwhelming on top of implementing the engineering project within a limited time. The quote below exemplifies the challenge:

> I think the gripe I've had is that we spend a lot of time writing rather than doing the engineering. I recognize this is necessary in engineering, but I feel like I just wrote the same thing repeatedly. It would have been easier, and I think more fun to get rid of or condense a report such as the project scoping report and the project selection report or maybe a design summary & design proposal. I think the writing really turns people off from this class and it's the major complaint among students. -3037

Iterating with Peer Feedback

Students emphasized the importance of peer feedback during their engineering and design experience in the class. Students mentioned the need for constructive feedback among team members which helped improve their team contributions, attitudes and behaviors during the project process. The two quotes below highlight the theme,

> I think this project affected my view of engineering and the design process by showing me there are a lot of steps that I need to take while trying to design anything such as a [project]. I also realized that the feedback that we give to ourselves can be very helpful if we use it. -1220

> Originally, I thought the design process was linear but the [project] proved otherwise. Many different prototypes were up for consideration and even after choosing one we had to repeat the process many times to improve on what we had. It also showed me that sub teams are not independent but they rely heavily on each other whether their material is needed for other teams to progress or if feedback is needed to improve on what they had.-1134

These excerpts also suggest that the opportunities students found to give and receive feedback were connected to the multiple iterations of the tasks involving the project.

Managing Projects

Managing project documents and tools using proper guidelines and steps is an important aspect of engineering design as mentioned by a few students in their responses. The quote below exemplifies the importance of project management in engineering design,

> This project helped me to better understand the importance of collaboration within engineering. It is very important to consult with others when making decisions in order to explore different perspectives. With the design process, I learned to take things step by step and to tackle obstacles one step at a time for better handling and management. It is important not to rush the project because this could yield to more errors. -1243

Working in Teams

This theme was one of the most highlighted and common themes from the survey data. Students emphasized the importance of effective teamwork and how it had a direct impact on their project outcomes. Some of the teamwork characteristics mentioned were to productively coordinate among team members, solving issues when conflict arises during the project process, and communicating effectively among team members. The following quotes highlight the importance of working in teams that helped students during their design process,

> I feel like I have gained more insight into what designing and executing a product in a group setting entails. When designing something by oneself, you do not need to communicate to yourself so you gain efficiency, but you lose out on the insights and perspectives others can provide. This experience has directly demonstrated this simple but powerful principle of teamwork. It felt very gratifying to see the ideas we collectively conceived take shape over the course of the project, in ways that could not be accomplished in the same manner, had we been working alone. -2171

> I thought the project would be simple to do as one person, but the planning and teamwork involved in making a physical prototype and documenting the process required lots of coordination and teamwork. We had to check each other's work and communicate outside of class a lot. -3005

> When it came to developing ideas, I had a say on what prototype would be beneficial and the best fit in our grading system. Having the opportunity to share my work while also giving suggestions to my team members. Each sub-team would give and receive feedback. I found it great that I was able to share ideas with the [team name] on developing an additional feature for our [project]. Being active and having conversations through messages or zoom meetings. Even if the group did not have many social interactions, we all shared our interests and the goals that allowed us to move forward whenever conflict appeared. -1057

As mentioned before, students discussed communication from a two-fold perspective: within the team and from the team to an audience. The previous excerpts provide insights on the former: the importance of effective internal communication for a team to perform effectively.

Discussion and Conclusion

To answer our research question, the results from the study suggest that students' perceptions of engineering and design after taking an Online Project-based Learning class were positive and seemingly unaffected by the online format of the class. In their responses to the quantitative survey and open-ended questions, students did not spontaneously discuss online format as a challenge towards their learning experience. However, this argument has a caveat: most students in this course only had online college experience by the time of this study; while this does not affect their perception of learning, it might prevent them from establishing comparisons with previous in-person PjBL experiences. This might offer an alternative explanation to why students did not address challenges related to the online format of the course.

The results from the thematic analysis suggest that students have positive perceptions of their learning about engineering design which is supported by a clear understanding of the design process, from the iterative nature of design to the use of prototypes and other tools, and to the importance of collaborative work in tackling complex challenges. Some of the key patterns from the thematic analysis also map to the student learning outcomes in the class. For example, one of the course learning outcomes is to "*Contribute effectively to an engineering team*" which includes ability to maintain productive communication with team members, creating and applying project management skills and being able to provide constructive feedback. This learning outcome maps to the definition of the following themes: *Managing projects, working in teams and Iterating with Peer Feedback.* Another learning outcome of the course is to "Demonstrate proficiency with implementing an engineering design process" which includes collect, analyze, represent, and interpret data and to use systematic methods to develop solutions for problems maps to the definition of the following themes: *Data-driven Design* and *Prototyping with a Purpose*. Students' reflection on themes directly related to the student learning outcomes supports the argument that this course was a success in promoting a learning environment even after transitioning to the online format, although not without some challenges.

In contrast to students' positive perceptions of their learning about engineering design, the results show perceptions of interest and motivation towards engineering were moderate. A few students discussed the challenges of attending class or meeting and working with teammates online, but the frequency of these comments does not lead us to conclude that the online format for this course had the major impact on student motivation. That said, we believe instead that motivation can be highly impacted by the characteristics of the project students worked with. Other questions in the survey asked students about their perceived level of autonomy in making project-related decisions. Since the instructors used a range of projects with varying levels of structure and autonomy, future research will explore whether these differences resulted in significant differences in student motivation. Also, in future we will explore the motivational aspect informed by the Self-determination theory.

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