Will the First-Year Makers Please Stand Up? Understanding What Drives Student Choices in a First-Year Maker Experience

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Academic Practice: Will the First-Year Makers Please Stand Up? Understanding What Drives Student Choices in a First-Year Maker Experience

Abstract

The proliferation of Makerspaces across institutions of higher education is due in large part to their ability to engage students in hands-on activities, fostering higher levels of engineering self-efficacy and confidence in engineering abilities amongst students. It is especially important for first-year students to participate in these spaces to amplify their self-confidence, creativity, and problem-solving skills early in their college experience to increase a sense of belonging. One critical issue many university Makerspaces face, however, is the necessity to scale hands-on, often time-intensive, experiences across a large population of undergraduate engineering students.

At The Pennsylvania State University, the Learning Factory has designed and developed multiple "maker modules" for our first-year engineering design course, which serves ~650 students per semester. This first-year maker experience allows students to choose from five projects: Aluminum Pen, Embroidery, LED Acrylic Display, Wireless Charger Housing, and Ultrasonic Range Finder. Each of these projects has been developed to engage students in different parts of the Learning Factory Makerspace through using tools in the woodshop and textiles shop or via 3D printing and laser cutting. As a first step to understanding how students interact with the makerspaces through this course project, this paper focuses on understanding what projects the students prefer and why.

In this paper, we report on the ranked order data from student project preference as well as responses collected through an open-ended survey question to understand more about how students choose their projects. Our results show that students often favored the LED Acrylic Display, Wireless Charger Housing, and Aluminum Pen project because they were motivated to have "something cool" at the end of the class project. For the Embroidery and Ultrasonic Range Finder projects, students were more motivated by the process of making and learning through the project. While this work shows us that motivations do differ based on projects and that more students preferred certain projects, we do not yet know how demographics and self-efficacy play a role in these motivations, and therefore, more work is required to unpack these motivations.

Introduction

Fostering a sense of belonging in undergraduate students is critical to ensuring students can thrive academically [1], [2]; academic environments can significantly affect students' sense of belonging more broadly [3], [4]. In the past decade, makerspaces have emerged as a critical space for informal learning on college campuses, fostering creativity and curiosity in undergraduate students through hands-on projects and activities. The Learning Factory at The Pennsylvania State University has been an active makerspace for students and the community since 1995. While the space started as a 3,500 sf building ([5], [6]), it has recently grown to over 40,000 sf integrated into the new 105,000 sf Engineering Design and Innovation Building, where most cornerstone and capstone courses are taught. These courses have always incorporated making into the curriculum, but the supporting makerspaces had previously been spread across

the campus. Over the last five years and through the transition to the new building, the Learning Factory has directed efforts to encourage more students to use the space with a focus on DEIB [3]. One such effort has been the Cornerstone Maker Experience activity [7].

The Cornerstone Maker Experience activity is a hands-on engineering design activity developed to improve students' design, project management, and making skills. The Cornerstone Maker Experience activity is currently part of the Cornerstone Engineering Design course (EDSGN 100), which comprises primarily first-year students with an intended major in the College of Engineering at Penn State. This course has ~20 sections (36 students each) in the fall and spring semesters in addition to several summer sections, engaging more than 1500 students per year. In the Cornerstone Maker Experience activity, students are provided with several pre-defined project options and encouraged to select the option that aligns with their personal interests and goals. While the projects are pre-defined, each incorporates one or more designed elements, allowing students to be creative and personalize the final design to their unique preferences. Following project selection, EDSGN 100 instructors provide students with the necessary materials to complete the designs. Depending on the selected design, students complete additional training, such as that required for the woodshop or embroidery machine. Each project is intended to provide students with distinct manufacturing and design experiences by exploring different tools, materials, and processes. One underlying objective of this project is to enhance the Engineering Design Self-Efficacy (EDSE) of first-year students, as prior work suggests that hands-on manufacturing tasks and engagement with makerspace equipment can positively affect EDSE [8]. This work specifically examines students' preferences in selecting the Cornerstone Maker Experience options by exploring different factors that influence the student's perception of the projects, therefore helping us understand the motivation for student project choice.

While this project was created with a focus on the manufacturing and design experience it offers to first-year students, students' perceptions surrounding the benefits of this experience still need to be analyzed. Therefore, this research aims to understand the student experience more deeply.

Literature review

The following sections discuss literature relevant to makerspaces in undergraduate education and the history of the Learning Factory at Penn State.

The Role of Makerspaces in Undergraduate Engineering Education

Makerspaces provide students with rich out-of-classroom experiences that deepen technical knowledge [9], [10] and aid in the formation of peer-to-peer relationships [11] through a shared identity as a "maker". This shared identity can lead to the formation of peer-to-peer relationships that can last long after students have left the makerspace. In fact, the "Maker Movement" is credited with the democratization of design [12], [13], [14] and has contributed to greater access to technology and equipment [12], [13]. As a result, makerspaces have become an essential part of the educational landscape, providing students with a unique and valuable learning experience that they might not find elsewhere.

Engineering education has incorporated the concept of making into the curriculum and increased its focus on teaching design skills through multi-disciplinary project-based learning and student engagement within the classroom [15], [16]. Makerspaces support engineering design classes, various outreach and entrepreneurial programs, student organizations, and events that unite, educate, and promote the community via making. These spaces offer students access to a range of tools and equipment, including 3D printers, laser cutters, and other advanced technology, that they might not otherwise have access to [17]. Students can use these tools to explore their creativity and experiment with new ideas, which can help them develop a deeper understanding of technical concepts.

Makerspaces are not only places for technical innovation, but they are also communities that promote diversity, inclusion, and collaboration [18]. The importance of community and diversity in makerspaces lies in the fact that they provide a platform for people of different backgrounds, cultures, and experiences to come together and work on projects that benefit society[17], [19]. Makerspaces promote social cohesion, mutual respect, and shared learning, which are critical elements in creating a positive and supportive environment for innovation. In addition, by bringing together people with different perspectives and skill sets, makerspaces encourage the development of more innovative and creative solutions to complex problems [20]. Ultimately, promoting community and diversity in makerspaces is essential to creating a more inclusive and equitable society where everyone has the opportunity to contribute to the advancement of technology and science [21].

Moreover, it is essential to note that the lack of diversity in maker communities can lead to limited perspectives and a narrow range of ideas [17], [22]. This can be due to various factors, including cultural norms, lack of representation, and unconscious biases. A sense of belonging is crucial for creating an inclusive and supportive environment in makerspaces. When people feel they belong, they are more likely to engage in collaborative projects, learn from others, and share their knowledge and skills. By promoting inclusivity and diversity, makerspaces can become more effective at fostering innovation and creativity [23].

While a sense of belonging is a major selling point of makerspaces, they have another inherent purpose – helping makers make. Makerspaces are a space for students to design, fabricate, and build skills [15]. Students' confidence in their ability to complete engineering design tasks successfully, or their self-efficacy, is a crucial factor in determining the success of first-year engineering students in their engineering design courses [24]. Self-efficacy in engineering design can be developed through various means, including hands-on experience, project-based learning, and mentorship.

Research has shown that students who have higher levels of Engineering Design Self-Efficacy are more likely to persist in their engineering programs and perform better academically. Therefore, it is important for engineering educators to focus on developing self-efficacy and creativity in their students [25], [26]. This can be done by giving students opportunities to engage in hands-on projects, giving them constructive feedback, and offering mentorship and guidance throughout the design process. By promoting self-efficacy in engineering design,

educators can help students become more confident and successful in their engineering careers, leading to a more diverse and innovative field.

The Learning Factory at Penn State

The Learning Factory is the makerspace for the College of Engineering, although it is open to any Penn State students, faculty, and staff. In addition to supporting capstone and first-year cornerstone courses, it supports a number of other engineering courses, entrepreneurial activities, and passion projects. The original Learning Factory opened in 1995 to support the capstone courses of the Mechanical and Industrial Engineering Departments. Since that time, capstone participation has grown to include students from 12 departments in two Colleges—the largest multi-disciplinary, client-sponsored capstone program in the world. In 2023, the Learning Factory moved to a new facility with over 40,000 sf of "shop" space within a 105,000 sf building designed to support hands-on engineering education. In the first five months in the new facility, more than 2,000 students received training to use equipment within it safely.

Research Objectives

To understand more about student use of the Learning Factory through the Cornerstone Maker Experience activity in their Cornerstone Engineering Design course. To understand this, we will focus on two research questions:

Which Cornerstone Maker Experience project do students prefer and why?
: Through this question, we hope to understand student preferences within the five projects offered and how they picked their top choice.

Methodology

A survey was conducted to understand project choice among students in our Cornerstone Maker Experience activity. The Cornerstone Maker Experience survey was sent to instructors of all course sections, and they were asked to provide students with 10 minutes to complete the survey at the start of a class session. Before the survey was administered, students selected one of the five projects available to complete for this activity. Overall, 270 of the 650 students enrolled in the course participated in the survey. The subsections below outline the Cornerstone Maker Experience projects, the Cornerstone Maker Experience survey conducted for this research, and the content analysis methods.

Cornerstone Maker Experience

The Cornerstone Maker Experience activity allows first-year students to gain confidence and experience in the Learning Factory [27]. Students select from a menu of "canned" individual projects, each of which introduces different elements of the space. Each student receives a kit of materials and a set of associated instructions for their project. These are provided at no cost to the student—the materials are purchased with donor funds, and the associated training and

equipment are available through the Learning Factory. The projects were designed to appeal to a broad range of students and provide different opportunities for self-expression. They also expose students to various aspects of engineering and will hopefully a) build their confidence in the makerspace and b) provide an anchor to which they can tether future experiences in their more abstract engineering courses.

Through the Cornerstone Maker Experience assignment, students can choose from five projects: Aluminum Pen, Embroidery, LED Acrylic Display, Wireless Charger Housing, and Ultrasonic Range Finder. These projects are described on the Learning Factory website (a screenshot from the website with relevant information is included in Figure 1) so students can access more information about them. The overview page shows a short description of each project, and the details page has a materials list and detailed instructions for completing the project. Table 1 shows the description provided on the overview page and an example of each project.

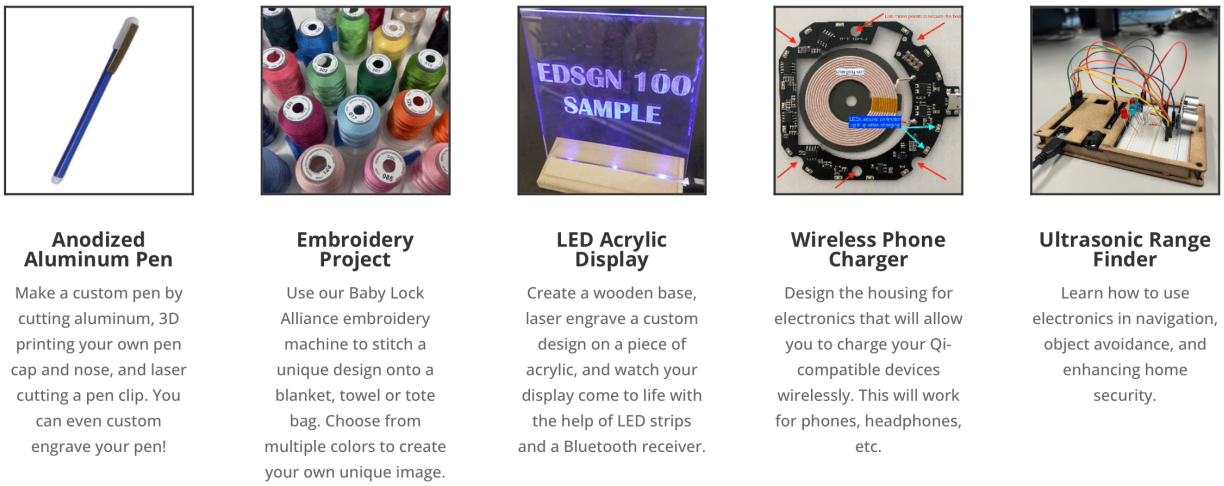

Figure 1 Description Cornerstone Maker Experience Projects [27]

Metrics and Analysis Tools

Cornerstone Maker Experience Survey

To understand more about student choices, we administered an optional survey to students enrolled in EDSGN 100. Overall, 270 of the 650 students completed the survey. At the beginning of the survey, a written overview of the study was provided, and implied consent was obtained in alignment with Penn State's Institutional Review Board policies. The survey started with a demographic information section, including current college standing (first-year, second-year, etc.), intended major, gender, race or ethnicity, LGBTQ+ identity, and US-born and first-generation students. After collecting demographics, we asked students which project they selected and requested them to rank the projects from favorite to least favorite. To understand more about their ranking, we asked students to answer the open-ended question, "Why did you rank your top project as number 1?"

Content Analysis

Inductive content analysis [7] was utilized to analyze the open-ended responses to the question, "Why did you rank your top project as number 1?". Before coding, the raters reviewed the responses individually and then developed a coding scheme together. The responses were divided into three categories: product, process, and project.

The product category represented responses focused on the end product students gained from completing this project (e.g., a pen, embroidered towel/bag/blanket, LED display, wireless charger, or ultrasonic range finder). Student responses focused on the product were further broken down into categories of "want it," "use it," and "creative," which encompassed the reasons they gave for their desire to have the final product.

The process category represented responses focused on the act of making the project. Student responses focused on different parts of the process in responses, which we broke down into "make it," "enjoy/fun," "use makerspace," and "learning."

The project category represented responses focused on the project and its course components. When discussing the project, student responses were divided into two categories: "easy" and "complex."

Results and Discussion

This survey was completed by 270 Cornerstone Engineering Design students at The Pennsylvania State University. Participants identified as male (187), female (78), non-binary (3) or chose not to say (2). The sections below provide results and a discussion of them in the context of our research question.

What is motivating student project choice in the Cornerstone Maker Experience project and why?

To answer our research question about the motivation of student project choice, we first needed to identify which projects students chose for this activity. We asked students to rank their project preferences for all five project options. Through our survey, we learned that the top choice for over a third of the students was the LED Acrylic Display (104), with the Wireless Phone Charger (58) being the next favorite first choice, with about half as many students selecting it. As seen in Figure 2, the Ultrasonic Range Finder and the Embroidery projects were chosen as the last choice by far more students—approximately 35% and 41%, respectively—than the other three projects. While the Embroidery project was the least preferred option by more students than any of the other projects, students identified this option as the first choice at a rate similar to the Wireless Phone Charger and Aluminum Pen projects. This validates that this project option is desirable among a subset of students, and further analysis of how demographics impact project choice could be valuable for determining which projects to offer. Further, while this was the first offering of the Ultrasonic Range Finder, it was associated with the lowest number of students

ranking it as a first choice and a high number ranking it as the last choice. These results may indicate that this is a niche project, and students selecting this option may have targeted motivations and goals for the project, which are explored through content analysis below.

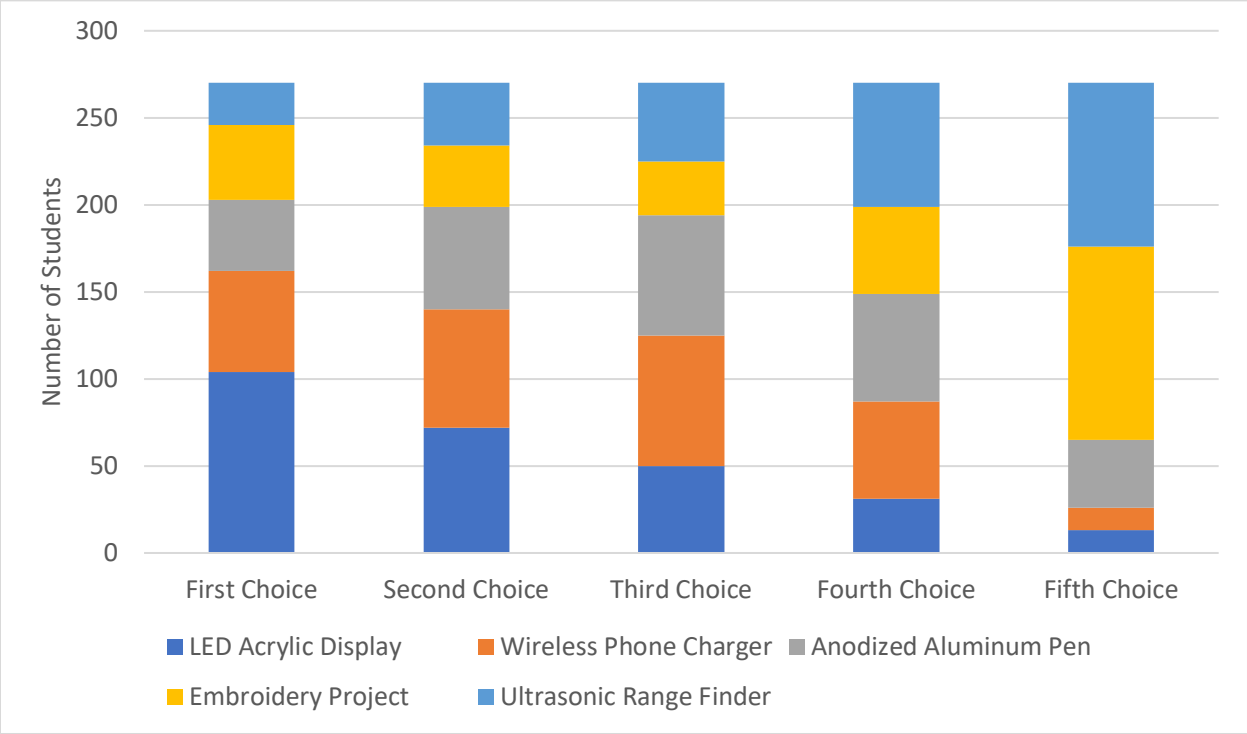

Figure 2 Number of students who chose each project option as their first, second, third, fourth, and last choice.

To understand what motivated their choices, student responses to the open-ended question, "Why did you rank your top project as number 1?" were analyzed using deductive content analysis [7]. Two raters independently reviewed the responses and created categories for analysis. The raters then discussed the categories and agreed upon a scheme before formally performing the content analysis. Each rater independently categorized each response, and then inter-rater reliability was assessed ($k = 0.89$ $p<0.001$). After inter-rater reliability was established, the raters discussed all disagreements until a consensus was made.

After completing the content analysis, we identified three key categories of motivators among student responses when answering the open-ended question "Why did you rank your top project as number 1?"—product, process, and project. Overall, the product, process, and project were mentioned by 157, 112, and 17 students, respectively, in their responses. Responses that mentioned the product frequently included "it's the most useful" (student id #265), and "it seems cool and I could put it in my room" (student id #18). Responses that mentioned the process often included "… I would like to gain more experience in both the woodshop and with the laser" (student id #3) and “I am most interested in learning how to use the sewing machines in the fab lab” (student id #119). Responses that mentioned the project said things like “least amount of work” (student id #191) and “…complicated so it makes for a good challenge” (student id #115).

To further understand these three broad categories, we analyzed the responses at a finer level to uncover what was driving project selection.

For students who mentioned the product, we identified sub-categories of creative, use it, and want it. Responses coded for creative included having a unique or customized product at the end of the project but did not necessarily focus on the act of making that product. For example, student id #29 said, “I think the LED Acrylic Display is the most unique option and it can be the most personalized.” This student was not focused on the making aspect but rather on the end product. The categories of use it and want it were similar, but distinguishable based on whether the students talked about using the final product (use it) vs displaying it or thinking it would be cool to have (want it). For the use it category, an example student response was, “I will be able to carry and use it every day” (student id #118). For the want it category, one student said, “It seems like a cool decoration …” (student id #22).

For students who mentioned the process, sub-categories were further defined as learning, use makerspace, enjoy/fun, and make it, with results shown in Figure 3. Students mentioning learning provided responses such as, “I enjoyed working with wood in high school and would like to learn how to laser etch” (student id #94). In this category, students mentioned learning how to make a product or how to complete a process. Within use makerspace, an example statement is, “It seems very interesting and incorporates many aspects that the EDGN building offers.” (student id #66). An example within enjoy/fun is from student id #41, who stated, “The LED Acrylic Display looked fun to create and I imagined that once I built it, it would be an interesting feature to have in my bedroom.” Within the make it sub-category, responses typically focused on the student simply stating a desire to make the product, or that they have always wanted to make it, rather than a focus on the process or learning. For example, student id #34 stated, “… is something I would want to make” and student id# 32 stated, “…and also something I have wanted to make before.”

For students who mentioned the project, the responses were associated with the perceived complexity of the project, with easy and complex being the sub-categories for coding. For example, student id #100 selected the LED Acrylic Display because “It seems like a fun and easy first project for me to do. I get to figure out how to use the wood shop.” Conversely, student ids #158 and #191 selected the Aluminum Pen Project because it is the “least amount of work.” While both examples highlighted the ease of completing the project, the motivation differed – an introduction project to figure out a new space vs. limited work. Within the easy category, most student responses were in line with those of student ids #158 and #191. Within the complex sub-category, student id #254, who selected the Wireless Phone Charger project, stated, “I wanted to do something that was out of my comfort zone to learn more and also something that’s not “easy” for me.” In these examples, some students focused on growth, regardless of the perceived complexity or challenge of the project.

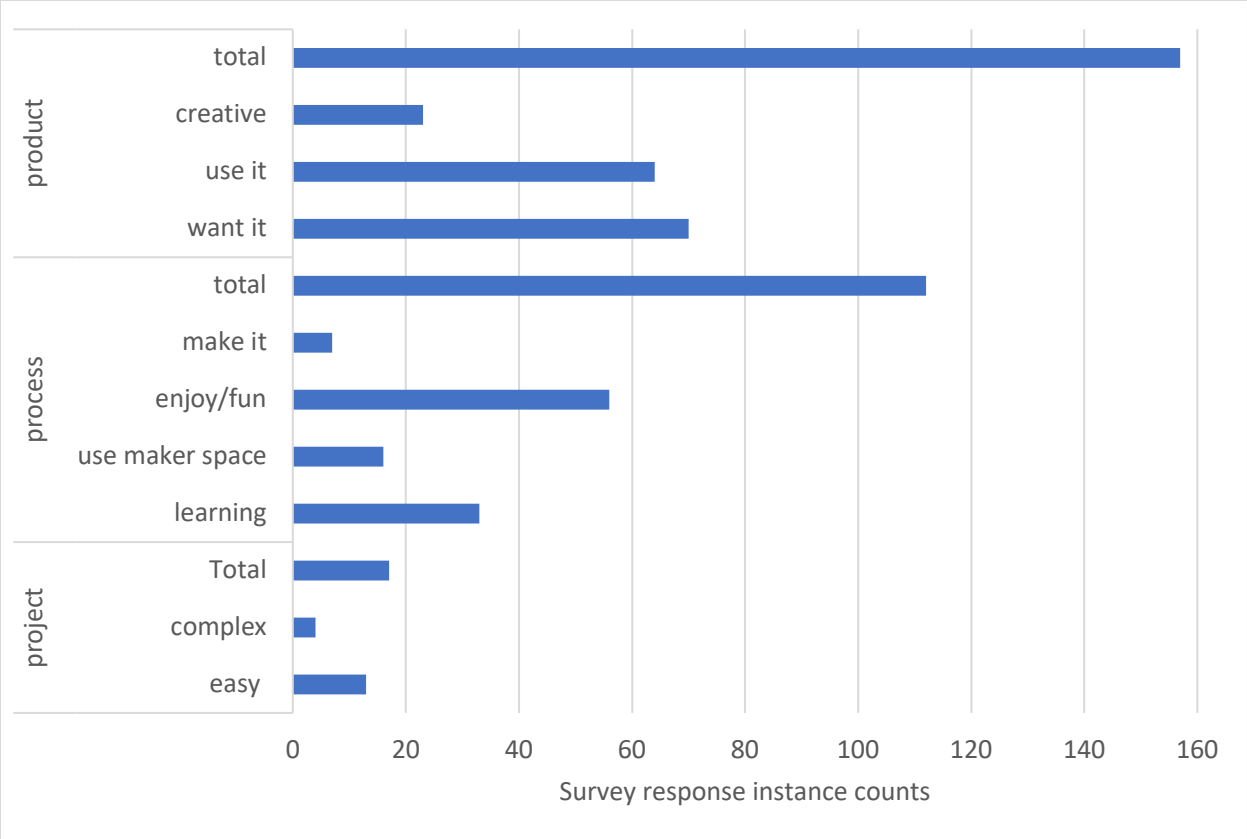

Figure 3. Detailed breakdown of the content analysis results. The figure shows that the three broad categories of motivators identified among student responses were product, process, and project.

As can be seen in Figure 4, the content analysis results, taken together with the project ranking results, demonstrate that the final product resulting from this project was more important to student project preference than learning how to create the product. While this is true when reflecting on the activity as a whole, for the students interested in the Ultrasonic Range Finder and Embroidery projects, the motivator for the project choice is switched—the students are more interested in learning how to make the product or how the product works.

Responses from students who identified the Embroidery project as their top choice included, "I think it will be really cool to learn how to embroider because it's a skill I can go beyond the class in" (student id #221) and "…it has been something I've wanted to try out and the result will be something I can actually use on a daily" (student id #260). Similarly, a student choosing the Ultrasonic Range Finder project responded, "Because I want to learn more about Arduino and how to use the electronics" (student id #108). While students in both groups focused on process as their primary reason for choosing the project, the students in the Embroidery group focused on the applicability to life outside of the classroom and how it would be fun to know how to embroider. Conversely, those choosing the Ultrasonic Range Finder project focused on learning technology. Understanding that student motivation can change depending on the project, educators can vary their projects based on the outcomes they hope to achieve.

If we look at each individual project and its desirability, shown in Figure 1, we can identify additional trends. Students' reasoning when selecting the LED Acrylic Display, the most chosen

project, was more evenly split between product (72) and process (48) than those choosing the Wireless Phone Charger (31 and 13, respectively) or the Anodized Aluminum Pen (24 and 9, respectively). The LED Acrylic Display has the most complex process of the projects, requiring the use of the woodshop and laser cutter to complete. It seems that students were either very interested in learning how to make this display or their desire for something "cool" drove them to take on the complicated project. Despite this being the most complex project, none of the students mentioned that the project's complexity was motivating project selection, while four students said it seemed easy. Meanwhile, the Anodized Aluminum Pen and the Wireless Phone Charger responses often focused on having something they would use daily at the end of the project or on the project being easier. Since neither of these projects require additional training, it is unsurprising that students think these projects are easier. Even though some students mentioned ease as an important factor, this was a relatively low number of total students, leading us to again see that students are more motivated by the final product than any other factors. Figure 4 summarizes the resulting motivator categories for the Cornerstone Maker Experience project options.

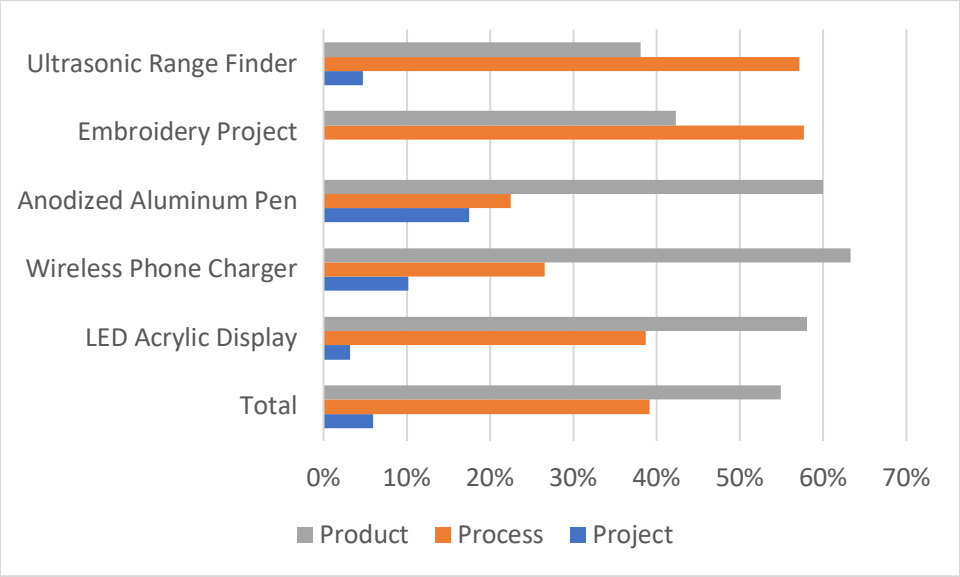

Figure 4 Results of content analysis demonstrating the percent breakdown across the three broad motivator categories (product, process, project) for the five project options in addition to the percent breakdown across all project options.

Are students getting the projects they prefer?

Beyond understanding what motivated project preferences, we also wanted to know if students were getting the projects they wanted, with the results displayed in Figure 5. Since the system works on a first-come, first-serve basis, we were unsure how close we would be to providing the students with their desired projects. Approximately 80% of students received their first project choice, and if they did not, they most likely received their second or third choice. Only 5 students received their fourth or fifth choice out of the 270 participants in this survey.

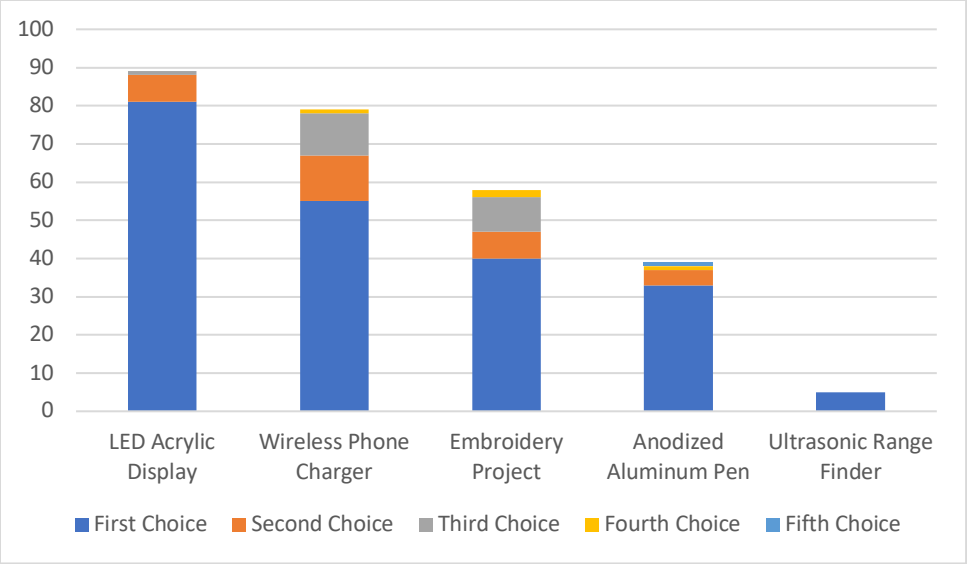

Figure 5 Projects received by students in comparison with their personal choice.

Conclusion

This research led to a deeper understanding of key choices made by students taking part in the Cornerstone Maker Experience project in the Learning Factory. This paper found the following:

- Significant trends were uncovered amongst student preferences across the five project options, notably:
    - The LED Acrylic Display was most likely to be a student's first choice for this activity.
    - The Embroidery and Ultrasonic Range Finder projects were most likely to be the last choice.
- Three categories were identified among student responses regarding why a project was chosen: product, process, and project.
- The final product seemed to drive choice more than process or project, but students who preferred:
    - The LED Acrylic Display talked more about the product but valued the product and the process highly.
    - The Anodized Aluminum Pen or Wireless Phone Charger talked more about the product and the ease of the project.
    - The Embroidery and Ultrasonic Range Finder projects talked more about the process.
- Most students received their first project choice, and only five students received their 4^{th} or 5^{th} choice.

These results indicate that students mainly choose their projects based on having "something cool" at the end of the project. Since a major benefit of makerspaces is skill development and the projects have been designed to provide training and experience within these spaces, future work can further understand if students are developing skills, even if it is not their initial reason for choosing the project. We also found that the reasons cited for motivation to complete the project differed between the five options, showing that the Embroidery and Ultrasonic Range Finder

projects were chosen because of the process rather than having a "cool" end product. To further understand these differences, future work is needed to explore if the level of motivation to complete the project depends on why students are motivated when selecting the project. Understanding this more fully will allow educators to better select course-based projects in the future to provide specified outcomes for student learning, self-efficacy, and sense of belonging in makerspaces.

Limitations and Future Work

Since this is an ongoing project, we have not investigated pre- and post-engineering and tinkering self-efficacy [28] but we plan to collect this data in the future. Prior work cites the positive effects that participating in and engaging with Makerspaces has on self-efficacy; however, students often engage with these spaces on a voluntary basis. Little work has explored if the integration of a Makerspace activity into a mandatory course assignment will have equally positive outcomes for students. The loss of agency in engagement with the space itself could have significant effects on student self-efficacy and thus is a critical next step to be explored. Further, while this work gives us insights into why students choose specific projects, we want to know if and how demographics play a role in these choices and how the projects impact their self-efficacy, stress, creativity, and sense of belonging in these makerspaces. It is important to note that Penn State is a Predominately White Institution, and thus, informal education space could be viewed as a "White Space" as conceived by Anderson [29]. Thus, forced participation in these spaces by those in minoritized groups may not benefit the students themselves if the space is perceived as unwelcoming. It is critical, therefore, that we understand for whom and under what conditions Makerspaces are maximally beneficial and what structural barriers exist for the inclusion of all students. Finally, while this work provides deeper insights into the motivation behind student project choice, it is limited by the nature of the study itself. Specifically, the survey was not mandatory, and it is likely that we failed to capture a complete snapshot of student perceptions. Second, the survey itself encouraged students to provide short form answers, thus, many of the student responses were no longer than a sentence. Future work should incorporate semi-structured interviews to gather more contextually relevant data and richer student perceptions of their own experiences.

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