Developing an Engineering Identity through Immersive Design Challenges in Academic Makerspaces: A Qualitative Case Study

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Introduction

Academic makerspaces are becoming commonplace in engineering schools across the country [1-3]. These spaces, often blending aspects of community makerspaces with aspects of traditional engineering school spaces (e.g., machine shop, wood shop), are places where creative individuals have access to a variety of digital and physical tools and can work independently or in collaboration to solve problems and create artifacts. For schools of engineering, makerspaces generally serve two important roles. First, they house a variety of tools and technologies that aid students doing the work of an engineer. Second, they provide a place in which students can become entrepreneurs [4].

In the past, much of the academic makerspace literature focused on asking questions related to how to outfit a makerspace, how to collect data to determine the flow of people and materials in a makerspace, or how to discover best practices in a makerspace [5-7]. More recently, engineering professors, makerspace managers, and educational researchers have begun asking questions related to how to design learning experiences in makerspaces that afford students unique opportunities to engage in engineering skills and mindsets such as: creativity, self-direction, and persisting through (and learning from) failure [8]. Because of the increasing popularity of academic makerspaces, this shift in inquiry represents an important change in perspective. Academic makerspaces are now recognized and valued as places in which programming, people, and processes are as important—or perhaps more important—than access to tools and materials [1,9].

At the same time as academic makerspaces grow in popularity, many schools of engineering across the country have continued their focus on design as an instructional approach [10]. That is, engineering schools continue to use design to give their students a hands-on introduction to the practice of engineering. Taken together with the recent increase in popularity of academic makerspaces, this continued focus on design stands to change the landscape of post-secondary engineering education as more and more students complete design activities within academic makerspaces. Amid this changing landscape, few researchers have investigated how implementing design-based activities within an academic makerspace influences how students learn engineering content, develop engineering identities, or encourage students to become engineers.

Within the literature in engineering education, the development of an engineering identity and a sense of belonging have been identified as critical factors in students’ perseverance and success in undergraduate engineering programs [11-12]. The development of an engineering identity, early in the engineering track, is particularly critical for students in programs where classification as "engineering students," by the College of Engineering, does not occur until after the sophomore year in the program [13]. This lack of engineering identity often results in students leaving the engineering pipeline early into their programs and tends to have a stronger effect on female students as it adds to other issues women face.
in engineering such as self-efficacy and gender cultural mismatch [14].

Historically, women have been and continue to be underrepresented in the field of engineering, both in post-secondary engineering programs and engineering careers after graduation [15]. Independent of early classification, the literature suggests that the "leak" in the engineering pipeline for women is due to lower levels of self-efficacy, fear of failure, conflict with the male-dominated field, and lack of self-identification and being identified by others as engineers [11, 16]. Regardless of gender, the literature also suggests that positive engineering experiences in the engineering programs can influence students’ decisions not only to persevere but also develop an engineering identity [13]. These experiences have shown to have a stronger influence in women, particularly with regard to satisfaction in an engineering major and interest in engineering as a career [17]. For example, Amelink and Creamer [17] found that relationships formed with peers and the degree of respect and support received during engineering-based group activities plays an important role in shaping engineering goals for female students. Furthermore, they found that these types of interactions, peer-to-peer and student-to-faculty, tends to have both a short- and long-term impact on interest in engineering as a major and a career.

While the literature on women in engineering education is rather extensive, the scholarship on the experiences of female engineering students in makerspace-based programming, particularly on participation in engineering design activities, is practically non-existent. To address this gap in the research, we developed and implemented an immersive design challenge (IDC) in which 16 students used the resources of the Student Innovation Lab (SIL), an academic makerspace in the School of Engineering at Private Southern University (PSU), to redesign a mobile makerspace to better meet the needs of the students and teachers who were to interact with it. During this design challenge, we asked: How does participating in an immersive design challenge situated in an academic makerspace influence students’ development of an engineering identity? In answering our research question, we looked not only at engineering identity development, but also at its implications for women in engineering in particular.

**Theoretical Framework**

To answer our research question, we developed a theoretical framework derived from the literature on situated learning theory in education [18], the learning potential of the maker movement in institutions of higher education [19], and the experiences that impact the process of undergraduate students becoming engineers within communities of practice [13]. In our framework (see Figure 1), we define space as the physical and social environment found within the makerspace. We then position (1) the makerspace as a community of practice within the school of engineering, (2) making as participation in the activities that take place within the space during the IDC that provide certain experiences for students, and (3) makers as the identities engineering students form, as they participate in the IDC. Surrounding and influencing makers, we position (a) accountable disciplinary knowledge as the changes in what counts as engineering knowledge throughout the IDC, as determined by experienced members of the space, (b) identification as the process of students identifying themselves, as well as being identified by others, as engineers, and (c) navigation as the ways in which students become experienced users of the space. To better understand the specifics of the
framework and their theoretical underpinnings, a brief overview of each component follows.

![Diagram](image)

*Figure 1. Adapted framework positioning makerspaces as communities of practice [19] where, students' development of an engineering identity [13] can be analyzed.*

**Situated Learning in Education**

Situated learning theory describes learning as situated within context, culture, and activity [18]. This theoretical view emphasizes that learning is a result of the relationships that emerge within and from the socially and culturally constructed world. More specifically, situated learning theory posits that learning emerges naturally through an individual’s legitimate peripheral participation (LPP) in a community of practice. That is, newcomers develop knowledge and skills in physical and social settings where they have an opportunity to participate peripherally with old-timers in relevant activities. Through LPP, newcomers shape their identities, gain knowledge and skills, and move progressively towards becoming experienced members of that community of practice. Once newcomers become experienced members of a community of practice, identifying themselves as legitimate practitioners, they contribute to the sustainability of the practice and eventually become old-timers themselves.

In this work, we define "experienced members" as those individuals who are regular users of the SIL, are highly proficient using the tools and equipment in the SIL, and are identified by the SIL staff and other regular members as "expert" members. We define
"newcomers" as those individuals who are not very familiar with the SIL, the tools and equipment in the space, or the regular members of the space. An example of an expert member would be a person at the SIL who normally trains others on how to use the machines in the SIL; he or she may be an upper-level engineering student or SIL staff. A newcomer would be someone who is completely new to the space and the tools and materials, or has spent very little time working in the space. With this understanding, of newcomers and experts, the SIL is then conceptualized as a community of practice where experts regularly interact with newcomers, from the time they attend the initial "orientation" training until they are certified as experts themselves. This certification process involves an expert member (SIL staff or student) observing the non-expert member perform a set of tasks using the tools and equipment in the SIL without any assistance. Before requesting certification, a newcomer must become confident enough using the tools and equipment in the SIL on their own, which normally only happens when they work under the close guidance of the expert members and progressively become independent.

Learning Potential of the Maker Movement

Drawing upon the literature on learning situated in communities of practice, through legitimate peripheral participation, Halverson and Sheridan [19] argue that the maker movement has a learning potential in institutions of higher learning that merits further exploration. Their argument is based on an understanding that the maker movement "stretches across the formal/informal instructional divide, creating an opportunity in research and in practice to understand learning and schooling as related but independent concepts"(p. 503). In their work, the maker movement in higher education is conceptualized as a transformative enterprise grounded on the theoretical roots and connections to prior research in education of its three main components: makerspaces, makers, and making.

Halverson and Sheridan [19] developed a theoretical framework where they conceptualize (1) makerspaces as "communities of practice constructed in a physical place set aside for a group of people to use as a core part of their practice," (2) makers as the "identities of participation that people take on within the maker movement," and (3) making as the "set of activities that can be designed with a specific goal in mind" (p. 496), within or outside a makerspace context. The authors argue that community also emerges "around makerspaces as members co-participate in a range of activities, including taking walks, playing board games, caring for resident pets, and attending Maker Faires and community events unrelated to making" (p. 502). Furthermore, the identities formed by makers range from individuals who participate in maker activities but do not consider themselves makers, to individuals who consider themselves makers in and out of the makerspace. And finally, that making allows for the sharing and transfer of knowledge, skills, and practices among members of the maker community, through the interactions that take place between newcomers and experienced members. Through the conceptualization of these components as integral characteristics of situated learning, establishing makerspaces as communities of practice, makers as identities of participation, and making as learning activities, Halverson and Sheridan [19] provide a framework through which learning within the context of makerspaces can be better understood and analyzed. In our work, we conceptualize the SIL as a community of
practice where makers (newcomers and experienced members) meaningfully engage in making activities that allow for the investigation of identity development, as a product of learning through legitimate peripheral participation. The IDC we designed required students to work in collaborative groups, composed of both newcomers and experts. In order for each group to complete the overall tasks they would need to learn from each other. The close interactions that were to take place during the transfer of knowledge from experts to newcomers allowed us to better understand changes in engineering identity.

**Becoming an Engineer**

In their ethnographic study, Stevens et al. [13] developed an analytical framework to investigate the changes that occur over time as undergraduate students navigate their education in engineering, and how the interactions of those changes impact their process of becoming, or not becoming, engineers. Over the span of four years, the authors developed the framework and applied to two engineering students at two different schools to understand the interactions among its dimensions. The framework, referred to as "Becoming an Engineer," involves three dimensions: accountable disciplinary knowledge, identification, and navigation. The examination of the three dimensions, and their interrelationships, as they unfold over time allows for a better understanding of how undergraduate students become engineers. The authors conceptualize (a) accountable disciplinary knowledge (ADK) as the "actions that when performed are counted as engineering knowledge" (p. 357), (b) identification as "the formation of an identity as a particular type of disciplined person" (p. 357), and (c) navigation as the ways in which individuals move through their educational careers and the experiences they encounter over time. The dimension of ADK focuses on the changes of what constitutes accountable disciplinary knowledge over time, and how students respond to those changes. Moreover, the dimension of identification draws upon the literature on situated learning and looks into how an engineering identity (as a process of self-identification and being identified by others) develops over time, and how such identification, or lack thereof, impacts the process of becoming an engineer. Lastly, the dimension of navigation looks into how the experiences of navigating through engineering education impacts an undergraduate student’s process of becoming an engineer, whether influenced by his or her accountable disciplinary knowledge, engineering identity, or both.

Through applying their analytical framework, Stevens and colleagues found that undergraduate students’ decisions to persevere or leave the engineering pipeline were influenced by the quality of their experiences in the three dimensions investigated, as well as the interactions found among them. Furthermore, they found that the dimension of identification played a more important role in becoming an engineer, as identifying and being identified by others, as an engineer influenced how students responded to the changes in ADK and how they navigated through the competitive and intense field of engineering. By positioning the SIL as a community of practice where students engage in meaningful engineering tasks, through maker-based programming, we apply the dimensions in the "Becoming an Engineer" framework developed by Stevens and colleagues to better understand engineering identity development through participation in engineering activities situated in academic makerspaces. We found it critical to combine the existing frameworks [13, 19] because its combination and adaptations allows us to
investigate engineering identity development within makerspaces. Adapting only one or the other would not allow us to account for either the social factors that are present in communities of practice or different factors that are known to influence engineering identity development. Taken together, we are able to investigate one, situated within the other. Figure 1 may help clarify our adaptation.

**Intent of this Paper**

In this paper, we extend Stevens et al.’s [13] findings by investigating how participation in an immersive design challenge situated within an academic makerspace in the school of engineering impacts undergraduate students’ development of an engineering identity and the implications of this impact on students in their early years of their engineering programs and female engineering students in particular. To investigate this question we adapted the frameworks discussed in Lave and Wenger [18], Halverson and Sheridan [19], and Stevens et al. [13] to create a lens through which the three dimensions of “Becoming an Engineer” can be investigated, within the context of a makerspace as a community of practice.

**Context**

At the SIL, we use immersive design challenges—short, intense, client-driven projects grounded in the principles of human-centered design—to develop and implement rigorous design activities based on real-world problems. The IDCs we develop are rooted in human-centered design. The core principle of human-centered design involves developing a first-hand understanding of the human needs and behaviors related to a system. Once a designer understands the system, he or she follows by making decisions based on inspiration from the humans operating within the system. During an IDC, students: (a) use human-centered design methods and rapid prototyping tools to solve a real-world problem, (b) collaborate with various stakeholders and potential end users, and (c) pitch a solution to a client. For example, in the previously, we ran an IDC during which students designed a mobile makerspace to visit children in hospitals who were in isolation but wanted to engage in making. To complete this challenge, students met with children under those conditions, hospital staff, and parents to better understand their needs. The students later developed several prototypes to determine what worked best, and finally built a final model and proposed it to the funding committee.

**The Makerspace**

The SIL is a student-centered makerspace equipped with both high-tech and common tools and materials such as 3D printers, laser cutter, CNC carving machine, vinyl cutter, and power tools. Once oriented to the space, students gain 24/7 access to the SIL. All university students, at both the undergraduate and graduate levels, from across campus are welcome to use the space. With a little training, students are allowed to use tools and materials to create objects and complete projects, both personal and for class. The informal learning space is the perfect place for students to explore, push themselves and develop their ability to struggle through ambiguity, persevere in the face of challenges, and drive towards an end result. Through active participation in the space, students become part of the SIL community and culture, allowing them to learn from
experienced members of the space and share their work with others, as they engage in a variety of making projects.

The Mobile Makerspace Redesign Challenge

The IDC on which this study focused was to redesign and improve the university’s newly acquired mobile makerspace, to better meet the needs of the students and teachers who were to interact with it. The mobile makerspace was formerly a delivery truck that had been hastily converted into a mobile makerspace. The challenge represented an opportunity for students to participate in a variety of hands-on activities where the use of the SIL, as a physical and social setting, was expected. The nature of the activities required applications of engineering knowledge and skills to develop human-centered solutions for the multiple uses of the truck. Given the magnitude of the overall task, teams were expected to form where students would have the opportunity to work closely with experienced members of the SIL and interact with people with a range of engineering backgrounds.

To accomplish their goal of redesigning the truck, participants were given full access to the tools and materials in the makerspace and were provided with a substantial budget to ensure their ideas would not be limited by cost. In addition to assistance from the IDC facilitators, participants could also access assistance from several engineering graduate students, who were expert members of the space. This would ensure that inexperience with tools and technology found in the space would not limit their work. The IDC lasted an entire week (Monday through Friday), from 8:30 a.m. to 4:30 p.m. Although these were the designated work times, several students showed up earlier or stayed after the designated hours to continue working on their projects.

Method

To investigate our research question, we took an ethnographic approach to conduct a case study [20] focused on the experiences of first-time participants as they engaged in the activities designed for the immersive design challenge. Three teams were formed, composed of students from different engineering backgrounds, types of expertise, and levels of experience in similar challenges. We followed each of the teams, individually and together, and collected data, such as observational field notes, videos, photographs, and post-IDC survey responses, on instances relevant to students’ ADK, identification, navigation, and their relationship to the makerspace, making activities, and their participation as makers.

Participants

Sixteen students (12 from the host university and four from a local high school) volunteered to work in three different teams to redesign and improve the mobile makerspace. From the university, there were five freshmen, one junior, one senior, four first-year masters, and one master graduate who had recently been accepted into an engineering Ph.D. program. All students from the high school were juniors. The inclusion of the high school students was part of a community partnership between the School of Engineering at PSU and a local high school that housed a makerspace. Although some of the students had used some of the tools and equipment at their
makerspace, none of them had previously worked at the SIL or in engineering activities similar to the IDC.

The IDC was led by Lindsay and Jake, the makerspace manager (pseudonyms used). Both served as facilitators throughout the challenge, guiding, assisting, and training the teams whenever necessary. Lindsay had previously worked with the mobile makerspace when it was first built at another institution; her experience with makerspaces was far more extensive than anyone else’s at the SIL. PSU’s acquisition of the truck was in great part due to her efforts and her work in a maker-based education project. In addition to the SIL staff, a panel of experts in maker education and K-12 makerspaces as well as one of the original founders of the mobile makerspace, was brought in on the first day to offer the teams important background information on maker education, the value of makerspaces in K-12 schools, and the potential impact the mobile makerspace could have on K-12 students. This panel was composed of a PSU STEM education professor, a principal from an all-girls K-8 school with a makerspace, a makerspace teacher from private school, and a makerspace teacher from the partnership high school. The founder of the mobile makerspace spoke to the students via Skype for two hours to discuss his previous experience with the truck.

Although the IDC staff were present throughout the IDC, the role of experts was taken mostly by the graduate engineering students, who participated in the IDC as either part of a team or facilitators. Their participation in the IDC ensured that expert assistance was always available, if needed. On the first day of the IDC, participants were asked to brainstorm on ideas to improve the truck, using what they had learned from the panel of experts, the virtual chat they had with one of the founders of the truck, and their own visit to the truck. Their ideas were sorted into three main areas: furniture, content, and systems. Participants were then asked to form teams to work on each of those areas. Most participants seemed to have gravitated towards the area with which they were most familiar, or the area on which they at least felt most confident working. We make this assumption based on the comments during team selection (e.g., "I’m pretty good with the wood shop tools," "I’ve worked with Illustrator before," etc.). Table 1 provides details on the composition of each team as well as expert involvement.
Table 1

Additional details on the composition of each team, as well as relevant information on the SIL experts.

<table>
<thead>
<tr>
<th>Team</th>
<th>Name (pseudonyms)</th>
<th>Gender</th>
<th>Ethnicity</th>
<th>Dominant Language</th>
<th>Newcomer/Expert</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIL Staff</td>
<td>Lindsay</td>
<td>Female</td>
<td>White</td>
<td>English</td>
<td>Expert</td>
<td>Sil Director</td>
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<tr>
<td>SIL Staff</td>
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<td>Male</td>
<td>White</td>
<td>English</td>
<td>Expert</td>
<td>Sil Manager</td>
</tr>
<tr>
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<td>Male</td>
<td>Asian</td>
<td>English</td>
<td>Expert</td>
<td>Graduate</td>
</tr>
<tr>
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<td>Male</td>
<td>White</td>
<td>English</td>
<td>Expert</td>
<td>Graduate</td>
</tr>
<tr>
<td>Furniture</td>
<td>Mark</td>
<td>Male</td>
<td>Hispanic</td>
<td>English</td>
<td>Expert</td>
<td>Graduate</td>
</tr>
<tr>
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<td>White</td>
<td>English</td>
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<td>Undergraduate</td>
</tr>
<tr>
<td>Furniture</td>
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<td>Latinx</td>
<td>English</td>
<td>Newcomer</td>
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<tr>
<td>Furniture</td>
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<td>White</td>
<td>English</td>
<td>Newcomer</td>
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<td>Newcomer</td>
<td>Undergraduate</td>
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<td>High School</td>
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<tr>
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<td>Black</td>
<td>English</td>
<td>Newcomer</td>
<td>High School</td>
</tr>
</tbody>
</table>

Data Collection and Analysis

During the IDC, the first author assumed the role of a non-participant observer and collected all the data used in this study. Following an ethnographic approach, he did not engage in any of the activities in which the students participated throughout the IDC and interacted with them only when observation alone did not provide data on instances he believed to be relevant to answering the overarching research question (e.g., when participants worked quietly, independently, or engaged in self-reflection). Main sources of data consisted of extensive field notes, videos, and photographs. Additional data sources included post-IDC attitude survey responses and theoretical and analytical memos. The vast majority of the data consists of observational field notes focused on the interactions that took place between newcomers and experts throughout the challenge. Video and photograph data mostly focused on the students’ final presentation of the completed truck where they described both their overall experience in the IDC and their individual contributions. The post-IDC surveys was used to further gain insights into students’ individual experiences in the IDC and their interest in participating in future engineering-
based projects. Lastly, theoretical and analytical memos were used to understand how the dimensions of our adapted framework were interacting with each other throughout the IDC. They also allowed us to identify emerging themes that were not part of our study, but interesting enough to attempt to investigate in the future. The role of language negotiation between English Language Learners was one such theme.

In their call for further exploration of learning in academic makerspaces, Halverson and Sheridan [19] claim that learning in these spaces is a product of legitimate peripheral participation between newcomers and expert members that allows newcomers to become experts overtime. In this view, "the unit of analysis is not necessarily individual learners over time but, rather, what happens in the space and how to design the space to enable distributed expertise and open configurations of learning" (p. 502). Following this notion, we consider the IDC as the unit of analysis, the case, bounded by the space (physical and social) and its duration. Within this case, we investigated subcases to better understand student experiences, as independent and interrelated.

We focused our analysis on three contrasting subcases to build an interpretive case study [20]. The subcases (Figure 2) were "The Furniture Team" (FT), “The Content Team" (CT), and "The Systems Team" (ST). The interpretive case is the “immersive design challenge” (IDC), bounded by the context within which it took place and its duration. In other words, the collected data focused on the activities that occurred in the makerspace, within and among the teams, from the time the challenge began to the time it was completed. Within each subcase, we used a maximum variation sampling strategy to identify individuals who were first-time participants but had different degrees of participation with experienced members of the SIL within their teams and within the makerspace [21]. We defined degrees of participation with experienced members in three terms: 1) close participation, where experienced members engaged in activities that allowed the first-time participant to participate peripherally yet meaningfully, 2) just-in-time participation, where the experienced members assisted the first-time participant just when it was necessary (e.g., when asked, or where working in close proximity and decided to help), and 3) drop-in participation, where experienced members only engaged with first-time participants when they could not reach a consensus, in terms of directions or designs, from several options. This sampling strategy allowed us to investigate the experiences of undergraduate first-time IDC participants in different team compositions. More specifically, we found it critical to sample varying subcases to be able to investigate similarities and differences in the experiences of first-time participants across the three subcases. And we found it necessary to define the degrees of participation with experienced members, as we were trying to understand its impact on the experiences of first-time participants within each subcase. While in the Furniture Team we were able to sample Jane as our first-time IDC participant, the dynamics and composition of the other two teams were vastly different and forced to either analyze the entire team a sample unit (Content Team) or each member as an individual sample (Systems Team).
Building the narratives. Guided by our research question, and informed by our theoretical framework, we conducted our analysis in two stages: within-subcase and across-subcases [20]. To better understand the experiences of our sampled participants, we conducted a within-subcase narrative analysis for each team (FT, CT, and ST). In this stage, we developed a coding framework to focus our analysis on the interactions between newcomers and expert members in two main categories: The development of engineering identity (using engineering ADK, identification, and navigation as codes) and learning situated within a makerspace (using the makerspace, making activities, and maker identities as codes).

Through this framework, we analyzed one subcase at a time, using every piece of collected data relevant to newcomers’ changes in engineering ADK, identification, and navigation, to build rich narratives of their individual experiences in those dimensions, and their possible relationships to the makerspace, making activities, and maker identities. During this stage, we relied mainly on observational field notes, as such data offered far more descriptions of newcomer/expert interactions than any other type we collected. Given that we were observing the interactions that took place within each team and among them, we kept all the data together and later sorted it by team to build each narrative separately. Once we had sorted the data, we began to apply our coding framework. The following excerpt from the Furniture Team observational data provides an example of our coding process:
In this excerpt, you can see several labels used to describe each instance relevant to our framework. These labels were later sorted according to the code under which they best fit. For example, under the code "using engineering ADK," we placed the instance labeled as "newcomer engaged in meaningful low-risk tasks." Similarly, under the code "using the makerspace," we placed the instance labeled as "learning to use new tools/technology."

**Comparing the sub-cases.** Once we completed each of the narratives, we moved on to the second stage, where we conducted an inductive analysis of all three subcases to understand the processes and outcomes across the subcases as explained by their local conditions [21]. More specifically, in this stage, we looked for similarities and differences across the narratives, with respect to the varying degrees of participation with experienced members and the processes and outcomes that emerged from them. We also looked for similarities and differences across the narratives, in terms of how the experiences of the sampled participants were impacted by the makerspace, the making activities, and their identities as makers. For example, when comparing the Furniture Team subcase to that of the Content Team and the Systems Team, we looked at how different amount of expert assistance instances in each team impacted the newcomer’s ability, in each team, to acquire the necessary skills to move forward and complete their tasks. Similarly, we compared in each team the number of instances where newcomers were observed working independently, without expert assistance.

**Results**

In this section, we present our subcases separately to illustrate their individual experiences in the form of narratives. All the statements made in each narrative are based on our observational data, unless noted otherwise. Following, we provide an analytical description of their differences and similarities in processes and outcomes across the narratives. All names used are pseudonyms.

**The Furniture Team**

Within the subcase of The Furniture Team, we sampled Jane. Jane was a first-time IDC participant who was in a group composed of two other first-time participants (Tara, a high school junior and Laura, a university freshman), and an experienced member of the SIL (Mark, a recent engineering master graduate student). We also chose Jane because of her close relationship with Mark from the beginning of the IDC. Based on our initial observations, they seemed to get along very well, and even though teams were not formed until the end of first day, they tended to discuss ideas with each other and work on similar tasks. The overall dynamics of this team were rather interesting. Mark was the only male in the group, and he was also the only expert. He held both the highest level of engineering experience and SIL experience in the team. Perhaps based on strategy, or his emerging relationship with Jane, he was observed spending far more time working with her than with the other two female members of his team, who were also newcomers.

During the first two days of the IDC, Jane was observed spending most of her time observing Mark and learning about the tools and technologies present in the makerspace. When working with Mark, Jane engaged in meaningful but relatively low-risk tasks
related to completing the IDC. For example, she provided input on the solutions her team created and assisted Mark when he used power tools to cut large pieces of wood for their model of the new cabinets for the truck. During these early days, although Jane was engaged and demonstrated a keen interest in learning more about the functions of the tools in the makerspace and how to operate those tools, she was still solidly at the periphery of the challenge. She had not taken the lead on any tasks or proposed different ways of completing them. She simply followed the guidance of her more experienced teammate, Mark.

In the following two days, Jane was observed approaching tasks with a different attitude. She began to spend less time assisting Mark, and more time working independently and taking the lead on various projects such as cutting the pieces for the cabinets and asking Laura and Tara to assist her by holding the large pieces of wood. During these days, Jane demonstrated her increasing confidence by using a variety of power tools she had previously not used alone (e.g., power drill and circular saw), and by making critical decisions vis-à-vis the plans for designing and constructing parts for the new cabinets. During the second half of the third day, Mark had to leave the team to work on a project outside the SIL. Mark’s absence became an opportunity for Jane to engage in the team’s tasks in a different manner. For example, when the Systems Team decided to change the location of the air compressor box from one end of the truck to the other, Jane took the initiative to redesign the cabinets and shelves on one side of the truck to adjust to those changes, while ensuring storage space would not be lost. Additionally, when more pieces of wood were needed for the cabinets, Jane cut the pieces herself using the circular saw, while Laura assisted her by holding one end of the wood. By the end of the fourth day of the IDC, Jane had transformed into someone who was highly confident in her ability to use the power tools in the makerspace as well as in her ability to make critical decisions related to the project. On the last day of the challenge, Jane assumed the role previously held by Mark. Her teammates began learning from her and following her lead. For example, at the start of the day, Jane’s teammates, Laura and Tara, began to observe her while she used the jigsaw. Later, they asked her to teach them how to use it, and by the end of the day, Jane’s teammates were consulting with her to verify the accuracy of the new shelves they had cut using the jigsaw.

In the absence of the graduate student mentor, Jane was able to assume his role, train her first-time teammates on a variety of tools, and lead her team to complete the project. Throughout the course of the IDC, Jane progressively transformed from a timid, yet engaged participant who possessed very limited knowledge of the tools in the SIL, into an experienced member of the team who could confidently assist others. Along the way, she also developed a collection of highly relevant engineering-related skills and knowledge such as quick prototyping and iterative design. This transformation would arguably not have taken place without the close guidance of the experienced member, who not only worked closely on meaningful engineering tasks with Jane, but also provided her with opportunities for her to engage in those tasks and eventually complete those tasks independently.

The Content Team

The Content Team had a very different member composition than The Furniture
Team. This team had two high school juniors and two university freshmen, with all being first-time participants. Unlike Jane’s team, there were no experienced members in this team, and no opportunity for any of the first-time participants to work closely with other experienced members outside their team. It was difficult to follow one single individual from this team because they decided to tackle the entire challenge as a team. For that reason, we selected the whole team as our second subcase, and we investigated the interactions between the team as a whole and the expert members of the SIL who assisted them during the IDC.

During the first day, this team was observed struggling with organization. They formed into a group based on the ideas they had proposed individually as improvements for the truck. Most of their ideas revolved around the physical look of the truck and the marketing and signage needed. This made sense, as two of the members mentioned being proficient with a popular visual design software, and wanting to make the truck a welcoming environment for anyone who stepped into it. By the end of the day, the team had not spent much time discussing the goals of the challenge. They had yet to develop a plan of action or a tentative list of items to address.

On second day, the team decided to begin by redesigning the look of the "tool card," an existing booklet describing all the items in the truck. They wanted to improve the overall look of the booklet by creating a logo for each tool card and developing a layout that was consistent throughout. They worked on that task for most of the day, until the teams regrouped to discuss the progress with everyone. After the team shared their progress, one of the facilitators realized the team was not going in the expected direction. They were focusing on the visual aspect of the tool cards, as opposed to the type of content displayed on the cards. That was problematic because the design was already being completed by an outside source. The need to address in this challenge, according to what students had determined on the first day, was to make the content relevant to those who visit the truck. In other words, in addition to describing the tools and materials in the truck, the cards also needed to describe possible uses in classroom maker-based projects. Based on this understanding, the facilitators redirected the team and provided additional guidance regarding their next steps.

After realizing they were going in the wrong direction, the team appeared quite disappointed. However, they quickly gathered back together and discussed ways to complete the new task without having to start over. Their new plan did not come without issues; it required a different set of knowledge, tools, and materials to complete the new task and none of the members had significant experience with any of them. For example, to improve the content on the tools cards, such that they showed connections to K-12 education, the team needed to know the specific content areas and grade levels where connections could be made. This became an issue, as one member mentioned having zero knowledge of K-12 teaching. Nevertheless, one member took on the challenge of searching online for lesson plans showing those connections. Another issue in their new plan was the use of the vinyl cutter, laser cutter, and the 3D printer. Although one member had some knowledge of how to use a laser cutter, the one at the SIL was different than the one she had used before. This team spent more time trying to learn how use the tools on their own, than actually using them. On several occasions, Johnny, one of the graduate student facilitators, noticed they were struggling with the
machines and he offered to train them on how to use them. However, every time he finished training them, Johnny would leave the team to work on their own. When the team moved on to a different machine, Johnny would approach them and offer training again. Similarly, Aiden, another graduate student facilitator, had to help the team several times. Once, with the 3D printer, and another time with the sewing machine. By the last day, the team had completed all of their tasks and even taken on additional tasks. They struggled through each of them because they were either unfamiliar with the tools needed, or their content knowledge was simply not enough to meet their needs. The assistance of Johnny and Aiden were, arguably, what helped them move forward and complete their tasks. Once one member of the team knew how to use a machine, he or she would train the rest. Eventually, they were all observed confidently using the 3D printer, the laser cutter, the vinyl cutter, and even the sewing machine.

**The Systems Team**

The Systems Team was very different from both the Furniture and Content Teams. This team had six members, and all were male. Two were engineering master students, one was a junior, two were freshmen, and one was a high school junior. While this team did not have any experienced SIL members, most of them had strong engineering backgrounds and experience using the tools found in the SIL. With the exception of the high school student, all were engineering students at the host university.

On the first day, and just like the other teams, the team formed based on their individual ideas for the redesign and improvement of the truck and their expertise with the knowledge and skills needed to complete the individual tasks. The team focused mostly on ventilation, noise reduction, and efficiently powering the equipment. From the time they first met as a group, the division of tasks was very clear. Although James, the high school junior, took it upon himself to lead the group and coordinate the tasks and assign members to each task, the other members did not necessarily follow his lead. Once the tasks were divided, and subsequently the team into sub teams or individual work, the power dynamics changed. Every sub team and individuals were observed working on a task independently, and without asking for any assistance. The members working on each task seemed to possess enough knowledge to complete the tasks on their own, without any guidance or direction from others. Sam and Jacob, the two master students, and Paulo, the university junior, decided to build an AC unit using an ice cooler and a small fan to address the ventilation issue in the truck. Alex, the university freshman, took the challenge of building an insulated wooden box for the air compressor and reduce the noise it made in the truck. Alan, the other university freshmen on the team decided to create a 3D model of the truck on a modeling software, to better illustrate different ways in which the AC unit and the air compressor box could be best installed. James decided to look into adding LED lighting to the truck as well as a pull-out tent for the side of the truck.

For the following three days, the small group and the other three individuals worked independently. The AC group did not encounter many issues, in terms of finding possible solutions. They encountered challenges in communication as they were speakers of languages other than English. However, they found ways to communicate either by rephrasing what each other said, using hand signals, or sketching their ideas on the
whiteboard. At times, one of the IDC facilitators would join their conversations to help them reach a consensus. Many times, they had too many options and could not agree on the best ones. Other times, the facilitators reviewed relevant content knowledge, such as air flow dynamics, to help them determine their best option. The facilitator, however, never told them what to choose; he served more as a mediator.

Alex and Alan continued working on their projects independently. At times, Paulo would help Alex with the prototype for the air compressor box, when his teammates were not present, but once they returned, he would go back and join them. Alex finished the prototype practically on his own. Once he tested it, and concluded it worked, he began to work on the box for the truck. Similarly, Alan worked on the 3D model on his own. Paulo created a similar model, but when he realized Alan was creating one too, he abandoned his. During these days, and for unknown reasons, James missed several sessions. He never made any progress with the LED lights, and did not work on any other tasks. He visited the other members, as if he were checking on their progress, but never made any progress of his own. The rest of the team shared their progress with him, when visited, and continued working on their own.

During the last days, the teams worked on finishing and installing their units. James, once again, missed some of those sessions and eventually left the challenge. According to his friends from school, he had other things to do that overlapped with the IDC, so he had to leave. The team eventually completed and installed an AC unit, a noise-reduction box for the air compressor, and a breaker box for the electronics in the truck. Even though the breaker box was not something the sub teams were initially working on, Sam and Jacob possessed sufficient electrical engineering knowledge to complete it on the last day in less than an hour.

**Cross-case Analysis of the Teams**

It is clear that the experiences within each team were quite different. In the Furniture Team, we found what most would expect; a newcomer becoming a full participant through legitimate peripheral participation with an experienced member of a community of practice. Jane’s case illustrates how an individual can transform when he or she engages in activities with experienced members, that allow them to meaningfully participate and grow within a community. Her case further illustrates how, once a full participant herself, she became an experienced member to her other two first-time participant members. While Jane initially did not consider herself an engineer and did not possess the necessary ADK to complete the tasks, she was very comfortable navigating the markerspace and working with the expert member. This allowed her to gain the skills she needed from her mentor and in the process gain confidence in her ability to lead the team, strengthening her engineering identity. Arguably, it was the opportunities to participate in meaningful progressive tasks that allowed her to develop that confidence. In the following quote from our survey data, Jane reflects on her previous experience with power tools:

> My dad would just spend an hour lecturing me on what not to do with them [power tools] or what they were for, but never let me use them. Those tools were just for the boys... Many girls might be afraid to use power tools. I
was at the beginning, too. But I think the only way to get girls to use them is by letting them try. Show me how they work, and then let me do it on my own.

The experiences in the Content Team were not like that of Jane. The lack of an experienced member played an important role in how the members of this team engaged with the tasks, navigated the space, and identified themselves as makers. Even though they were able to complete all of their tasks, they encountered far more issues than Jane did. With no experienced member in close proximity, they had to figure things out on their own most of the time. And while they possessed some taskrelevant ADK, that became useless when their tasks changed. Perhaps their “growth mindset” approach to learning is what helped them persevere throughout the IDC. However, the impact of the two experienced facilitators, who were able to assist them just when they needed it, is undeniably what helped them move forward and complete their tasks. These facilitators played a role similar to Mark in Jane’s case, where they worked closely with different team members, although for shorter periods of time, and were able to transfer the taskrelevant ADK right when they needed it. When the facilitators left these members to work on their own projects, they had opportunities to become more confident with their newly-acquired knowledge and skills and transfer them to the rest of the team. Arguably, as our framework suggests, the degree of expert participation with the team is what made the difference between the two cases. Whereas Mark’s close-participation with Jane allowed her to acquire the task-relevant ADK and eventually become an expert herself, the facilitators’ just-in-time participation may not have been as impactful as in Jane’s case, but it was nevertheless effective. As the following quote from our video data suggests, in spite of the issues the team encountered, even the least experienced members of the team gained a certain level of knowledge and skills through their participation in the challenge:

I’m part of the Content Team, and I helped with the content, the graphics, and things like that. I got better at using Adobe Illustrator and Adobe Photoshop, and I learned how to sew… and I had a lot of fun doing so.

The experiences in the System Team were quite different from the other two teams. In this team, most of the members had strong engineering backgrounds and had high levels of experience using many of the tools found in the makerspace. The only member who did not share a similar level of experience or engineering background was James, the high school junior. Although none of the members of this team were experienced members of the SIL, they possessed a level of knowledge and confidence that allowed them to easily navigate the space, and approach their tasks, as experienced members of the SIL would. Perhaps it was these characteristics of the team that, in a way, did not let James fully participate. Once the team broke the overall project into smaller tasks, and each individual working on those tasks possessed strong engineering knowledge and skills, James was unable to join any of them. In a sense, he was not needed. In fact, not even the facilitators were needed. These members were so independent and self-sufficient that the only time they interacted with the facilitators was when they needed a mediator to settle differences in opinions. And for the most part, they never asked for the facilitator’s assistance; facilitators’ drop-in participation occurred mostly when they decided to join the team’s conversations. Whereas the Content Team lacked an experienced member, the Systems Team had too many. Perhaps not by being identified by others as experienced, but by identifying
themselves as such and valuing each other’s engineering knowledge and prior experience with making tools as highly relevant to the tasks in which they engaged. Had James been given the opportunity to join one of the other members and work closely with them, perhaps he would have had a different experience – one similar to Jane’s, in the Furniture Team, if not even more transformative, or perhaps one like the Content Team that was minimal yet fruitful.

Discussion

In this paper, we presented an interpretive case study of an immersive design challenge, situated within an academic makerspace (the SIL) at the School of Engineering at Private Southern University. Within our case, we investigated three subcases to understand how undergraduate first-time IDC participants developed an engineering identity, as they participated in the activities designed for the challenge. More specifically, we investigated how the undergraduate first-time participants’ engineering identity was influenced by the interactions that occurred between them and the experienced members of the SIL, throughout the IDC. These interactions were then investigated in terms of how students dealt with changes in accountable disciplinary knowledge in making tasks, identification as makers throughout the challenge, and navigation of the makerspace in general.

Each of the subcases we investigated presents a different narrative. The Furniture Team case illustrates an example of how a transformation from newcomer to full participant can take place when opportunities for newcomers to participate peripherally with experienced members of a community of practice are present. Furthermore, this case shows how, in spite of the male-dominated culture in both engineering and makerspaces, women can successfully become full-participants through an apprenticeship approach. Thus, the Furniture Team case offers a model that can enable such transformations by designing teams, activities, and working environments with the characteristics found in the team (i.e., diverse levels of expertise in the team, opportunities for close collaboration between inexperienced and experienced members, and a space that is conducive to highly collaborative work). The Content Team case illustrates the ways in which the transformation found in the Furniture Team case can be limited, if not eliminated, when the components of the experienced member and member task-relevant knowledgeable skills are missing. This is consistent with Steven et al.’s [13] findings suggesting that low levels of ADK and identification can negatively impact students’ ability to persevere in engineering. The Content Team case offers information about the necessary degrees of participation with experienced members to help newcomers become full participants within a community of practice. Our last case, The Systems Team, further illustrates that missing the component of the experienced member, does not necessarily mean full participation will be limited. The engineering background and prior experience with task-relevant tools allowed members of this team to function as experienced members of the community. Not necessarily because they possessed high levels of both, but likely because their engineering knowledge and prior experience with maker tools matched very well with the IDC activities. Even in the case of the group students whose dominant language was not English, it was evident that what helped them move forward and complete their tasks was their high levels of ADK and identification. Their confidence in their propose solutions to the tasks at hand allowed them to persevere during times when communication was difficult and find other ways to understand each other (e.g.,


sketching or using hand signals). Nevertheless, it is important to note the negative side of this team’s approach to completing the IDC activities. Their division of tasks and separation from the less experienced member demonstrate how having too many experienced members in one team can be beneficial for accomplishing the overall goals of the team, but also negatively affect its less experienced members. This is consistent with the notion that engineering as a field and makerspaces can also contribute to the exclusion of certain individuals when unwelcoming cultures emerge among the regular members [22].

Implications

The implications of our work are two-fold: what do these findings mean for engineering education as a whole and what do they mean for women in engineering in particular? As described in the introduction section, the literature suggests that many engineering students begin to "leak" out of the engineering pipeline early in their undergraduate programs [11]. Among the several factors identified as decisions to leave, the lack of identification with engineering and by others as engineers, and the lack of opportunities to engage in meaningful engineering experiences early into their programs, seem to be the strongest ones [17]. In our work, we explore how makerspaces can serve as places where undergraduate engineering students, classified as such or not, can engage in such experiences, and how these experiences can help these students develop stronger engineering identities through close participation in meaningful engineering tasks with experienced engineering students.

Our work highlights how programming in makerspaces, such as an IDC, may provide access to participation for underrepresented populations such as women. The literature on engineering education suggests that the male-dominance of the field often keeps women from persevering in the engineering track [23]. This is further exacerbated when other factors such as low levels of self-efficacy and engineering identity are considered. By providing spaces that consider these factors and are intentionally designed to minimize or eliminate gendered power dynamics and capitalize on the strengths of every individual, makerspaces have the potential to not only increase the participation of underrepresented groups in engineering but also to foster the development of stronger engineering identities through continuous programming such as the IDC. In our IDC, we attempted to accomplish just that. However, given the self-selected groups, we were unable to investigate the experiences of women in the IDC on a deeper and broader level. At minimum, this works provides some direction for future research. One that, in addition to the frameworks we used, feminist theory is considered to better understand women’s development of an engineering identity.

Although not the focus of this paper, the language dynamics observed among English Language Learners in the Systems Team provide a limited, yet interesting view of how possessing a strong engineering knowledge can help overcome language barriers. This particular group of students, in spite of their communication difficulties due to English language proficiency, was able to complete not only their own task (build the AC unit), but also assist others (with the air compressor box) and even take on additional tasks on the very last day of the IDC (installing a breaker box). With the limited data from this work, we can cautiously state that engineering-based programming in academic
makerspaces might have the potential to increase the inclusion of students who belong to a language minority in the field of engineering, so long as they possess high levels of ADK and engineering identification. The literature in engineering education situated within makerspaces is still at its infancy, and as we move forward, the investigation of learning in these spaces for English Language Learners in engineering demands further exploration.

**Limitations**

This work contributes to both the literature in engineering education and learning in academic makerspaces. While we intend to highlight some of the benefits of design-based programming in these spaces for engineering students and underrepresented groups, we are cautious about the claims we make. Given the qualitative nature of our work, we do not intend to generalize our findings to a larger population or identify factors that cause one outcome or another. Rather, our intention with this work is to give salience to the individual experiences of engineering students in these spaces and understand how these experiences impact their development of an engineering identity. Given the small sample and the short period of time we spent observing our participants, we cannot make claims suggesting that what we observed will have long-term effects. Nevertheless, we discuss the findings in this work contextually, with an understanding that the goal is not to generalize or replicate, but to explore and further understand the constructs we investigated.

**Conclusion**

In our study, the framework we developed allowed us to investigate the experiences of undergraduate first-time IDC participants in three different cases within the same general context. In answering our research question, we attempt to extend the work of Stevens and colleagues on undergraduate engineering identity development and discuss the implications for engineering students in the early years of their engineering programs and underrepresented groups in engineering such as women and English Language Learners. As discussed in Stevens et al. [13], several engineering schools do not identify their students as "engineering students" until they are formally accepted into their programs, after their sophomore year. By this time, changes in engineering identity, in terms of ADK, identification, and navigation, have shown to impact students’ decisions to stay or leave the engineering pipeline. Our work, focusing specifically on the experiences of undergraduate students, contributes to this line of research by illuminating some of the ways in which academic makerspaces can provide those engineering experiences identified as critical in engineering identity development for undergraduates in their early years. Furthermore, our work highlights how the design of engineering-based programming in academic makerspaces have the potential to provide access to participation to women and students who belong to language minorities. The IDC on which this study focused, arguably provided those experiences, though to varying degrees due to accidental group dynamics. We then argue that through intentional programming where undergraduate students in their early years are offered opportunities to work closely in meaningful engineering tasks with experienced students in the upper levels, makerspaces can serve as formal and informal spaces where engineering identity development can be fostered through active participation. Given the limited, yet
importance of some of our unintentional findings, we also contend that further research is needed vis-à-vis learning in these spaces for underrepresented groups such as English Language Learners.
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