University Makerspaces: Opportunities to Support Equitable Participation for Women in Engineering

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Abstract
Undergraduate women are more likely than their male peers to leave engineering majors because they do not feel that they belong in the engineering classroom. The growth of university makerspaces provides a potential opportunity to establish new patterns of interactions that provide female students with a sense of community. But we cannot realize this potential to retain female engineering majors, due to our limited understanding of their sense of community in these new university makerspaces. A critical examination of how females experience community within makerspaces through an equity lens is needed to identify what interventions are needed to facilitate the successful participation of a diverse student body. During a 13-month qualitative study, we performed 27 interviews with undergraduate female university engineering students and leaders of university makerspaces, and engaged in participant observation of university and independent makerspaces to identify ways to support and limit a sense of community among female students. Our findings inform design principles for university makerspaces to support a sense of community including supporting project assessment, member assessment, perspective taking, signals of approachability, structured help-seeking, and credentialing. Theoretically, we contribute an emergent framework for understanding what mechanisms undergraduate women take into account when evaluating their sense of community in makerspaces.

Keywords: makerspaces; university makerspaces; engineering education; sense of community; gender diversity; design; design communities; equity; women in engineering

1. Introduction

In order to develop a workforce that can develop technological solutions to complex global problems, such as climate change and disparities in healthcare, we need to attract and retain undergraduate women majoring in engineering because they bring diverse perspectives to solving these complex issues [44]. While the number of females and women of color enrolling in engineering programs at four-year universities are increasing [2,7], women are still more likely than men to abandon their engineering majors [12]. Engineering education researchers identify female students' lack of a sense of community as a primary reason that women leave their respective engineering fields [37].

While many approaches, such as hiring female role models [7], community diversity training [28,51], and design thinking [49] have been adopted in the classroom to motivate diverse student participation, few approaches focus on the social infrastructure needed to establish a sense of community among marginalized groups. Supporting a positive sense of community is imperative given in growing number of university makerspaces where engineering majors attendance is often required [66]. Participation in university makerspaces provides the opportunity to build technical skills while seeking advice and working alongside a wide range of engineering experts, leaders, and peers [11,44]. However, because university makerspaces must serve a large and diverse population including undergraduates, graduate students, and faculty, makerspace leaders face unique challenges with managing the complex interactions that take place in an informal community of learners.

University makerspaces are places that support physical collaboration and often require students, through the engineering curriculum, to utilize high powered tools, interact with others in the space, and engage in activities of "making" or "tinkering" [38]. Universities around the United States have begun to put greater investment in developing makerspaces – building new spaces, purchasing tools, hiring staff, and developing programs [11,26,38]. Due to ABET accreditation requirements, many undergraduate engineering curriculums often require students to enter university makerspaces as a part of their engineering education to learn hands-on design processes [27,66]. Unlike other university spaces, like classes where work and interactions are highly structured around classroom activities or lectures, students in university makerspaces interact with each other informally with intermittent guidance from the makerspace leaders. It is this opportunity for informal interdisciplinary collaboration and hands-on 'making' or 'tinkering' in a shared space that categorizes our study context under definition of makerspaces [38]. Despite the greater investment in university makerspaces to achieve academic outcomes, our understanding of how a sense of community is developed in these spaces is limited, particularly for female students in engineering majors.

Studying female students' experiences in university makerspaces can provide us better insight into how to design these spaces to support a sense of community, thereby retaining our much needed female engineering population [39,59,62]. Through a qualitative study involving 27 interviews and participant observations of students and leaders in makerspaces, we address the following research question: *How does the design of university makerspaces support or limit a sense of community for female engineering majors*? Our contributions include 1) an emergent framework of how female engineering students develop a sense of community in university makerspaces and 2) design implications for university makerspaces to support a sense of community among female engineering students.

2. Related Work and Theoretical Development

In order to understand how makerspaces in university settings can be designed to support a sense of community among female engineering majors, we build on related work around female retention in engineering, equity in makerspaces and engineering education, and psychological factors in developing a sense of community.

2.1 Female Student Retention in Engineering

Even though the number of females enrolling in engineering programs at four-year universities is increasing [2,7], women are still more likely than men to switch to non-engineering majors [12]. Reasons include reduced self-efficacy, stereotype threat, and disappointment with engineering courses [13,42,45,55]. While women in engineering enter the field with high levels of self-efficacy—defined as the belief in one's capability to organize and execute actions necessary to manage prospective situations, research finds that their engineering self-efficacy declines significantly during their first year in engineering and never reaches the same level [43]. Stereotype threat, defined as the social-psychological threat that arises from a situation for which a negative stereotype applies to the student, is one reason for reduced self-efficacy among female engineers [7,13]. In a study of stereotypes, people reported perceiving females with strong engineering skills as unnatural rather than something to be celebrated. These perceptions were particularly pronounced for women of color [22]. As a result, female students come to believe that they are inherently worse at or not fit for engineering [7,13]. Furthermore, female students report disappointment with engineering classes which heavily rely on stereotypical male examples such as cars and sports [10,42]. Building on the work of Margolis, Fisher, and Buechley, research on diversity in STEM fields finds that women do not join STEM communities because they are disinterested in the existing engineering culture, curriculum, and projects.

In addition to disappointment with classes and lack of confidence, researchers have identified a deeply engrained masculine culture in academic engineering settings. This masculine culture results in females feeling a lack of a sense of a community which has been shown to influence academic achievement and social acceptance [31]. A lack of a sense of community is yet another reason for women to leave their engineering major [22]. Previous work on how marginalized youth form a sense of community in academic contexts describes the particular importance of material resources (physical environment and organizational structure), relational resources (relationships with others), and ideational resources (an individual perception of self) [3]. While previous literature points to the importance of accessing these resources, we take an in-depth qualitative approach to identifying how university makerspaces can more equitably support access to these resources to support a sense of community for women in engineering.

2.2 Makerspaces and Equity in Engineering Education

University makerspaces provide a unique community context to encourage women to stay engaged in engineering by providing a place where students have the opportunity to identify as engineers by physically applying classroom lessons and developing relationships with engineering peers and leaders [11,20,26,38]. The popular Maker Movement, along with increasingly available rapid prototyping tools (e.g. 3D printers and laser cutters), has led to the growing construction and renovation of multiple university design facilities [66]. Educators are hoping these places can support not just using tools, but also learning how to apply design skills and work collaboratively with peers [66].

However, creating communities that support equitable access to academic opportunities is challenging. Addressing these barriers in university makerspaces requires both understanding the history of the making community with its roots in white, male, middle-class activity [64], and the history of marginalized students hoping to get involved, such as how their identity and personal experiences shape their relationship with the community [4,25,63,64,68]. Over the years, conversations around creating diverse communities have moved beyond identifying ways to expand membership to critically questioning and addressing how environments systematically marginalize certain groups from participating and succeeding [47,63,64]. In other words, educators should shift their focus from why certain groups are not interested in joining a community to why the community is not welcome to certain groups [47].

Increasingly, researchers seek to understand how makerspaces can support engineering activity among women [10,21] and other marginalized groups including youth [19,29], persons with disabilities [30,33], and low income populations [57]. For instance, work has been done in high school makerspaces, showing how the use of electronic textiles can break down traditionally masculine barriers to female participation in computing [36]. Others describe using design thinking methods to encourage female members to develop a positive identity with making [49]. Work on equity in education highlights that minority and marginalized students benefit 1) from seeing others with similar backgrounds in the community, 2) when teachers take the time to understand student personal backgrounds and how they might affect academic performance, and 3) when teachers actively hold discussions on social justice topics as part of the curriculum [47].

However, the majority of work on developing diverse makerspaces has focused on non-university contexts, such as independent makerspaces or high schools. In non-university contexts, community members often develop a sense of community by having a greater say in the spatial structure, function, and programming [32]. In contrast, academic makerspaces are usually developed by engineering educators and administrators with less input from students [66]. Unlike high school makerspaces, university makerspaces or more likely to include high-powered tools that can be particularly intimidating to members who do not feel welcome due to lack of experience [8]. Unlike independent makerspaces, participation in university makerspaces is often required by the engineering curriculum as accreditation commissions have increased attention to hands-on learning [1,66], making it even more necessary to design these spaces in a way that supports equitable participation. We seek to understand the community mechanisms by which female engineering students evaluate their ability to participate in engineering activity in university makerspaces.

2.3 A Theory of Sense of Community

We combine literature on equity in engineering and how sense of community is developed to examine how university makerspaces are succeeding or failing at supporting a positive environment for female members. Inspired by related work studying sense of community in academic settings [6,50], we adopt psychologist's McMillan and Chavis's theory of how sense of community is developed, which they outline through four main attributes: membership, shared emotional connection, fulfillment of needs, and opportunity to have influence [46].

Membership is feeling the right to belong because one's characteristics fall within the boundaries of how the community defines itself. Those who fall within the boundaries of membership tend to have stronger emotional safety in the community, identify with others in the community, are more personally invested in the community's success, and develop common norms of communication with other members. A *shared emotional connection* is having members be able to relate to each other through shared experiences and spending time together. Members who have a shared emotional connection are more likely to have positive interactions with each other. *Fulfillment of needs* is the belief that one's needs will be met by resources received through membership in the community. Fulfillment of needs not only allows members to grow, but also increases affinity between members because people tend to be attracted to those who can provide benefit in some way. Finally, *influence* is a sense of mattering, being able to have influence on the community, and allowing the community to influence oneself. This framework provides a lens through which to understand how female engineering students evaluate their sense of community in university makerspaces [46].

3. Methods

Research on equity in engineering highlights the importance of understanding the lived experienced of marginalized members, and calls for greater work in this area to identify how engineering spaces can be designed to support more equitable participation [64]. In order to understand the experiences of female engineering students in university makerspaces, specifically a sense of community, we take a qualitative research approach to understand the experience of female engineers through interviews and observations. We seek to both describe participant experiences as well as suggest design implications for how makerspaces can improve these experiences.

3.1 Participants and Sites

We performed semi-structured interviews with students and makerspace leaders as well as participant observations of makerspaces. Overall, we performed 27 interviews, including 17 interviews with female engineering students and 10 interviews with makerspace leaders. We also engaged in participant observation of 5 different makerspaces. The 17 female university engineering students (self-identified as 2 Hispanic/Latino, 4 Black/African American, 3 Asian/Asian American, 8 White/Caucasian) were from six different public and private universities (see Table A in appendix). The 10 makerspace leaders represented five different spaces (2 public, 1 privately-owned, and 2 university-based) (see Table B in appendix). By "public," we mean free and open spaces such as those located in community libraries; by "privately-owned," we mean independently owned makerspaces that require membership and/or fee to participate; by "university-based," we mean makerspaces in universities. Interviewing leaders and visiting spaces allowed us to access and interview people who intentionally promoted gender inclusivity and sense of community in makerspaces, helping us learn about their successful practices and challenges. We also performed participant observations in five makerspaces in the greater Chicago area to observe different approaches to building communities. Observations were critical to our understanding of how leaders and peers engaged in the spaces, allowing us to collect data unbiased by student and leader reflection.

3.1.1 Students

All of our student participants were female engineering students who were working or had worked on a project in their university makerspace. Participants self-identified as people who worked on at least one project in a university makerspace with majors including chemical engineering, mechanical engineering, biomedical engineering and engineering design. It was important for us to interview students who remained in the engineering curriculum to understand their experiences and gain knowledge of what successful practices encouraged them to stick with their engineering major. We recruited participants from November 2015 to July 2016 who had a range of experiences in the makerspaces prior to starting their university education. Some participants had a parent or family member that introduced them to makerspaces, while other participants had never seen or heard about makerspaces until their first year in university. Participants were recruited through email, social media, and outreach to extracurricular student groups related to engineering such as the Society of Women Engineers, the National Society of Black Engineers and Design for America. We posted on university engineering clubs, design emailing lists, and college engineering Facebook groups in 7 different universities across the country. When recruiting, we noted that we were looking for female engineering majors who were interested in telling us about their experiences in university makerspaces. In the recruitment materials, we defined a makerspace as "a physical place that promotes interdisciplinary collaboration, and requires hands-on engineering to utilize both the tools in their surroundings and the people in the space to engage in the activity of 'making' or 'tinkering'" [38]. All student participants were offered a $5 compensation for a 30-minute interview.

3.1.2 Makerspace Leaders

To understand the perspective of people who have greater power and responsibility to influence what norms are introduced, we recruited makerspace leaders by identifying makerspaces who intentionally promoted gender inclusivity in engineering as part of their core values or mission statement. Makerspace leaders were not compensated for their participation in a 45-minute interview. Five of the makerspace leaders we interviewed were female and the other five were male. They were leaders of either a public makerspace, a privately owned makerspace or from a university-based makerspace (see Table B in appendix). We felt it important to include the perspective of leaders to gain a more complete understanding of the key stakeholders involved in community development, especially because the relationship between students and leaders affects student experiences, and because community interventions are typically implemented by the leaders.

3.1.2 Makerspaces

In addition to interviewing these makerspace leaders, we also observed activity in their makerspaces. The observed makerspaces were located in the greater-Chicago area and represent 2 university makerspaces one with an average of 50 participants and one with 25 participants at the time of observation, 1 private makerspace with 25 participants, and 2 public makerspaces one with 50 participants and another with 100 participants (see Table C in appendix).

3.2 Data Collection

We took a qualitative approach to best understand *the lived experiences* of members, similar to related research on maker communities [33]. Interviewing students provided an opportunity for students to describe how they perceived their experiences, and reflect on how these experiences influenced how the felt and behaved. Some student participant interviews occurred in person at their respective universities (6 students) while others took place over Skype (11 students). Participant observations provided an opportunity to observe behavior, unfiltered and unbiased by how participants perceived situations. Observations also allowed us to observe independent makerspaces that marketed an intentional focus on supporting gender-diversity, which may provide implications for what practices could be adopted in university settings.

For university engineering students, we asked questions about their experiences in the space and with the programming as they pursued their project work (see Appendix B: Student Interview Protocol). We asked students to think back to their first encounter with a makerspace, what influenced their first impressions, and if they sought out help from others in the space. We also asked students to describe if they felt a sense of community within their makerspace and what they thought could be improved to create a better sense of community. Interviews with students were 30-minutes on average.

For makerspace leaders, we asked questions around what decisions they made to develop the community culture, how they decided to physically organize the makerspace, and changes they have seen over the years with respect to gender diversity (see Appendix C: Leader Interview Protocol). For example, we asked how they sought to support inclusion in their programs and initiatives within the makerspace. We asked leaders to describe a specific time when they felt their program did a particularly good job at creating a space where females felt well supported and what factors contributed to this. We also asked leaders to describe what they consider are challenges for female students that are a part of their space, and what significant improvements they have seen over the years with respect to the diversity of the students that take part of their space. The makerspace leader interviews lasted 45-minutes on average. Upon completion, both the student interviews and the leader interviews were transcribed.

We conducted 9 hours of observations with five makerspaces in the Chicago area to observe different approaches to building community. The times of observation were representative of typical activity in the space with members coming and going at certain times of the day but the space was always occupied with participants working on a range of projects. Of the 9 hours of observation, this included 2 hours observing one university makerspace, 1 hour observing another university makerspace, and 2 hours observing two public and one private makerspace each (see Table C in appendix). A makerspace leader gave a formal tour of the facilities before each observation. Notes were taken during the observations with no interaction with participants in accordance with our IRB.

3.3 Data Analysis

We performed a thematic analyses [58] through three rounds of coding. During the first round of coding, one researcher read over the interview transcripts and field notes, making a list of general codes related to how participants evaluated their sense of community. The initial round of coding produced a list of 23 codes (e.g. interaction with leaders, collaboration, intimidation). In the second round of coding, we clustered codes together into the broad themes developed by McMillian's and Chavis' related work [46]: membership, shared emotional connection, fulfillment of needs, and influence. For example, Asking Questions, which we defined as *being able to articulate questions or design problems to leaders* and Navigating Questions, which we defined *knowing who or what resources to approach depending on the question*, were grouped together as "fulfillment of needs". We then performed a third round of coding to identify sub-categories that were unique to our university makerspace context. For instance, the broader theme of membership was divided into the sub-categories of project assessment and member assessment to reflect to two distinct mechanisms by which students determined whether or not they could join the makerspace community. Lastly, we re-assessed the theme titles to insure they most accurately captured the data. For example, we re-labeled "fulfillment of needs" to "structured help-seeking" to outline how students' desire to develop making skills (need) was primarily hindered by a lack of understanding for how to do so (structure for help seeking). All student and leader identities have been kept anonymous.

4. Findings

Our findings identify six mechanisms to address community engagement challenges that disproportionately affect female engineering students. Inspired by McMillan and Chavis's framework [46], the six mechanisms describe how female engineering students evaluate their sense of community in university makerspaces and opportunities for improvement via 1) Project assessment, 2) Member assessment, 3) Perspective taking, 4) Signals of approachability, 5) Structured help-seeking, and 6) Credentialing. Our interviews and observational data identify supportive and unsupportive ways that university makerspaces instantiate these mechanisms. While we present six distinct mechanisms, we acknowledge that they are not mutually exclusive but rather interrelated.

4.1 Project Assessment

Understanding community boundaries is a key way people evaluate their sense of community because it helps people determine who qualifies for *membership* and how to obtain it. Supporting project assessment helps address issues of equity because female engineering student self-efficacy significantly declines as they proceed through col-

Sense of Community [45]	Definition [45]	Makerspace Mechanisms	Definition	Examples of makerspace practices
Membership	Feeling that one belongs because one's characteristics fall within the boundaries of how the community defines itself	***Project Assessment***	Being able to determine what projects are allowed and how to get involved	- *Supportive:* Showcasing on the website and during tours range of projects being built in makerspace - *Unsupportive:* Limited explanation of range of pathways for getting involved
		Member Assessment	Being able to determine who would be accepted by the community	- *Supportive:* Having hair ties and smocks to reduce physical barriers for participation - *Unsupportive:* Leadership not reflective of diversity of makerspaces members
Shared Emotional Connection	Being able to relate to other members by sharing experiences and time together	***Perspective Taking***	Having community members and leaders respect one's identity and perspectives	- *Supportive:* Socialization opportunities where members can develop stronger bonds needed to facilitate understanding and respecting other people's experiences - *Unsupportive:* Members talk openly about how diversity initiatives are an inconvenience
		Signals of Approachability	Believing that community members and leaders will be receptive to requests for help, feedback, advice, and conversation	- *Supportive:* Members volunteer to provide guidance for those with less making experience - *Unsupportive:* Leaders do not try to get to know new community members
Fulfillment of Needs	Believing that one's needs will be met by the resources received through membership in the community	***Structured Help-Seeking***	Being provided a structure of how to seek help in order to develop skills and learn community interaction norms	- *Supportive:* Having posters next to machines showing a name and picture of who to ask for help - *Unsupportive:* Public and verbal shaming of new members who do not yet understand makerspace norms (such as how to ask for help)
Influence	A sense of mattering, being able to have influence on the community, and allowing the community to influence oneself	***Credentialing***	Having members and leaders acknowledge one's expertise in order to participate	- *Supportive:* Being able to be trained and acknowledged as an official leader or helper - *Unsupportive:* Assuming women are unskilled in engineering and automatically placing them in non-engineering project roles

Table 1: Mechanisms for creating a sense of community in university makerspaces include project assessment, member assessment, perspective taking, signals of approachability, structured help-seeking, and credentialing.

lege, often causing them to disproportionately assume that their work is not good enough compared to their male peers [43]. We found that there was a misunderstanding between how students and leaders determined project membership requirements, which exacerbated the extent to which female students negatively evaluated their work. While makerspace leaders believed that a wide range of projects were appropriate for the space, female participants felt their projects did not qualify given existing public information on websites, posters, and brochures about their university makerspaces. For instance, these public-facing sources tended to feature highly polished pieces such as a steel frame for the university's solar car team. Participants described preferences for seeing examples of others' work that represented a wide range of project types (e.g. soft goods, consumer goods, socially conscious designs) and materials (e.g. textile-based, wood-based) at different stages of the design process (e.g. ideating, prototyping, testing), as well as seeing pathways of how others got involved, would help them to more accurately evaluate whether their own work belonged in the space.

For instance, one third year student felt that her engineering project developed during her human-centered product design class to improve the way college students washed their dishes to reduce water and food waster was not advanced enough to merit being worked on in the makerspace. She described a discussion she had with her three other teammates, who were also female, and how they each questioned if their project idea, still in the prototyping stage, would be considered a legitimate project. Ultimately they decided to discontinue their work, despite their desire to join the makerspace environment to continue working. Instead, this participant chose to join her male friend's group's project only to realize that her original dish washing project was more advanced.

"It's so funny because once I got there, I realized like our [original] project was so much further along than anybody else's, and we would've worked so much harder than anyone in there [if we continued]."

Highlighting multiple pathways to getting involved would show that the space welcomes people of different expertise levels and project points and types. For instance, one makerspace on the West Coast showcases different types of projects being built in the space, from exploratory projects like taking apart a toaster to design projects like building an arduino device, demonstrating to members the range of activity accepted in the space. In addition, another independent makerspace in the Midwest intentionally placed sewing machines in a prominent position to show that they valued sewing projects, which has been shown to attract more females in the making community [10,54].

Others who had not defined a project yet, but wanted to participate, found that their university makerspace did not provide transparent pathways to becoming a member. For instance, participants described how makerspaces would put out an open call for participation, but provide few opportunities to initiate membership.

"Like they tell you these great benefits, and then I'm like how do you get involved?...Then they'll answer 'Oh you come up with a project and then you apply online,' and that's like the only answer I've ever gotten. And then I'm just like, 'I don't have a project. I just want to get involved.'"

Similarly, another participant asked, *"Well where do I start? And that's at least what keeps me out of the [university makerspace] -- I don't know how to 3D print, I don't know how to use any of those things."*

Defining a project is one of the most difficult parts of the design process because it involves being able to successfully traverse an ill-defined process of ideation, scoping, and planning [41]. The expectation to create a project and learn basic making skills before requesting membership can be daunting, particularly for members who might have already lower engineering self-efficacy.

Aware of this barrier to participation, makerspace leaders explained that if a student wanted to use a tool, like the laser cutter, the student could come in with their CAD file and then ask for advice. And if the student did not know how to make the CAD file, then the makerspace leaders could give a tutorial. However, few participants knew that this was a possibility, and chose to not enter the makerspace unless they had explicit permission from a professor or an existing friend who was a member.

Students who enrolled in classes which explicitly relied on the university makerspaces found it much easier to continue working in the makerspace outside of class and in the future. One student taking an introduction to biomechanics course described that she appreciated how the professor and teaching assistant provided office hours in the makerspace so that the students could gain familiarity with the tools and general environment with a mentor nearby. She described how this initial experience her first year gave her the confidence to later work on larger scale projects involving the water jet cutter and the CNC machine.

Others described getting involved in the makerspace by having an established relationship with someone who worked there:

"I've worked on some of my design projects in there, and that's just because one girl in my team has residency, so she'd just bring us into [the makerspace] and we'd stay there and do work [with the machines]."

Having a friend who already had an established relationship with the leaders and others working in the space helped ease her concerns and factors of intimidation by being introduced to others by her friend. However, having friend connections in the space as a primary pathway to involvement could exacerbate existing gender homophily effects – the tendency for people to attract those that are similar to themselves.

Scaffolding involvement, whether through a class, workshop, or formal and informal training, can provide pathways for students to get involved in their university makerspace. Scaffolding involvement is important because participants described being confused about how to get started or participate in their makerspace. Participants described wanting additional resources that could have helped them determine what was an acceptable project with respect to the level of fidelity and project type.

4.2 Member Assessment

While participants knew that women were technically allowed in the makerspace community, they described the importance of seeing indicators that the university makerspace valued the presence of women. Seeing physical supports and female role models helped them determine who would be accepted in the community and whether or not to join. Supporting member assessment helps address issues of equity because female engineering students are more likely to question their identity and acceptance in communities where they are the minority [22].

For instance, some participants appreciated seeing or expressed wanting physical indicators that reduced barriers to female participation, such as providing smocks to protect certain clothing or hair ties for long hair.

"I think it would be better if they have like smocks or something that you can wear because usually a lot of times I wear skirts or shorts or whatever and then it's like oh man I can't go in, I forgot. And I live all the way on the opposite side of campus, so it's like it's just like a really big hassle if I had to [go home]."

Being expected to wear pants, closed toe shoes and/or remember to bring the right hair accessories became an extra burden on students who felt that dressing more "feminine," such as in dresses or leggings, was an important part of their identity and how they related with their peers. Students that have worked in shops where materials, like smocks, hair ties and spare closed toe shoes, were made available expressed how these small gestures made a difference in how they felt when entering the space.

Participants also described appreciating having female leaders in their university makerspace because it helped to balance out the sometimes negative experience of working in a predominant masculine culture.

"When a girl would ask something or do something, the reaction would seem worse than when a guy would…This isn't the most comfortable thing, [but] of course you have to do it cause it's your grade."

While we have no way to verify if this difference in treatment is true, having female leaders provides an alternative way for members, who may feel uncomfortable approaching a predominantly male leadership, to seek advice and help. For example, one student noted, *"the director of [the makerspace] was female and the leading professor of the engineering design course was also a woman…which I think helped a lot".* Another student, when remembering hearing that a woman was going to be hired for her makerspace, described how she looked forward to asking her questions: *"I am going to go to her all the time."*

Observations in two local Midwest independent makerspaces revealed the importance of not only having female leaders, but female leaders with different backgrounds. For example, we observed a leader empathizing with female students from low-income backgrounds by sharing a story of exploring engineering by taking apart home appliances. The leader later described during her interview how she had been a part of a similar community outreach program and wanted to share with her students her story of getting involved in engineering. Through sharing her experiences, this female leader went beyond instruction on how to use the tools, allowing her students to feel a personal connection to her as a role model.

We found that acknowledging this multi-faceted aspect of membership was particularly important to participants who identified as more than one type of minority. For instance, one freshman, African American student described how multiple identities factored into how comfortable she felt with asking questions:

"I don't want to be that freshman but even more that girl that doesn't know what she's doing in the lab."

The intersection of different identities, such as being a female engineer, a woman of color in engineering, and/or a female freshman in engineering, can all compound to influence how one perceives oneself in relation to other community members [16,47]. Therefore, in order support a more positive sense of community among women, our data suggests the importance of providing examples of who are valued members and supports that reduce barriers for these members to participate.

4.3 Perspective Taking

Creating a culture that values diversity becomes imperative as universities seek to create and maintain a diverse engineering cohort. Perspective taking can help create *shared emotional connections* between demographically diverse peers by providing opportunities to understand and acknowledge female experiences in engineering. However, perspective taking for marginalized groups is often difficult to foster in environments where there is a dominant population, such as the traditionally masculine environment of engineering [8], where people often do not realize that women often deal with uncomfortable interactions on a day-to-day basis. Supporting perspective taking among divers community members helps address issues of equity because female engineering students are more likely to experience overt sexism and/or micro-aggressions that negatively impact their experience in the community [61].

While we observed few successful interventions in university makerspaces that supported perspective taking, female participants found that being able to socialize and develop friendships with male peers was a positive first step. For instance, a student from a small college in the south described how she felt more comfortable sharing her experiences with other members once they started holding external programming initiatives that encouraged socialization. These programming initiatives included having "popcorn days" where the makerspace leaders set up a popcorn making station, turning the university makerspace into a theater after hours to build connections between the arts and engineering, and having weekly show-and-tell days where students could share their progress and failures.

However, the opportunity for positive social interactions that could lead to perspective taking is often inhibited by the existing unwelcome conversations among peers. For instance, a student from a medium sized university in the Midwest described how she felt uncomfortable working in a community where issues of gender diversity and female safety were not taken seriously.

"One day people were complaining that they couldn't use certain words in [the makerspace] anymore because they were sexist. Like, 'Yea, you can't even touch a girl anymore, it's considered assault.'"

Participants described coping with these uncomfortable moments by trying to ignore the comments, actively moving to a different location in the makerspace, and/or having conversations with friends and family afterwards. Participants even described sacrificing their own self-comfort to try and help change the culture for other female members.

"There was a moment last year when I called my mom and I was like, 'I kinda don't want to work here anymore, like, I feel uncomfortable.' But, then I was like, no, I want to make it more comfortable for someone else, so it's like balancing those feelings."

As described by a female engineering student working on a project that helped design a device for a patient at a rehabilitation center involving wheelchair assistance, the *"tech bro-y"* culture that has traditionally existed in engineering spaces can alienate or distance female students because the values promoted often do not align with those of women who want to become involved [21,53].

While makerspace leaders express trying to create a more inclusive space, their efforts were undermined by broader cultural forces that were harder to address than setting rules around language. Ultimately, participants hoped that male peers would come to understand and respect the challenges of being a woman in engineering, rather dismiss or make fun of it. However, perspective taking is a complex process that often needs specific training and intervention to be done well [9,23].

4.4 Signals of Approachability

When leaders and members show signs that they are approachable and supportive to requests for interaction, participants were more comfortable socializing and asking for help. Asking for help and initiating conversations puts students in a vulnerable position, especially for minority students who might perceive larger power dynamic between them and leaders. By signaling approachability, leaders and members can provide greater opportunities to develop *shared emotional connections*, therefore reducing anxiety around seeking help and initiating new connections. Supporting signals of approachability helps address issues of equity because female engineering students are more likely to question if others accept them when they are the minority [34].

Developing these norms around approachable interactions may need to initially come from senior members in the community, whether older students or leaders, who could volunteer to provide or signal willingness to help even when it is not required. For instance, one leader who noticed that only particularly outgoing students were asking questions described a low-fidelity intervention where she wrote "Ask me for help" on a piece of paper and taped it on her back. Another participant described how the simple act of leaders walking around rather than staying in their office encouraged students to ask questions.

For instance, when thinking about her first year in her university makerspace, one first year student remembered the fear of asking for help the first time, wondering, *"Are they going to be disturbed?"* The tentativeness and lack of confidence to ask for help can lead to safety concerns for the student and others. Another participant described that when debating internally whether to ask a question, she compared the costs of getting help and the fear of making the wrong impression. Despite her acceptance into a highly selective engineering institution, she still struggled to feel accepted.

"It's still weird though asking about tools because you don't want to be the one who doesn't know how to use this. But, then like definitely it's important to ask before you hurt yourself. And after I heard that, I asked more…But, before I ask there's always that thought in my mind, like I should know how to use this, and then I don't want to ask."

Unfortunately, various participants described having a negative experience asking help for the first time, which can make a lasting impression on whether women comfortable asking for help in the future or returning to the space. For instance, one student described how it was intimidating when other makerspace trainers seemed irritated when approached, particularly when questions came from female members of the community.

The camaraderie established between makerspace trainers and certain students further exacerbated these divisions as some students felt that there were favorites within the space (one student referred to them as “stars”) that created subdivisions within the community. Students felt that leaders should help everyone feel like they are valued and worthy of instruction rather than only a select few. While it is natural for leaders to develop stronger relationships with student groups that are more active or present, students who often feel more excluded to begin with, such as women in engineering settings, may be less likely to actively engage, and therefore, less likely to become part of this in-group.

Others found the academic context of the makerspace also limited approachable interactions between members. While some participants expressed that they wanted to get to know peers working in the space, they found that most people just wanted to finish project assignments and then leave. While we acknowledge university engineering curriculums are challenging and time-consuming, establishing a culture where conversation and social support are encouraged would help students develop connections with more people who could provide advice, help, and best practices. For instance, a participant described how she felt more welcome when a senior member stepped in to answer her questions and walk her through using tools when leaders were busy.

Socialization, peer support, and healthy relationships with leaders are needed for communities to prosper [65]. Participants described how being able to approach members and leaders for help were a crucial aspect of their community onboarding experience.

4.5 Structured Help-Seeking

Leaders must not only feel approachable to students, but also be able to provide support effectively. Students participate in makerspaces in order to *fulfill intellectual needs* of applying classroom knowledge and interacting with experienced others [8,37]. Supporting structured help-seeking helps address issues of equity because it creates clearer paths to developing mentor-student relationships, which are particularly significant to female students [56].

First, leaders felt they could be more helpful and patient if students came to them “prepared.” One student described how the leader she felt most connected to in her makerspace was the one that was very clear about what processes had to be done in order to ask a question. That particular leader always wanted to the student to have made a lo-fidelity prototype or drawing prior to approaching the leader and the student found this particularly helpful in accessing help. However, for others, participants’ lack of knowledge on how to be prepared limited their ability to successfully interact with leaders in order to develop skills.

For instance, one participant described how one of the first times she asked for help, the leader admonished her for not coming prepared with the right information and materials.

“*He was just like ‘What do you want? Like you need to show me blah blah blah.’ And my reaction was like, I'm sorry, it's my first time asking you a question, like I don’t know. There's not like a poster on the wall that sets a precedent of how I'm supposed to ask you a question…Now I have to figure out how to approach this person without being like just completely shot down.”*

While learning what to bring for help-requests was useful, she expressed that this unfriendly interaction deterred her from seeking help in the future. Another participant later in her undergraduate engineering program described how first year students often forgot to even articulate what they wanted help with: “*Don’t just say, hey we have a project. And expect a response.”* If leaders prefer when questions are asked a certain way, participants described desiring clear hints or scaffolds that would help them understand these expectations beforehand.

Others even described that when they first joined the makerspace, they had trouble identifying who was a makerspace trainer and whether or not that person was available to give help. To avoid asking the wrong person or bothering someone, participants expressed wanting tools that would help them start to answer the question themselves.

“I don't really know who the trainers are and they look kind of busy. So, I would really rather be able to do it on my own…Even a book where you could read like how to use a tool would be better.”

However, much of the skills that need to be learned in makerspaces, such as using a high-powered milling machine, cannot be easily or safely learned from a book. To address these concerns, participants described how it might be useful to have designated short refresher courses or open help sessions at pre-determined times of the week. For instance, one participant who considers herself a member of a makerspace that offers this feature describes how it helped her develop needed technical skills.

“One of the things that were really helpful for me were the Wednesday hacknights. And those were really cool for me because they were like non-discriminatory in several ways, like you didn't have to have any experience and there were several people there to help you…That's when I felt most like invited into that space.”

Other makerspaces that we observed offered an online sign up tool to reserve 15 minutes of 1:1 help from a leader, therefore reducing the fear of having to request for help verbally and knowing whether or not the leader is available. During an observation of a Midwestern public makerspace housed within a library, we saw posters next to the 3D printing stations to help students trouble shoot based on common mistakes that had been previously made by others. This poster allowed students to explain how they tried certain approaches before resorting to asking for help. Another space included photos of makerspace leaders next to tools, so that students knew whom they could ask for help. Help-seeking tools could help students be more prepared and confident in developing relationships, and would also help leaders manage a more efficient way of providing help.

4.6 Credentialing

Having a sense of community not only involves how the community influences members, but also how members are able to influence the community. For example, participants described the value of being able to prove that they had technical skills through official credentials (e.g. official makerspace trainer), so that male peers would be more likely accept them as fellow engineers. Supporting credentialing helps address issues of equity because female engineering students are more likely experience stereotype threat and question if they even have engineering skills to participate [7].

Female participants described challenges with having community influence because peers often did not acknowledge their engineering expertise. These negative experiences often occurred during teamwork when team members automatically assumed female team members were less skilled in making. For instance, one participant in an all male engineering team described having to assert her skill level.

“It was always like everything was questioned. It was really interesting because I was the only person that had shop experience out of all of them. And they were still just like, ‘I know what I'm doing,’ and I'd say 'You’re drilling in reverse, it's not going to work’…You have to be a lot more assertive in order to use the machines when you're with mostly just guys.”

In this case, the participant had the skills needed to use makerspace tools and felt confident in her ability; yet stereotype based biases still limited her ability to participate fully.

Another student who also had building skills had to learn to be more assertive after a male team member refused to share project building responsibility. She explained how, since then, she has learned to insist on having building responsibilities during team projects.

“My dad builds boats. Like I grew up in a woodshop. I took shop class in high school. Like, I came here, and this kid in the first day of class was like ‘I'm going to be the builder for this group,’ and he just kind of wouldn’t tell us when he was going to be in the shop. I would show up when the prototype was close to being done and I hadn't learned anything…So ever since then, I've been pretty into getting my shop time…I think it was such a missed opportunity my freshman year, and um yeah, that was so sad.”

Another participant described how she observed her female peers also taking on team responsibilities unrelated to the makerspace—*“Girls end up doing the writing parts of the project, so they don't get to be in the shop.”*

One participant of a makerspace described how these types of negative experiences motivated her to go through the training to become an official student helper in the space.

“A lot of my experiences in the shop, like I guess I felt very intimidated by the people in there, and I kind of wanted to be like a shop trainer that someone could come to and not feel scared to ask a question.”

She felt that by having this official status, it would not only encourage her male peers to see her as qualified, but also help other novice female members develop the confidence to acquire these skills and credentials themselves. Similarly, another participant described wanting to have a certificate that proved her expertise and that “*no one could take away.”* While such indicators might make some difference in how peers perceive females in the community, they would have to be repeatedly defended by respected community members in order to be effective.

We emphasize that the mechanisms outlined in this framework focus specifically on challenges that *disproportionately* affect female engineering students' sense of community in makerspaces. For instance, while both men and women may suffer from low engineering self efficacy, women are *more likely* to have reduced confidence in their work quality and sense of belonging. Therefore, in order to address issues of gender equity, interventions need not be overtly female specific, but must primarily address challenges that disproportionately affect women in engineering. Interventions that address gender equity can also strengthen the community as a whole and provide benefits to all members, in alignment with suggestions for how to design with feminist values [5].

5. Discussion and Design Implications

Our data presents six mechanisms by which female members of university makerspaces evaluate their sense of community: project assessment, member assessment, perspective taking, signals of approachability, structured help-seeking, and credentialing. By contributing a novel framework for understanding what makerspace features undergraduate female students take into account when evaluating their sense of community in engineering spaces, we can further design makerspaces to support members who may not relate to engineering in traditional classroom environments. Theoretically, we contribute to theories of equity, perspective taking, and help-seeking in university makerspaces.

5.1 Designing for Equitable Participation

As the number of makerspaces in university settings continues to grow, it becomes increasingly imperative to design these places in a way that supports the diversity of students who are expected to and who desire to participate. Supporting equitable participation has shifted from just expanding outreach efforts to critically examining the design of the entire community experience [64]. We contribute to literature on equity in making and engineering education by understanding and identifying specific pain points female engineering students face while joining and working in university makerspaces, and outline implications for community designs informed by interview and observation data.

Researchers studying equity in engineering education argue that the way we conceptualize making, including who participates and why, can either restrict or expand pathways to participation. In mainstream culture, making has primarily been considered a white, male, middle-class activity, therefore discouraging participation of marginalized students from working class backgrounds, students of color, and women [64]. Over the years, the making community has taken the issue of diversity seriously and worked to change how we think of making so that it supports more diverse histories, stories, and experiences. For instance, people have developed feminist makerspaces where women-organized sites support female empowerment through hacking [21]. Others have created makerspaces with programs focused on addressing accessibility by pushing for the use of rapid prototyping in Do-it-Yourself Assistive Technologies [33]. Furthermore, public makerspaces that we observed facilitated participation from lower socioeconomic communities by having leaders connect with students from similar backgrounds through shared stories.

While some independent, non-university makerspaces are making strides in supporting equitable participation, many university makerspaces are lagging behind. Our data highlights unique challenges that university makerspaces face in fostering diverse community development. McMillan argued that working for membership provides a feeling that one has earned a place in the group, which also positively influences one's willingness to develop shared emotional connections with others and invest in the growth of the community [46]. Our data highlights a challenge with establishing a sense of membership as participants described the difficulty of developing shared emotional connections when most people in the space are primarily motivated to just finish their homework assignments. Second, unlike classroom environments where a teacher can plan out the day-to-day curriculum for a certain group of students, leaders in makerspaces have to manage a large engineering student population of hundreds of students (both undergraduate and graduate level), while having less control over their activity (different students working on different projects at different stages at different times of the day) and interactions (students interact at any time for different purposes). We find that all of these combined challenges have created an environment where marginalized members, such as female engineering students, are left out and unable to grow personally and intellectually.

Understanding how to design communities that suffer from biases established in larger social contexts is particularly challenging, and has been highly documented in literature on the sociology of communities. For instance, work on the sharing economy highlights racial barriers to participation in terms of where people live [60] and because members often consciously or sub-consciously block requests from certain racial groups [17]. Similar to research on the masculine culture of engineering, work on Wikipedia and gaming communities finds that high instances of men harassing women online deters female participation [14]. We contribute to related work on community development by identifying specific unintended consequences of how these university makerspaces are structured, and providing concrete and feasible ways to improve.

5.2 Scaffolding Participation

Novice learners often have difficulty explaining their thought process and reasoning, which limits their ability to express their needs and approach help-seeking effectively [48]. The history of learning to work in places with dangerous machinery is heavily based in the practice of apprenticeship where a mentor physically acts out a task so that the learner can imitate under supervision [40]. While apprenticeship is considered one of the most effective ways of learning [15], it is not scalable as it requires extended 1:1 interactions with experts. This is particularly difficult in university makerspaces where leaders must be able to support hundreds of students at a time. In these environments, students that are more aggressive or comfortable with asking for help are often more likely to receive the needed training, while students who do not feel that they belong in the engineering community—often women—are less likely to benefit.

Previous work on help-seeking, finds that there are multiple steps to a successful help-seeking interaction including, being aware that one needs help, deciding to seek help, identifying who to seek help from, employing strategies to seek help, and reflecting on the help-seeking attempt [48]. Unfortunately, these steps are not clearly expressed or facilitated, which can cause student-leader conflict and negative help-seeking experiences. While some might argue that "tough love" is a part of learning these norms in engineering education, female participants felt that this way of initiation to be particularly abrasive, turning them off from asking questions and participating in the future. Similar findings have been observed in other male-dominated communities, such as Wikipedia and online gaming [14]. Research on supporting women in computer science finds that instruction through "tough love" is only effective if it is also paired with long-term dedicated mentorship [42].

Related work on soliciting feedback also finds that the way one asks a question can lead to significantly different quality of responses [24]. Researchers find that scaffolding requests for feedback by providing more specific sub-questions promotes more in depth and useful feedback than generic requests (e.g. "Give feedback on this project.") [24]. Similar designs could be tested on scaffolding help requests in university makerspaces. For instance, as described in the findings, one student was admonished by a makerspace leader for asking a question without having the right materials prepared. To mitigate these conflicts, students who want to ask for help, but are unsure how to, could refer to posters or resources in the space that outline what materials to bring and how to word a help request, when approaching specific leaders.

Other potential designs could include posted leader profiles online and offline with information on their professional skills and personal interests. Information on professional skills could help students determine who to ask for help depending on their needs, while sharing personal interests could help students initially see leaders as more approachable. For instance, related work on help-seeking tools in enterprise contexts finds that a seeing a summary of someone's skills, their job title, and where they are located in an online profile were particularly important in determining whether help-seekers wanted to reach out for advice [67]. This allows the participants in the makerspace to know who to approach and that they are willing to be approached for help.

5.3. Making Values in Diversity/Equity Visible

While structural changes that support skill development are needed, broader societal biases can make it especially challenging to combat the dominant male culture that tends to be established in engineering environments [18,42]. Dismissing issues of gender discrimination in conversations, sexualized jokes, and lack of diverse leadership, actively deterred female participation and probably will not be fixed through changes in academic participation structure alone. Our findings highlight the need to build diversity into multiple aspects of community experiences, including member representation, project representation, and membership training.

5.3.1. Member Representation - Students from minority or marginalized groups in engineering, such as women, students of color, and students from low-SES backgrounds, are more likely to feel comfortable in a new community where they see similar others [47]. Seeing similar others as peers and leaders helps students feel that people like them are accepted as members and can succeed in the community, a key part of *Member Assessment* [46]. Research on curriculum design provides similar suggestions to show educational material that not only visualizes diverse representation in images, but also promotes positive perceptions of marginalized people, such as showing women of color as engineers and leaders and not in just subservient positions [47]. We found similar evidence in our own data that having female leadership positively influenced how female students felt in the space. The importance of representation was so pronounced that some participants described choosing to stay in a hostile engineering environment in order to serve as role models for other female students. In addition to hiring female leaders, we suggest actively recruiting female participants in the space to participate in official leadership roles, such as running workshops and providing help to new members.

5.3.2. Project Representation - In addition to seeing diverse members, participants expressed wanting to see diversity represented in the types of project promoted. Being able to see different types of projects (e.g. consumer and social impact products) constructed with different types of machines (e.g. sewing machines as well and high-powered machines), out of a variety of materials (e.g. fabric, wood, and aluminum) as well as projects at different stages (e.g. ideation, prototyping) helped with *Project Assessment*—determining if one's project would be accepted by the community. Without these examples, participants were likely to assume that their project was not advanced enough to fit within the bounds of the community. These findings reflect suggestions in engineering curriculum design research to show and assign projects that cater to a wider range of interests [51]. For instance, designers of the LilyPad arduino found that incorporating the activity of sewing into technology motivated greater maker interest and activity among female students [10]. Other middle school maker programs have incorporated jewelry making activities in their 3D printing modules, citing greater female interest in these activities [35]. Studies in university settings highlight that female students are also more likely to be motivated to study engineering if they can see how work has positive social impact [42]. We suggest displaying in the physical space and online makerspace websites different types of projects at different stages of their process. We also suggest highlighting different pathways to getting involved in these projects so that potential new members can identify concrete first steps to joining university makerspaces.

5.3.3. Training for Perspective Taking - Having open conversations around diversity and equity is needed to foster perspective taking and directly address topics of gender, race, bias, and discrimination in the community [47,52]. However, these conversations are often muted in the classroom, and particularly in STEM contexts, where these topics are not seen as important to the direct goals of the community [47,52]. While these conversations are difficult to navigate and manage, researchers argue that muting these topics entirely only perpetuates inequitable pathways to participation in engineering. Literature on training shows that perspective taking is a skill and can be taught through targeted instruction and group interventions [9,23].

Previous work on facilitating training and conversations around diversity highlight the importance of having committed leaders [51], clarifying and agreeing upon goals [28], acknowledging histories of discrimination [64], and providing opportunities to evaluate training and give feedback [28]. Trainees can often tell if leadership is actually committed to the longevity and success of diversity initiatives, suggesting the importance of training leaders as well [51]. Trainees often do not understand why they are being trained, which can result in mixed perspectives and intentions in the training cohort, ultimately affecting the quality of discussion [28]. Furthermore, because training goals are not always made explicit, trainees often want to provide feedback, but were unsure about how to evaluate the success of their experience [28]. Taking into consideration this prior work, university makerspaces could work with experts in facilitating training and incorporate session in classes that use the university makerspaces or during novice onboarding. This could also be a unique opportunity for senior students invested in supporting diversity to learn how to run and improve diversity training, an avenue for having community influence.

We believe these interventions of diverse member representation, diverse project representation, and training, combined with clearer structures of participation will foster greater perspective taking and more equitable opportunities for participation in university makerspaces among female engineering students.

6. Limitations and Future Work

The presented exploratory study is not without limitations. First, geographic diversity of our observations were limited as we only observed Chicago-based makerspaces. This approach was taken so that we could easily access these locations for data collection. To overcome our convenience sampling approach, we chose a range of makerspaces within Chicago that varied in size, participant demographics, and private/public spaces. We also interviewed students from university makerspaces across the United States. Although useful for gathering rich descriptions and corroborating information gathered through interviews, participant observation can be subject to the biases of the researchers, in this case, women in engineering.

7. Future Work

In future work, we plan to work with university makerspaces to implement the designs identified through this study with the goals of facilitating equitable participation, scaffolding help seeking, and making values in diversity visible. We hope findings from such interventions will continue to provide greater understanding of how design choices in makerspaces can better facilitate community interactions. In the future, we also hope to better understand the experiences of other marginalized groups within professional communities, such as co-working spaces, to better support greater equitable participation.

8. Conclusion

Through interviews with students and leaders, and observations of makerspaces, we found that that university makerspaces provide a unique opportunity to develop a sense of community among women in engineering. Our findings inform design implications for university makerspaces to better support a sense of community through project assessment, member assessment, perspective taking, signals of approachability, structured help-seeking, and credentialing. We recommend diverse member and project representation, opportunities for perspective taking, clearer structures of participation, and credentialing in order to support more equitable participation in university makerspaces among female engineering students. By understanding and designing for mechanisms that support sense of community, we can help to realize the potential of makerspaces as a place to reinvigorate engineering education to better include female perspectives and experiences.

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Appendix A: Participant Demographics

Participant ID	University Location	University Size	University Type	Engineering Major	University Year	Gender	Race/Ethnicity
P1	Midwest	Mid-Size	Private	Mechanical	3rd	Female	Black/African American
P2	Midwest	Mid-Size	Private	Biomedical	4th	Female	Black/African American
P3	Midwest	Mid-Size	Private	Biomedical	4th	Female	Black/African American
P4	Midwest	Mid-Size	Public	Mechanical	4th	Female	Hispanic/Latina
P5	Midwest	Mid-Size	Private	Mechanical	4th	Female	Hispanic/Latina
P6	Midwest	Mid-Size	Private	Chemical	2nd	Female	Black/African American
P7	Midwest	Mid-Size	Private	Mechanical and Design	3rd	Female	White/Caucasian
P8	Midwest	Mid-Size	Private	Mechanical and Design	5th	Female	Asian/Asian-American
P9	Midwest	Mid-Size	Private	Design	3rd	Female	White/Caucasian
P10	South	Large-Size	Public	Mechanical	1st	Female	White/Caucasian
P11	Midwest	Large-Size	Public	Mechanical	2nd	Female	White/Caucasian
P12	Midwest	Small-Size	Public	Mechanical	3rd	Female	White/Caucasian
P13	Midwest	Small-Size	Public	Mechanical	2nd	Female	White/Caucasian
P14	Midwest	Large-size	Private	Mechanical	4th	Female	Asian/Asian-American
P15	Midwest	Large-size	Public	Mechanical	4th	Female	White/Caucasian
P16	East	Mid-Size	Private	Mechanical	3rd	Female	White/Caucasian
P17	South	Large-size	Private	Mechanical	4th	Female	Asian/Asian-American

Table A: Table of female university engineering students interviewed

Participant ID	Makerspace Type	Gender	Race/Ethnicity
L1	Public	Male	Hispanic/Latino
L2	Privately-owned	Male	White/Caucasian
L3	Privately-owned	Male	White/Caucasian
L4	Public	Male	White/Caucasian
L5	Public	Female	White/Caucasian
L6	Public	Female	White/Caucasian
L7	Privately-owned	Female	White/Caucasian
L8	Privately-owned	Female	Asian/Asian-American
L9	University-based	Female	White/Caucasian
L10	University-based	Male	White/Caucasian

Table B: Table of makerspace leaders interviewed

Makerspace ID	Makerspace Type	Location	Number of Members
M1	University-based	North Chicago Area	50
M2	University-based	North Chicago Area	25
M3	Privately-owned	North Chicago Area/Evanston	25
M4	Public	West Chicago	50
M5	Public	South Chicago	100

Table C: Table of makerspaces observed

Appendix B: Student Interview Protocol

1. Could you describe the makerspaces that you visit on your campus?
2. How often do you visit makerspaces on your campus?
3. Do you participate in makerspaces outside of your campus?
4. Thinking back to your first time in a university makerspace, what stood out the most to you? Was it the physical aspects of it? Was it the people who were involved in that space?
5. Thinking back to your first in a university makerspace, what was the most intimidating aspect? Was it the physical aspects of it? Was it the people who were involved in that space?
6. When you are/were in the makerspace working did you seek out help from others in that space? How did you go about seeking help? If not, why?
7. What are physical improvements do you think can be made in that to create a more comfortable learning environment to ask questions or seek out help?
8. What are community-programming initiatives that you think can be made to create a greater sense of inclusion in the makerspaces you are a part of?
9. What are online technologies and tools that you think can be made to create a greater sense of inclusion in the makerspaces you are a part of?
10. Is there anything you want to add, that I did not touch on that you think is important to note, further investigate or consider?

Appendix C: Leader Interview Protocol

1. How long have you been involved in this makerspace?
2. What attracted you to this program or position in the first place?
3. How do you try and support inclusion in your programs?
    a. Could you describe a specific time when you felt your program did a good job of supporting an inclusive space"
    b. How do you take into account student feedback?
4. What significant improvements have you seen over the years with respect to the diversity of students you attract to your makerspace?
5. What are the biggest challenges you face with fostering diversity and inclusion in your makerspace?
6. Do you see certain challenges arise with your students who identify as gender or ethnic minorities in STEM fields?
7. What would you consider are challenges for minority students to stay engaged in makerspaces like this one?
8. Have you seen specific things (activities, design layouts, programming, leaders) that support inclusion and help retain minority students in makerspaces?
9. What would you consider are barriers of entry for more minority students to participate in makerspaces like this one or in general?
10. What success stories in makerspace initiatives have you heard from past participants that have helped retain them in engineering?

Author Biographies

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