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 community. University makerspaces provide a unique context to understand and support females' sense of community within engineering because they are able to apply engineering classroom knowledge while working alongside peers and leaders. Despite this opportunity, university makerspaces often fail to create an environment supportive of women. A critical examination of how females experience community within the space through an equity lens is needed to identify what changes can be made 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 supportive and unsupportive ways of encouraging a positive sense of community among female members. Our findings inform design principles for university makerspaces to support a positive 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 makerspace mechanisms undergraduate women take into account when evaluating their sense of community in engineering spaces.

Keywords: makerspaces; university makerspaces; 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 combating climate change and accessible healthcare, we need to attract and retain undergraduate women majoring in engineering. While the number of females and women of color enrolling in engineering programs at four-year universities are increasing [2,6], women are still more likely than men to leave engineering majors [11]. Engineering education researchers find that not having a strong sense of community in engineering is one of the main reasons women leave their respective STEM fields [36].

While many approaches, such as hiring female role models [6], feminist hackerspaces [50], community diversity training [28,50], electronic textiles projects [34], and design thinking [48] have been adopted to support greater female participation and empowerment in engineering, few have yet to focus on how to establish a positive sense of community in a gender diverse university setting. Participation in university makerspaces provides the opportunity to build technical skills while seeking advice and working alongside a wide range of engineering experts and peers [10,43]. However, because university makerspaces must serve a large and diverse student body, 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 and people in the space to engage in activities of "making" or "tinkering" [37]. Universities around the United States have begun to put greater investment in developing makerspaces – building new spaces, purchasing tools, hiring staff, and developing programs [10,25,37]. Due to ABET 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 [27,63]. Despite the greater investment in maker spaces 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 makerspaces can provide us better insight into how these spaces can be designed to support a sense of community among a diverse population of engineers [38,57,59]. 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 makerspaces and 2) design implications for makerspaces to support a sense of community among female engineering undergraduates.

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 Retention in Engineering

Even though the number of females and women of color enrolling in engineering programs at four-year universities is increasing [2,6], women are still more likely than men to switch to non-engineering majors [11]. Reasons include reduced self-efficacy, stereotype threat, and disappointment with engineering courses [12,41,44,54]. 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, studies have shown that their engineering self-efficacy declines significantly during their first year in engineering and never reaches the same level [42]. 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 because female students come to believe that they are inherently worse at or not fit for engineering [6,12].

Researchers have identified a deeply engrained masculine culture in academic engineering settings, which has been shown to be a major reason for why women often leave engineering [21]. For instance, a study on engineering culture in university settings, finds that people often see females with high engineering skills as unnatural rather than something to be celebrated [21]. In addition to just gender divisions, others find these negative effects to be particularly pronounced for women of color. For instance, the National Science Foundation found that even though African American women are one of the fastest growing populations in college, they continue to be underrepresented in STEM fields, especially in predominately Caucasian institutions [35], whereas students who reported a strong sense of belonging had a greater likelihood of persisting at their institution, regardless of racial and gender background [26].

How one identifies with the academic community has shown to influence academic achievement and social acceptance [31]. Previous work on how marginalized youth form their identity 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 identify how university makerspaces can more equitably support access to these resources 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 [10,19,25,37]. The popular Maker movement, along with increasingly available rapid prototyping tools (e.g. 3D printers), has led to the growing construction and renovation of multiple university design facilities [63]. Educators are hoping these places can support not just using tools, but also learning how to apply design skills and work collaboratively with peers.

However, creating communities that support equitable access to academic opportunities is a challenge. Addressing these barriers in university makerspaces requires both understanding the history of the making community with its roots in white, male, middle-class activity [61], and the history of marginalized students hoping to get involved, such as how their identity and personal experiences shape their relationship with the community [4,24,60,61,65]. 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 [46,60,61]. 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 [46].

Increasingly, researchers seek to understand how makerspaces can support engineering activity among women [9,20] and other marginalized groups including youth [18,29], persons with disabilities [30,32], and low income populations [55]. For instance, work has been done in high school makerspaces, showing how the use the use of electronic textiles can break down traditional masculine barriers to female participation in computing [34]. Others describe using design thinking methods to encourage female members to develop a positive identity with making

[48]. More broadly, work on equity in education identifies the importance of students seeing similar others in the community, teachers understanding personal background and how that might affect academic performance, and teachers actively holding discussions on social justice topics as part of the curriculum [46].

However, the majority of work on developing equitable makerspaces has focused on non-university contexts, such as independent makerspaces or high schools. Unlike high school makerspaces, university makerspaces or more likely to include high-powered tools that can be particularly intimating to members who do not feel welcome due to lack of experience [7]. Unlike independent makerspaces, participation in university makerspaces is often required by the engineering curriculum as accreditation commissions have increased attention to design [1,63], 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 [5,49], 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 [45].

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 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 do or do not achieve a sense of community in university makerspaces.

3. Methods

Previous literature 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 [61]. In order to understand the experiences of female engineering students in university makerspaces, we take a qualitative research approach to understand the experience of female engineers involving 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

We performed 27 interviews, including 17 female university engineering students (self-identified as 2 Hispanic/Latino, 4 Black/African American, 3 Asian/Asian American, 8 White/Caucasian) from six different public and private schools (see Table A in appendix), and 10 makerspace leaders representing four different spaces (2 public, 1 privately-owned, and 2 university-based) (see Table B in appendix). By "public," we mean free and open spaces like 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. This allowed us to access and interview makerspace leaders who intentionally promoted gender inclusivity in engineering to learn about their successful practices and challenges. We also performed participant observations in five makerspaces in the greater Chicago area (2 public, 1 privately-owned, and 2 university-based) to observe different approaches to building communities. Observations were critical to our understanding of how peers engaged in the spaces, allowing us to collect data unbiased by student reflection.

All of our student participants were female engineering students who 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 design engineering. 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 kept them in their major. We recruited participants from November 2015 to July 2016 who had a range of experiences in the makerspaces prior to college. 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 college. Participants were recruited through email, social media and outreach to student groups related to university makerspaces 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'" [37]. All student participants were offered a $5 compensation for a 30-minute interview.

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).

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 [32]. Interviewing students provided an opportunity for students to richly 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 while others took place over Skype. 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. We asked students to think back to their first encounter with a makerspace, what stood out the most, such as the physical aspects or the people who were involved in that space. We also asked students if they sought out help from others in the space and if they did not, what prevented them from doing so. We asked students to describe if they felt a sense of belonging within their makerspace, what worked, and what they thought could be improved to create a better sense of belonging. Eleven student interviews took place on the phone and six were performed in person. 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. 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 gender minorities felt well supported and what curriculum pieces contributed to this. We also asked leaders to describe what they consider are challenges for the gender minority 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 expert interviews lasted 45-minutes on average. 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 [56] of our data to develop themes following McMillan and Chavis's definition of sense of community [45], which is made up of four main attributes: membership, shared emotional connection, fulfillment of needs, and influence. We initially started out with McMillan and Chavis's definition of belonging as the lens of analysis, but have since broadened our lens to their larger framework of sense of community, which we felt more accurately captured what we observed in our data.

The data was analyzed 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 belonging. The initial round of coding produced an list of 23 codes (e.g. interaction with leaders, collaboration, intimidation). In the second round of coding, we clustered codes together into the broader themes of sense of community as defined in the related work: 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 under the sense of community theme, Fulfillment of Needs. We then performed a third round of coding to identify the aspects of sense of community unique to our university makerspace context. For instance, Fulfillment of Needs was re-labeled as Structured Help-Seeking because participants primarily expressed a desire to develop making skills (need), but did not know how (structure for help seeking). Similarly, the broader theme of Membership was divided into the sub-categories of Project Assessment and Member Assessment to reflect to two general areas by which students determined whether or not they could join the makerspace community. All student identities have been kept anonymous.

4. Findings

We identify six mechanisms inspired by McMillan and Chavis's framework [45] through which female engineering students evaluate their sense of community in university makerspaces: 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 our final themes are not mutually exclusive as mechanisms relate to each other.

4.1 Project Assessment

Understanding community boundaries is a key way of evaluating sense of community because it helps people determine who qualifies for *membership* and how to obtain it. However, we found that there was a misunderstanding between how students and leaders determined project membership requirements. While makerspace leaders believed that a wide range of project could join the space, female participants described assuming that their work did not qualify. Participants described that seeing examples of others' work, representing a wide range of project types (e.g. textile-based, wood-based) and at different stages of the design process (e.g. prototyping, testing), as well as how others got involved, would help them to more accurately evaluate their own work.

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 was not advanced enough to merit being a project in the makerspace. She described the 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 in the makerspace. Ultimately they decided to discontinue their work, even though they really wanted to continue the project in the makerspace environment. Instead, this participant chose to join her male friend's group's project only to realize that her original dish washing project was advanced enough to be accepted in the makerspace.

"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 [9,53], just as much as projects that used high powered machines.

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 limited pathways to participate.

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.

"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 [40]. 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 they could give a tutorial. However, few participants knew that this was a possibility, and chose to not enter the makerspace unless that had explicit permission from a professor or an existing friend connection with a member.

Students who enrolled in classes that took place in university makerspaces and walked them through the design process 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 freshman 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.

Scaffolding involvement, whether through a class, workshop, or formal and informal training, can provide pathways for students to get involved in their university makerspace. Furthermore, 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 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.

For instance, various 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 than 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 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 and hair ties, 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 alterative 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 self-confidence in oneself and one's work [15,46]. Therefore, in order support a more positive sense of community among women, our data notes 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 [7], where people often do not realize that women often deal with uncomfortable interactions on a day-to-day basis.

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.

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 shop, 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 [52] can alienate or distance female students because the values promoted often do not align with those of women who want to become involved [20].

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 [8,22].

4.4 Signals of Approachability

In order to create a community that encourages socialization and peer support, leaders and members must show signs that they are approachable and supportive to requests for interaction. 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 provide greater opportunities to develop *shared emotional connections*, therefore reducing anxiety around seeking help and initiating new connections.

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 noticed that only particularly outgoing students were asking questions, and 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. One participant described feeling "*completely shot down."* Another student described how it was intimidating when other shop trainers seemed irritated when approached, particularly when questions came from female members of the community.

The camaraderie established between shop trainers and certain students further exacerbated these divisions as some students felt that there were favorites within the space or project "stars" that created subdivisions within the community. It is important that leaders make everyone feel like they are valued, because if leaders treat certain groups or students differently this can also become alienating for women in the makerspace that might feel like perpetual newcomers. 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 [62]. Participants described how being able to approach members and leaders 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 choose to participate in makerspaces because they can *fulfill intellectual needs* of applying classroom knowledge and interacting with experienced others [7,36]. 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 before you come to him with a question. That particular leader always wanted to the student to have made a lo-fidelity prototype 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 engineering career described how freshmen 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 norms beforehand.

Others even described that when they first joined the makerspace, they had trouble identifying who was a shop 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 answer the question themselves.

"I don't really know who the shop 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 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 is part 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. Another Midwestern makerspace housed within a library created a poster that was right next to the 3D printing station 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 troubleshooting in certain ways 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 shop trainer), so that male peers would be more likely accept them as fellow engineers.

Female participants described challenges with being able to participate in making activity, let alone have 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 cultural 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 similar patterns in other project teams—*"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 community members in order to be effective.

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 women 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 equitably supports the diversity of students expected to participate. Supporting equitable participation has shifted from just expanding outreach efforts to critically examining the design of the entire community experience [61]. 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 more equitable community design 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 [61]. 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 [20]. Others have created makerspaces with programs focused on addressing accessibility by pushing for the use of rapid prototyping in Do-it-Yourself Assistive Technologies [32]. 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 healthy community development. First, membership often requires little to no up-front investment in behalf of students because participation is often required by coursework or graduation requirements. 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 [45]. Our data highlights this challenge 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, while having less control over their activity (different students working on different projects at different stages) 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 engineers, are left out and unable to grow personally and intellectually.

Understanding how to design communities that suffer from biases established in larger socioeconomic 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 [58] and because members often consciously or sub-consciously block requests from certain racial groups [16]. 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 [13]. Therefore, we contribute to related work on community development by identifying specific flaws in 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 [47]. 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 [39]. While apprenticeship is considered one of the most effective ways of learning [14], 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. In these environments, students that are more aggressive or comfortable with asking for help are often more likely to receive the needed apprenticeship 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 [47]. 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 [13]. 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 [41].

Related work on soliciting feedback also finds that the way one asks a question can lead to significantly different quality of responses [23]. Researchers find that scaffolding requests for feedback by providing more specific subquestions (e.g. "What is one thing you like and dislike about this project") promote more in depth and useful feedback than generic requests (e.g. "Give feedback on this project.") [23]. 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 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 [64]. 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 [17,41]. Through our data, we find that explicit issues with supporting diversity, such as 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. Literature on equity in engineering argues that it is necessary to build diversity into all 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 [46]. 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* [45]. 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 [46]. 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 also expressed wanting to see diversity represented in the types of project promoted. Being able to see different types of projects (e.g. sewing and high-powered machining) as well as projects at different stages 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 good 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 [50]. For instance, designers of the LilyPad arduino found that incorporating the traditionally female activity of sewing into technology motivated greater interest and activity among female students [9]. Other middle school maker programs have incorporated jewelry making activities in their 3D printing modules, citing greater female interest in these activities [33]. 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 [41]. 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 [46,51]. 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 [46,51]. 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 [8,22].

Previous work on facilitating training and conversations around diversity highlight the importance of having committed leaders [50], clarifying and agreeing upon goals [28], acknowledging histories of discrimination [61], 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 [50]. Trainees often do not understanding 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 wanted to provide feedback, but were unsure about how to evaluate the success of their experience [28]. Taking into considering 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. 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 makerspace communities to implement the design implications identified through this study with the goals of facilitating equitable participation, scaffolding help seeking, and making values in diversity visible. For now, we are currently working with members of our own university makerspace to prototype and test poster designs and content as ways to support leader approachability and structured help-seeking. We hope findings from such interventions will continue to provide greater understanding of how to 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 other professional communities, such as co-working spaces, to better support more 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. 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:

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

Author Biographies

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JULIE HUI is a PhD candidate in Mechanical Engineering and the Segal Design Institute at Northwestern University. She studies innovation, entrepreneurship, and skill development in online and offline communities. Her work contributes to the fields of human-computer interaction and engineering education. She received her B.S. in Physics from MIT.

ELIZABETH M. GERBER is an associate professor in the McCormick School of Engineering and School of Communication and Director of the Segal Design Research Cluster at Northwestern University. She earned her B.A. in Art and Engineering from Dartmouth College, and her M.S. and Ph.D. both from Stanford University in Product Design Engineering and Management Science and Engineering, respectively.