Listening to Makers: Exploring Engineering Students' Recommendations for Creating a Better Makerspace Experience

Madeleine Jennings, Arizona State University, Polytechnic campus

Madeleine Jennings is a doctoral student and graduate research assistant at Arizona State University - Polytechnic Campus, pursuing a PhD in Engineering Education Systems & Design. She received a B.S. in Manufacturing Engineering from Texas State University - San Marcos. Madeleine's research interests include investigating and improving the experiences of invisible identities in engineering, such as LGBTQ+ and first-generational engineering students, and engineering students with mental health disabilities.

Dr. Brooke Charae Coley, Arizona State University, Polytechnic campus

Brooke Coley, PhD is an Assistant Professor in Engineering at the Polytechnic School of the Ira A. Fulton Schools of Engineering at Arizona State University. Dr. Coley is Principal Investigator of the Shifting Perceptions, Attitudes and Cultures in Engineering (SPACE) Lab that aspires to elevate the experiences of marginalized populations, dismantle systematic injustices, and transform the way inclusion is cultivated in engineering through the implementation of novel technologies and methodologies in engineering education. Intrigued by the intersections of engineering education, mental health and social justice, Dr. Coley's primary research interest focuses on virtual reality as a tool for developing empathetic and inclusive mindsets among engineering faculty. She is also interested in hidden populations in engineering education and innovation for more inclusive pedagogies.

Dr. Audrey R. Boklage, University of Texas, Austin

Audrey Boklage is research assistant in the Cockrell School of Engineering at the University of Texas at Austin. She is particularly interested in improving the culture and environment of undergraduate education experience for all students, particularly those from underrepresented groups. Audrey has expertise in qualitative research methods including exploratory case studies and narrative inquiry.

Dr. Nadia N. Kellam, Arizona State University, Polytechnic campus

Nadia Kellam is Associate Professor in the Polytechnic School of the Ira A. Fulton Schools of Engineering at Arizona State University (ASU). She is a qualitative researcher who primarily uses narrative research methods and is interested more broadly in interpretive research methods. In her research, Dr. Kellam is broadly interested in developing critical understandings of the culture of engineering education and, especially, the experiences of underrepresented undergraduate engineering students and engineering educators. In addition to teaching undergraduate engineering courses and a graduate course on entrepreneurship, she also enjoys teaching qualitative research methods in engineering education in the Engineering Education Systems and Design PhD program at ASU. She is deputy editor of the Journal of Engineering Education.

Listening to Makers: Exploring Engineering Students' Recommendations for Creating a Better Makerspace Experience

Abstract

This paper explores the ways that students experience university-affiliated makerspaces as captured in interviews and during observations. Our research questions are focused on understanding the ways that engineering students have experienced makerspaces in a variety of institutions and institution-types, and their suggested ways of improving these makerspaces. In particular, we are interested in the ways that students from underrepresented groups have experienced these makerspaces and their suggestions for improvements to the makerspaces. Data collected for this study was gathered using semi-structured interviews with a diverse set of students from seven different institutions. An a priori codebook was developed to analyze transcribed interview data. The codes that are the focus in this study are the following: "experiences that shape identity," "pathways to engineering," and "recommendations for makerspaces" and the emergent patterns are around equipment-focused, logistical, curricular, and social recommendations for makerspaces. It was generally found that women and ethnic minorities tended to recommend social change in makerspaces, while men of all ethnicities tended to recommend equipment and technology changes. The implications of this study are to establish student makerspace recommendations in order to create more inclusive and welcoming environments in makerspaces and other engineering spaces.

Introduction

Makerspaces are generally thought of as accessible spaces with the tools that makers need to build, tinker, and collaborate with others [1]. These spaces have become quite popular in conjunction with engineering programs at academic institutions through recent years [2]. Due to their popularity, engineering education researchers have sought to understand best practices and cultural norms for these spaces, the effects of makerspaces on users, as well as how best to utilize these spaces to spark interest in students who otherwise would not have considered engineering as a field of study [2]. However, there has been concern regarding the social implications of makerspace practices, and the possible perpetuation of harmful trends seen in engineering spaces, such as excluding women and marginalized identities from the space through active or passive tactics [3], [4]. These trends may serve to drive away students that may otherwise be interested in and benefit from maker culture and engineering.

Best practices for makerspaces regarding equipment, space location, and similar have historically been gathered via observation rather than through actively gathering experiences from makerspace users [2], [5], [6]. While this may provide researchers an opportunity to interpret the needs of makerspaces through the lens of their own expertise, there is much to say about gathering recommendations for best practices from the makerspace users themselves through semi-structured interviews. This paper aims to provide these recommendations for makerspaces through data collected from semi-structured interviews conducted with a diverse set of students.

Methodology

The research questions that prompted this study were as follows:

1. What are recommendations that student makers have for improving academic makerspaces?
2. How do recommendations between makers differ according to their race, gender, and other marginalized identities?

These research questions are answered best through qualitative research methods, and thus we designed this research using standards common in qualitative research and in engineering education to ensure a high quality project and to minimize potential validity threats [7]–[9].

In this study, we visited and conducted ten observations at seven university-affiliated makerspaces, conducted semi-structured interviews with 67 engineering students, and conducted interviews with seven makerspaces managers, staff, and faculty affiliates. The makerspaces were embedded within several universities that included minority serving institutions, doctoral universities, private institutions, and public institutions. Student demographics are included in Tables 1 & 2. All student and university names provided in this paper are pseudonyms. The student pseudonyms were created to include the race and gender of the participant. For example, if a student indicated that they were Black on the demographic survey, their pseudonym would begin with the letter B. In addition, if they indicated that they are a female, we would give them a name that generally corresponds with that gender. In the case of a student who indicated that they are female and Black, a name such as Becky would be used. If they checked more than one race, their name would begin with the letter M to represent multiracial.

Table 1-Student ethnicity by gender

Table 1

Student Ethnicity by Gender

Ethnicity	Female	Male
Hispanic	0	4
Black	3	14
Ethiopian	0	1
Asian	6	6
Indian	0	1
Other - Middle-Eastern	1	0
Native Hawaiian	0	1
Multiracial	4	5
White	13	12
White International	0	1

Table 2-Multiracial Student Identity by Gender

Table 2

Multiracial Student Ethnicity by Gender

Ethnicity	Female	Male
Black/Hispanic	1	0
Asian/Hispanic	1	0
Asian/White	2	1

Black/Hispanic/Native American	0	1
Pacific Islander	0	1
White/Hispanic	0	1
Native Hawaiian/Hispanic	0	1

In the semi-structured interviews, we asked students about their experiences and stories in engineering and makerspaces, about their or their peers' experiences as members of underrepresented groups, and about their identity as a maker and an engineer. As the focus of this paper, we were interested in the students' recommendations for makerspaces. The following interview questions were of particular interest to this work:

- Tell me about your experiences making (or in makerspaces)?
- In this study, we are interested in students from underrepresented groups and their experiences as engineering students and as makers. How has being a _____ [refer to responses in demographic survey, e.g., Black woman] influenced your experiences as a maker and as an engineering student?
- As a _____ [again, referring to demographic survey responses], how could your experience be better in engineering and in the makerspace?
- If you could tell the university something to make your experience better, what would it be?

To analyze this interview data, we first developed an a priori codebook based on our research questions [10]. During the first iteration of coding, we coded 67 interview transcripts using this codebook [10], [11]. The codes that are the focus in this study are the following: "experiences that shape identity," "pathways to engineering," and "recommendations for makerspaces." In subsequent iterations of coding, we allowed for additional codes to emerge. These include: "creating inclusive cultures," "curriculum," "removing barriers," "productive pathways to engineering," and "pedagogical experiences that shape identity." To then begin to reduce the data, we engaged in pattern coding. Pattern coding helped us pull together the coded excerpts from the earlier iterations of coding into fewer and more meaningful themes. As the focus of this paper was on recommendations, we developed patterns within codes related to recommendations, these included equipment-focused, logistical, curricular, and social recommendations. The equipment-focused recommendations were focused on equipment and materials within the makerspace. The logistical recommendations included housekeeping practices, such as cleaning, storing materials, and updating equipment. The curricular recommendations included processes that could be used to get more students engaged in making or to improve the quality of the learning process. Finally, the social recommendations were focused on social or cultural recommendations within the makerspace; these recommendations included developing a multidisciplinary and collaborative makerspace and creating inclusive environments. These pattern codes then laid the groundwork for comparing the experiences across types of students (by race and gender). In this paper, we will focus on presenting the pattern codes that emerged from this analysis focused on recommendations, with consideration of the background of students (gender, race, and ethnicity) and whether recommendations differed across these students.

Results

After preliminary coding, we discovered several patterns within recommendations as described above. It should be noted that these recommendation categories are not exclusive; that is, a recommendation may bridge the gap between equipment-focused and logistical, logistical and social, or social and equipment-focused. Within each of the pattern sections below, we will discuss any patterns that emerged considering the background of students.

Equipment-focused Recommendations: Diversifying & Repairing Equipment in the Makerspace

Equipment-focused recommendations tended to refer primarily to diversifying and repairing equipment or materials within makerspaces. This could include fixing broken equipment, introducing new software, or simply adding new equipment to make the space more versatile. Additionally, students without university-provided access to materials may not be able to utilize makerspaces because they are not able to afford their own materials for projects. As Ishaan, an Indian man, states:

> I think that studying here is already really expensive. So, I think if the materials are made [readily] available then that would be a big help... even sometimes things that are not that expensive like the Arduino kit. They could be provided for free.

We found that many of the recommendations we received about equipment-based needs of makerspaces came from men. There were no ethnicity trends to note regarding male students' recommendations for equipment needs. Overall, male students tended to make more recommendations for new equipment and software, while also requesting a more integrated curriculum that values making as a part of engineering, as well as good housekeeping practices. Despite a majority of equipment recommendations being made by men, some requests were made by women, as well. White and Asian women also had a tendency to make recommendations for equipment. While the number of requests from white and Asian women for improving equipment in makerspaces was not as frequent as men's, it is notable that these demographics did include equipment-focused needs in their recommendations for improving makerspaces. Rose, a white woman, recommends "smaller scale" equipment to learn on before students begin working with heavier machinery in makerspaces. Additionally, Ava, an Asian woman, expressed frustration with inoperable equipment in her makerspace:

> Our milling machine, first of all, it has so many broken parts and it's so difficult to use and it's so outdated, even back when I took that class a year and a half ago, two years ago, it was already broken and I can't imagine years before.

Logistical Recommendations: Improving the Physical Space

Logistical recommendations included housekeeping practices within their recommendations, such as organizational strategies, general cleanliness, improved storage, and machine upkeep, as well as how to improve the makerspace environment. Students recommended improving storage space, as well as including more places to study and collaborate. A universal complaint from many students was the lack of storage and study spaces, specifically around the end of the semester. Wagner, a white man, described this need,

> More storage space, that might be a nice thing there, because when it comes down to the finals week with final projects, you've got a lot of engineering students with projects and nowhere to put them... [And] maybe finals time they could add a couple more tables.

Housekeeping recommendations were fairly prominent amongst a variety of demographics. These recommendations included organizational strategies, general cleanliness, and again, improving storage, as well as more abstract concepts such as machine caretaking and labelling procedures. For example, Walter, a white man, explained,

> Recently, I tried to use the band saw and I noticed very fast that someone must've cut metal with it. That band saw, the blade itself is not meant for metal, so it dulled really fast. Not two days before that, it was almost a brand-new blade. As a result, the cuts were coming out crooked because the blade's wobbling because it's dull. It was frustrating, because now my cut was crooked, that should've been straight. I guess just get more informative signs that are saying materials that can be cut with certain things. Put the materials for do's and don'ts. They have that on one of the table saws, you're not supposed to cut specific woods with it, if it's treated with certain things or it has aluminum paneling on the side of it, don't cut it on that saw. That one's important, and make them very visible, because otherwise you're going to break the machines, then no one can use it.

Caretaking, housekeeping, organization, and improving the atmosphere of the makerspace through manipulation of physical artifacts was a common recommendation from men and women from all racial and ethnic groups.

Curricular Recommendations: Integrating Makerspaces into Courses

Curricular recommendations referred to suggestions by students around imposing changes to the curriculum to expose more students to the makerspace and to leverage making in helping students learn engineering concepts while applying them in projects. Both women and men had a near equal tendency to request a more integrated curriculum that includes utilizing the makerspace into assignments, as a direct function of these students valuing making as an integral part of engineering. For example, Waldo, a white man, discussed his idea to better integrate making into the curriculum.

> We do have students coming in from a handful of classes that want to use the printers for their projects, but it's not as integrated into the curriculum as I think it should be. That's something we're definitely working on. Talking to professors saying, 'Hey, maybe you could have one project that tells your students to come to this printing lab.'

One white international woman student, Wren, even attributes her success as an engineering student to the makerspace at her university. She explains how her success as an engineering student is attributed to her involvement in makerspaces, thus making the case for integrating makerspaces into course curriculum:

> Makerspaces, I think, are important because they offer a gateway for people to start getting involved in actually hands-on things. I think a big thing in engineering is that classes [only] offer solving equations and doing homework, but they don't really force you to get in there and build something. Having makerspaces, and places that have a fun environment, really help people get in and get their hands dirty, which I think is important as an engineer. I think you should take that into consideration when you're thinking, 'Oh, our Makerspace is actually making a difference.' They definitely are. Without the Makerspace, I wouldn't know how to build anything on my own yet, or laser cut anything.

Wren explains the dissonance between engineering curriculum and the process of making. This recommendation refers specifically to tactics that could be used to get more students involved with makerspaces, as well as to improve their quality of learning by incorporating the real-world aspect of the hands-on facet of engineering work.

Social Recommendations: Developing a Multidisciplinary and Collaborative Makerspace

The multidisciplinary social recommendations were focused on students explaining that they would like to have students from more majors engaged in the makerspaces and considering ways of encouraging more collaboration within the makerspace. Some academic makerspaces that we visited only gave engineering students access to the makerspace, while others gave access to all students within the university. The recommendations in this section of the paper only include makerspaces with access that was restricted to engineering or STEM students.

One white woman, Winter, recommended allowing makerspaces to be multidisciplinary, meaning not just engineering students having full access to the space. She believed that excluding students based off their major did them a "disservice," stating that many of them may want to use the space, as well. The belief is that diversifying the academic background of students utilizing makerspaces provides the opportunity to benefit the space by fostering new ways of thinking, as well as to instill a sense of collaboration, inclusion, and community into the space. Wynne, a white woman, explained the importance of collaboration further.:

> I think there are people who don't have ideas right now, or they have ideas but they don't know how to go about making them, and there are other people who have these skills, but maybe don't have certain things they want to make, and connecting those people, and learning and teaching, learning from each other. It's something that I still want to see.

Student recommendations also stressed the importance of collaboration within makerspaces, as well as removing barriers of entry for students who are interested in making spaces and culture. Most genders and ethnicities in engineering felt that removing barriers to entry in makerspaces would be a good step towards recruiting more makers. These barriers referred to the lack of knowledge regarding equipment, to ensuring that staff are friendly and approachable. Students from most genders and ethnicities tended to recommend classes or workshops to teach new makers about the equipment used in their makerspace. However, Bryce, a Black man, extended this

recommendation to an encouragement that makerspace staff collaborate with new makers in order to make them feel included as a means to removing a barrier to entry:

> … have people there that are, I guess, kind of just asking around more so than just kind of walking around doing their thing. Have them talk to you, be like, 'Hey, do you want to make something? Did you want to help me with something?' Or like that. Be a little bit more inviting. [Have them ask], 'Do you want to try and screw this in for me?' Even if it's not something that's important, if it breaks it's whatever, just something like that. Just have a more inviting kind of vibe to it, I guess.

Social Recommendations: Creating Inclusive Environments

The recommendations around inclusive environments included suggestions around changing the culture to be more open, which would involve removing barriers to entry and having staff collaborate with new makers to help them feel more included in the space.

Women tended to recommend that makerspaces focus on building a more inclusive, collaborative environment. These recommendations could refer to utilizing workshops or classes to specifically create a more inclusive environment for women; however, a bulk of the recommendations from women emphasized the need for improving the culture in engineering spaces. Many women told stories about discriminatory instances they have had in both maker and engineering spaces. Women, and particularly women at the intersection of marginalized identities, tended to tell stories of men from engineering spaces making them feel "othered." For example, Betty, a Black woman engineering student, told stories about discrimination in both her makerspace and with a professor. She spoke about a time that she was using a file to finish a project, when a man in the makerspace accosted her, took her project from her hands, and began to file it himself, despite her insistence that she knew what she was doing. She is reluctant to attend this makerspace anymore without the makerspace's woman manager being present because of this and similar experiences. Betty also explained that she would constantly be confused with another Black woman that she had in a class, despite these two women looking nothing alike. She told her story:

> There was one semester we had a teacher that was talking to [my friend] about things, and she thought she just forgot something, but she talked to me later about the same professor and I told her about the conversation I had earlier [with the professor] and she was like, 'No, he was continuing that conversation with me.' And it happens at least once a semester, especially if we're taking the same class.

Engineering outreach and inclusion initiatives often include individuals who belong to a marginalized identity that is impossible to see. These identities are colloquially termed "invisible [12]," and can range from being an international student, to identifying as neurodivergent (having a mental illness or disability), or to belonging to the LGBTQ+ community. Students with these identities are often overlooked or even stigmatized, and as such, can endure discrimination in engineering spaces. One student we interviewed, Winnie, identifies as a transgender woman. Her stories demonstrate how the expectations of makers differ depending upon a maker's identity. As Winnie explains, the process of making and tinkering is inherently prone to failure, which is vital to the learning process. As a woman in a predominantly white, male space, the ability to fail (and

subsequently learn) is limited *because* of her identity as a woman. It is further compounded by her identity as transgender. She explains the complexity of navigating engineering spaces as 'other,' and highlights a troubling trend of having to be perfect in order to be accepted:

> I thought, 'Okay, I don't have the background that some of these wiz-kids do coming in.' They're all straight white men, or young straight white men. [They] don't really know how to communicate in a respectful way. I thought, 'Well I'm also trans, so you can be trans or inexperienced, but you can't be both.' So, like the barrier to entry – I've noticed from a couple other women in the space that they feel pressure to do it [make/tinker/create correctly] right the first time, and that's not how the world works… You're expected to fail in a good way [when making/tinkering/creating].

In Betty's words, "Makerspaces are defined by the people running them… The tools don't discriminate." Winnie and Betty both recommend providing an advocate for marginalized identities, stressing the necessity of fostering inclusive environments in engineering spaces. Betty stated that she will not enter the makerspace where she was discriminated against without the woman manager being present to advocate for her competence in the space. Winnie's mentor in her makerspace hired her as a technician because of her interest in the space and to provide an opportunity for inclusion that otherwise may not have existed. Regarding Winnie's mentor's acceptance and advocacy of her identity, as well as his willingness to learn about her identity:

> Coming out as trans isn't really a choice, it wasn't really a choice, it's what I had to do to survive... Even so, I had a hell of a time just being myself [at this university], and being in a supportive environment. There were some things professors here did correctly. [My mentor] for one, does a great job… He doesn't have to understand everything about my experience, but he's willing to learn, and he's one of very, very few people that I've ever met, who is willing to do that. To say, 'Teach me.'

These stories of engineering spaces' discriminating culture are troubling, but both women stated that they have found support from allies in these spaces. Allyship from those in power in makerspaces can serve to protect marginalized identities from harmful cultures in these spaces, and perhaps attract others, further building a space for inclusivity and support.

Conclusion

Generally, recommendations for equipment tended to come from men while recommendations for social improvement came from women. There was no distinction in recommendation trends between ethnicities for men and women. This was somewhat expected, as men are in the majority within engineering, and as such, may not feel socially excluded in engineering spaces such as a campus makerspace [13], [14]. Housekeeping, removing barriers, and curriculum recommendations came from both groups, belonging to all ethnicities and marginalized identities.

By incorporating a hands-on approach in classrooms utilizing campus makerspaces, classroom concepts can be conceptualized. As she stated previously, Wren would not be as fluent in engineering processes without her campus's makerspace. She argues that incorporating makerspaces into course curriculum would have the same effect amongst other students, as well.

Men and women belonging to underrepresented groups tended to suggest more social changes in maker and engineering spaces. Women at the intersection of multiple underrepresented identities gave the starkest examples of discrimination and bias in maker and engineering spaces. While maker spaces can be improved by adding new equipment and providing materials to students that need it, further work is needed to improve the experience of women, and especially intersectional women, in these spaces. This work highlights the differences in experiences that differing identities have, as well as the need to homogenize these experiences.

References

[1] G. Cavalcanti, "Is it a Hackerspace, Makerspace, TechLab, or FabLab?," *Make: DIY Projects and Ideas for Makers*.

[2] W. C. Barrett, T. W., & Pizzico, M. C., & Levy, B., & Nagel, R. L., & Linsey, J. S., & Talley, K. G., & Forest, C. R., & Newstetter, "A Review of University Makerspaces," in *2015 ASEE Annual Conference & Exposition*.

[3] C. B. Leggon, "Diversifying Science and Engineering Faculties: Intersections of Race, Ethnicity, and Gender," *Am. Behav. Sci.*, vol. 53, no. 7, pp. 1013–1028, 2010.

[4] C. E. Foor, S. E. Walden, and D. A. Trytten, "'I Wish that I Belonged More in this Whole Engineering Group:' Achieving Individual Diversity," *J. Eng. Educ.*, vol. 96, no. 2, pp. 103–115, 2007.

[5] D. M. Masters, A. S., & McNair, L. D., & Riley, "Identifying Practices of Inclusion in Maker and Hacker Spaces with Diverse Participation," in *2018 ASEE Annual Conference & Exposition*.

[6] V. Wilczynski, "Academic Maker Spaces and Engineering Design," in *ASEE Annual Conference & Exposition*, 2015.

[7] J. Walther, N. Sochacka, and N. Kellam, "Quality in interpretive engineering education research: Reflections on an example study," *J. Eng. Educ.*, vol. 102, no. 4, pp. 626–659, 2013.

[8] N. Kellam and A. Cirell, "Quality Considerations in Qualitative Inquiry: Expanding Our Understanding for the Broader Dissemination of Qualitative Research," *J. Eng. Educ.*, vol. 107, no. 3, pp. 355–61, 2018.

[9] J. A. Maxwell, *Qualitative research design: An interactive approach*, 3rd ed. Thousand Oaks: SAGE Publications, 2013.

[10] N. N. Kellam, A. M. Cirell, B. C. Coley, and A. Boklage, "Making a new path: Lessons learned during the 'making the data' phase of our project," in *ASEE Annual Conference*, 2018, pp. 1–12.

[11] J. Saldaña, *The coding manual for qualitative researchers*, 3rd ed. Los Angeles: Sage Publications, 2015.

[12] E. A. Cech and T. J. Waidzunas, "Navigating the heteronormativity of engineering: The experiences of lesbian, gay, and bisexual students," *Eng. Stud.*, vol. 3, no. 1, pp. 1–24,

2011.

[13] U. M. Akpanudo, J. L. Huff, J. K. Williams, and A. Godwin, “Hidden in plain sight: Masculine social norms in engineering education,” in *Frontiers in Education Conference (FIE)*, 2017, vol. 2017-, pp. 1–5.

[14] National Science Foundation, “TABLE 5-2. Bachelor’s degrees awarded, by field and sex: 2004–14,” 2016.