

Article

Alleviating Barriers Facing Students on the Boundaries of STEM Makerspaces

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Abstract: Makerspaces have become an increasingly prevalent supplement to K-16 STEM education, and especially so in undergraduate engineering programs. However, they also fall prey to hegemonic, marginalizing norms common in STEM spaces and, ultimately, the modern making movement has remained a white, male, middle-class pursuit. Despite calls to broaden student participation in makerspaces due to the benefits of participation, there has been no examination of why some students choose not to visit these spaces. We surveyed ($n = 151$) and interviewed ($n = 17$) undergraduate STEM students to understand the barriers facing students before and during their initial participation. Using the lens of Social Boundary Spaces, we identified six barriers to successfully crossing the boundary into the makerspace, including: (1) not having enough time, (2) not feeling you have a purpose for visiting, and (3) not knowing how to obtain the proper certifications. Further, students find approaching makerspaces to be intimidating because of (4) the design of the space and (5) the perceived technical skillset of the students there. Notably, non-dominant students face a multitude of (6) barriers corresponding with their social identities. We conclude with recommendations relevant to educators, makerspace administrators, and engineering leadership for alleviating barriers and supporting students' involvement in STEM makerspaces.

Keywords: makerspace; barriers; inclusivity; boundary spaces

Citation: Andrews, M.E.; Boklage, A. Alleviating Barriers Facing Students on the Boundaries of STEM Makerspaces. *Educ. Sci.* **2024**, *14*, 772. <https://doi.org/10.3390/educsci14070772>

Academic Editors: Virginia Snodgrass Rangel, Jerrod Henderson and Daniel Burleson

Received: 27 May 2024

Revised: 1 July 2024

Accepted: 10 July 2024

Published: 16 July 2024



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1. Introduction

1.1. Making and Makerspaces in STEM Education

Making, as an educational activity is on the rise, and with it, facilities designed to support students' making activities, known as makerspaces, have become increasingly prevalent throughout K-16 science, technology, engineering, and mathematics (STEM) education, and especially so in undergraduate engineering education [1]. Substantial resources have been invested into makerspaces based on an underlying assumption that their creation will lead to experiences that bolster interest, engagement, and persistence in STEM studies and STEM careers [2,3].

Makerspaces are described and conceptualized in a variety of ways throughout academic and public discourse, and this narrative is reflective of both the breadth of activities that happen in these spaces and the design of the spaces themselves. The STEM education community most often defines a makerspace following Sheridan et al.'s [4] classification as an "informal site for creative production in art, science, and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products" (p. 505). They are "physical location(s) that serve as a meeting space for a 'maker community' and house the community's design and manufacturing equipment" [5] (p. 2). Engineering makerspaces typically include advanced prototyping technology, machining equipment, laser cutters, and a variety of traditional hand tools, but the available equipment and the layout of the spaces vary greatly between facilities [1].

In these facilities, undergraduate engineering students are able to engage in STEM-rich making, or “making projects and experiences that support makers in deepening and applying science and engineering knowledge and practice, in conjunction with other powerful forms of knowledge and practice” [6,7] (p. 763). These spaces are thought to have the potential to support entrepreneurship, innovation, and design alongside the undergraduate engineering curriculum [2] and to help students develop skills necessary in the engineering workforce [8]. Sometimes compared to a Community of Practice [9,10], makerspaces are informal learning environments that can act as a form of anticipatory socialization for engineering students, where they practice professional engineering tasks and receive implicit feedback about their fit within STEM spaces, drawing some students further into STEM pathways and pushing some students out.

1.2. Outcomes of Making Experiences

Initially, STEM education research focused largely on the benefits of makerspaces based on the quality of physical prototypes and student design projects [11,12]. Studies then began to investigate the benefits to makerspace visitors, focusing on potential gains in skills like collaborative skills [13], computational thinking [14], creativity [13,15–19], critical thinking [20,21], entrepreneurial thinking [16], ethical reasoning [22], leadership skills [23], problem-solving skills [20,24], project planning and management skills [24,25], and technology literacies [26]. Many of these studies posit that these skills complement or supplement engineering coursework and curricular experiences.

Further, researchers have identified affective benefits to students’ appreciation of experiential learning [13], confidence [27], design self-efficacy [28–30], engagement [27,31], growth mindset [32], innovation orientation and innovation self-efficacy [28], motivation to learn [33,34], STEM enjoyment [20,35,36], STEM interest [24,37], sense of belonging to the makerspace [28,34], sense of belonging to the engineering community [28], technological self-efficacy [28], and a “toolbox” of interpersonal and intrapersonal proficiencies [38].

Broadly speaking, there is a wide body of literature examining factors that contribute to undergraduate students’ choices to persist in STEM disciplines, and consistently, affective outcomes and skills like the ones listed above have been proven beneficial for persisting in STEM and having a successful career within or beyond STEM (see Xie et al. [39] for a review). By participating in a STEM makerspace, students are given access to the opportunity to build these skills and efficacies; however, these benefits are only available to those students who are opting into making experiences by visiting an academic makerspace, and “there is little evidence that the maker movement has been broadly successful at involving a diverse audience, especially over a sustained period of time. The movement remains an adult, white, middle-class pursuit, led by those with the leisure time, technical knowledge, experience, and resources to make” [40] (p. 5).

1.3. Diversity, Equity, and Inclusion in Makerspaces

In their seminal, critical work that originated the call for what “counts as making” (p. 214), Vossoughi et al. [41] articulated the importance of foregrounding equity when researching makerspaces. They point out that “those makerspaces that have reached beyond dominant populations are the exception, and not the norm . . . [and there is] little research documenting what is working, how or why” [41] (p. 213).

While students can learn and develop skills relevant to professional engineering practice in makerspaces, when students try to access these opportunities, they are also faced with the hegemonic, marginalizing cultural norms prevalent in STEM disciplines [41]. STEM makerspaces are built around a restrictive, techno-centric definition of making [41,42], prioritizing the making practices recently rediscovered and recognized by dominant, gendered, white, middle-class cultural practices, and typically do not include materials or space for making that reflects “everyday practices that have been the historical domain of women”, like crafting and sewing [41] (p. 212). This not only privileges students from dominant backgrounds within these spaces, but also has the potential to limit who enters these

facilities and what they do there, particularly for students who are already marginalized in STEM spaces.

Despite nearly a decade passing since this call for an explicit examination of equity in makerspaces, a recent systematic review found only 34 studies that even mention equity in makerspaces [43] and only 10 that use a critical perspective to do so. These articles recognize that the modern making movement systematically excludes some students and practices [7,40–42,44–48], but they are the only studies identifying these barriers for students. To date, little research has interrogated the factors that may motivate or deter students from participating in makerspace experiences.

Instead, research on equity in makerspace relies on the voices and experiences of students who are already in the facilities. Given evidence that the modern maker movement remains a gendered, white, and middle-class pursuit [40,41] and that makerspaces foster a “maker culture” that is unwelcoming to non-dominant students [41], these samplings biases greatly limit our understandings of equity and inclusivity in these spaces; we must continue to reflect on “whose histories still remain silent in making worlds and in STEM” [40] (p. 39), such as students outside the boundary of academic makerspaces. Here, we investigate equity in makerspaces through the eyes of students who have been excluded from these spaces.

1.4. *Why Don't Some Students Visit Makerspaces?*

The closest the field has come to understanding students' decisions to participate in makerspaces is through Tomko et al. [10]'s investigation of women's pathways into engineering makerspaces. The authors position makerspace environments (and more broadly, engineering) as a professional Community of Practice (CoP) [9] plagued by a culture of masculinity. They interviewed 20 undergraduate women who identified as makers about their past experiences with making and found that these women experienced instances of legitimate peripheral participation [9], alongside moments of gendered disempowerment. They identify key aspects of women's pathways into university makerspaces, including “overcoming and resisting limiting gendered expectations imposed by others in early experiences in unfamiliar makerspace CoPs . . . and relationships in college that expanded access, leadership, and visibility toward fuller participation in makerspace CoPs” [9] (p. 714). This article positions these women as “trailblazing” [10] (p. 713) in recognition that there are barriers against participation in these spaces but does not focus on the experiences of those students who are not successfully breaking into the making community.

Similarly, in their comparison of six campus makerspaces, Bouwma-Gearhart et al. [49] investigated the affordances for engineering development offered by the (1) physical features, (2) climate features, and (3) programmatic features of makerspaces; their analyses focused on the benefits of the facilities, but in their conversations with interviewees, students expressed “concerning issues of access and accessibility” in makerspaces such as cost, eligibility requirements, facility location, and limited hours of operation (p. 17). Again, this work sampled only students already within makerspaces.

1.5. *Aims of This Study*

Thus, the voices of students on the boundary of engineering makerspaces remain missing from the academic discussion of equity and inclusivity in these facilities, particularly for non-dominant students who may face additional barriers to participation due to the historically marginalizing contexts of STEM and engineering spaces. Guided by the theoretical lens of Social Boundary Spaces [50], in this paper, we investigate perceptions of makerspaces amongst non-dominant undergraduate students who do not visit the spaces. Specifically, we ask:

1. How do students' perceptions of a makerspace influence their choice to participate in a makerspace or not?
2. What reasons do students provide for choosing not to participate?

This work is the first to target students on the periphery of the modern making movement and sheds light on barriers to participation in engineering makerspaces. Understanding students' perceptions of makerspaces before participating and during early experiences there is a necessary first step to broadening the reach of the potential benefits of makerspace participation beyond white, male, middleclass spheres. The implications for supporting students in makerspaces relevant to engineering educators, makerspace administrators, and engineering leadership are discussed.

1.6. Positionality Statement

We recognize the importance of acknowledging our positionality as authors in relation to the social and political context of this study [51]. The following positionality statements disclose our identities, experiences, opportunities, journeys, and perspectives [52,53] to this study and within academic makerspaces.

Both authors are STEM education researchers with bachelor's degrees in STEM. Author one's bachelor's and master's degrees are in mechanical engineering, with her doctorate degree in STEM education, and author two has a master's degree and doctorate degree in STEM education. As white women who have spent time in academic makerspaces and other STEM spaces, we have both experienced both privileging and marginalizing experiences, but recognize the privilege of our identities that have benefited our paths to research and academia. We also recognize that our perspectives and positionality are influenced by our experience as citizens of the United States in academic makerspaces located in the United States. We are committed to supporting the success of students in engineering and, more broadly, in STEM, being critical of oppressive education systems, and doing justice in our research.

Madison's interest in STEM education research was sparked by experiences of gendered marginalization during her undergraduate engineering studies. She first participated in a makerspace during undergrad through a mandatory class assignment, and later became interested in investigating students' experiences with academic makerspaces in conjunction with the unveiling of a large facility at UT (and seemingly every other institution). Despite several years of experience in and around these facilities, she still feels intimidated when walking into a makerspace and lacks a sense of belonging or community there.

Before entering academia through a post-doctoral fellowship, Audrey was a high school science educator. She began exploring academic makerspaces in her post-doctorate studies with a group of other engineering education researchers. During this time, she began to recognize the affordances and barriers of these spaces through her experiences in them. Currently, she examines interactions and participation in makerspaces using a critical lens with the goal of identifying and incorporating practices and pedagogies to support inclusion in these spaces.

Our research on STEM makerspaces aims to promote the critical examination of these spaces and to identify and encourage equitable practices within makerspaces. In focusing our study on an engineering makerspace, we do not intend to reify STEM disciplines as somehow better than others nor to say forms of making outside of this scope are not STEM or are lesser than STEM. Rather, as STEM education researchers, we value equity and inclusivity in a field that is historically more exclusionary than many other academic disciplines. We narrow our focus so that we might make "locally meaningful" [44] (p. 36) and "equitably consequential" [40] (p. 35) recommendations for inclusivity in STEM spaces.

We are committed to increasing diversity in STEM, which is expressed in a variety of forms, including the social identities which have historically been the basis of discrimination in this field. We are committed to promoting equity by actively challenging dominant norms and critiquing oppressive systems; we believe that all students should have access to and opportunity for learning experiences like those in makerspaces. We are committed to deliberately working to ensure that STEM spaces are places where all are welcomed, differences are celebrated and respected, and all persons feel a sense of belonging and inclusion. Throughout this paper, we use the terms dominant/non-dominant in reference to social

prestige and institutionalized privilege attributed to certain groups in their environment, recognizing the contexts that have and continue to marginalize certain learners.

2. Theoretical Lens

For this study, we rely on the lens of Social Boundary Spaces [50]. The literature on boundary spaces rests on the foundational idea that boundary spaces are both barriers to and spaces with potential for learning. This theory focuses on the inherent “discontinuit[ies] in ongoing activity resulting from differences that are often culturally and historically informed” [54] (p. 2). While some learning takes place in neatly encapsulated spaces (e.g., classrooms), learning also occurs when people “interact with, move across or participate in different practices” [54] (p. 1). We position an engineering makerspace both as one such “neatly encapsulated space” surrounded by a boundary line, and as a hybridized boundary space, where informal and formal engineering learning can occur—if students boundary cross into the makerspace [54] (p. 1).

The concept of boundary crossing was first articulated by Engeström et al. [55] as the process of “negotiating and combining ingredients from different contexts to achieve hybrid situations” (p. 319). In a recent systematic review, Akkerman and Bakker [50] synthesized prior understanding of social boundary spaces in science education, defining four processes by which learning can occur on the boundary: identification, coordination, reflection, and transformation (see Section 3.3).

One study has used this framing to explore learning in makerspaces, but these authors investigated only boundary types within the makerspace [56], rather than the boundary surrounding the facility, between participants and non-participants, as this study investigates. The authors identified seven boundary space types within university-based makerspaces: “(1) engineering and non-engineering disciplines, (2) novice and expert users, (3) academic/professional and personal activities, (4) theoretical and hands-on activities, (5) students and staff, (6) one sub-discipline or specialization of engineering and another sub-discipline or specialization of engineering, and (7) school-related and entrepreneurship/industry-related activities” (p. 10).

Following Akkerman and Bakker’s [50] conceptualization of the four learning processes in boundary spaces, Choi et al. [56] reported instances of students’ identification of “their own communities and practices in relation to those of others, as they reflected on how knowledge about individuals or practices of other communities may benefit their own identity development and future practice as aspiring engineers” (p. 16). Students also perceived coordination in boundary spaces, such as interactions between students and staff, but the authors found no evidence of transformation processes within the makerspace. In other words, while students were able to participate in the makerspace and work across the seven boundary space types, no significant transformation of practices occurred within the facility amongst participants.

This investigation was largely focused on identifying how university-based makerspaces might develop students’ 21st century skills, rather than how boundary spaces can help us understand the equity issues facing the modern maker movement. Here, we use Social Boundary Spaces framing to investigate students’ preconceptions about makerspaces before they boundary cross to understand the barriers students may face along the way. We aim to recognize that the hegemonic, marginalizing cultural norms prevalent in engineering may systematically exclude and limit non-dominant students’ access to learning experiences within makerspaces.

3. Materials and Methods

3.1. Overview

To answer our research questions, we administered a recruitment survey and conducted interviews with undergraduate students. The survey was administered via flyers in a common engineering building on a college campus, where the university’s engineering makerspace is housed. A total of 151 students answered the survey. Of these students,

17 participants were recruited for follow-up interviews to provide greater detail about their experiences. We asked students about their impressions of the makerspace, whether they have visited, if they have interest in the space, and what their reasons for participating or not were. Then, qualitative analyses enabled us to identify specific barriers to participation and instances of boundary crossings, interactions, and processes, etc. [50,54,57].

3.2. Context of This Study

This study was centered on a makerspace that is housed in a new engineering building on a campus in the Southwestern United States. While the building houses mostly Electrical and Computer Engineering courses and lab spaces, it also includes most of the engineering-specific student services (e.g., the Engineering Study Abroad office), the headquarters for engineering-specific student organizations (e.g., the Women in Engineering Program), the campus's Engineering Library, and the engineering-specific makerspace, The Invention Space (a pseudonym). The building also has a food court and ample seating available, and thus, the space is used as a communal meeting place for faculty, staff, and students of all engineering departments and students from other colleges.

The building has a 4-story deep atrium that houses these spaces, most of which are enclosed by glass window walls, allowing students to see into the various offerings hosted in the building. The 30,000 square foot makerspace takes up the lower two stories of the 4-story deep atrium, and while it has glass windows that allow students to see into the space, the doors into the facility are tucked away in hallways away from the atrium. This makerspace matches Hughes and Morrison's [42] observations of the design of STEM makerspaces—it has a very industrial aesthetic, with exposed pipework, concrete floors, white tables, etc.

The space is supervised by four professional staff members and a team of approximately 30 undergraduate student part-time employees who provide the majority of the support available to students using the makerspace. The space is not formally restricted to engineering students only, but engineering majors do make up the majority of the visitors [58]. Many classes in the engineering departments incorporate assignments into their curriculum that require students to visit The Invention Space to complete training modules on the available equipment and complete a project, such as 3D printing a set of puzzle pieces that fit together. The space includes a variety of tools, equipment, and workspaces, including 3D printers, an embroidery machine, hand tools, laser cutters, vinyl cutters, sewing machines, and soldering and circuitry equipment. Students can sign up for training appointments on the equipment via the makerspace's webpage or in-person.

3.3. Data Collection

To answer our research questions, we administered a recruitment survey and conducted interviews with undergraduate students. The survey was advertised via flyers in a common engineering space on a college campus, where the university's engineering makerspace is housed. The flyer contained a QR link to the online survey and advertised a chance to win a gift card for participating. The online survey contained multiple choice and open-ended questions centering around students' impressions of the makerspace, whether they have visited, if they have interest in the space, and what their reasons for participating or not were. The survey instrument also collected background and demographic information from the students. All questions had an option to select 'prefer not to answer', to select multiple options, and to select 'prefer to self-describe', with a space for students to do so. The survey also included a space for students to indicate if they would be willing to participate in an hour-long, paid interview about making.

A total of 151 students completed the recruitment survey. Then, 17 interviewees were selected from the survey respondents who were interested in the interview opportunity; we specifically targeted those students who (a) identified with at least one social identity that is non-dominant in engineering and (b) indicated they had never visited the makerspace or had limited experiences there. These follow-up interviews allowed students to provide

greater detail about their perceptions of making, experiences making, view of the makerspace, and how they would like to see the facility change. The semi-structured interview protocol is included in the Appendix A. Students were given the interview questions in advance of the interview via email and were allowed to choose whether the interview took place in-person or via Zoom. All interviews were recorded and transcribed via Zoom.

3.4. Research Participants

Table 1 provides an overview of the academic characteristics of the analytical sample. A total of 17 students completed an hour-long interview. The sample consists of 82% engineering majors and 18% non-engineering majors. The majority of students were enrolled in either the Electrical and Computer Engineering department. Most interviewees were undergraduate students and students from every year were represented.

Table 1. Academic characteristics of sample.

	Recruitment Survey Participants, <i>n</i> = 151	Interview Participants, <i>n</i> = 17
<i>College</i>		
Engineering	112	14
Natural Sciences	39	3
<i>Engineering Major</i>		
Aerospace	5	1
Architectural	3	0
Biomedical	11	2
Chemical	15	3
Civil	12	1
Computational	1	0
Electrical and Computer	33	6
Environmental	6	0
Mechanical	23	1
Petroleum	3	0
<i>Student Year</i>		
First Year	43	4
Second Year	38	4
Third Year	32	4
Fourth Year	26	4
Fifth Year +	1	1

Table 2 provides a demographic overview of the analytical sample, including students' gender identities, ethnic identities, racial identities, sexual identities, and identification with a disability or impairment. Compared to national statistics on engineering undergraduate degree attainment, the recruitment sample shows an overrepresentation of women (non-gender conforming statistics were not available), an overrepresentation of students of Hispanic, Latino/a/x or Spanish origin(s), and an underrepresentation of all other racial identities [59]; these representation patterns are consistent with the demographic profiles of the engineering departments at this institution [60]. Data for national statistics on engineering undergraduate degree attainment disaggregated by disability status or sexual identities were not available. However, compared to national statistics of doctorate recipients, the recruitment sample shows an overrepresentation of students with disabilities or impairments [59]; again, data by sexual identity were not available. Overall, the students

represented in this sample of students who do not, or no longer, visit the makerspace overrepresent student groups who are marginalized in engineering spaces.

Table 2. Demographic characteristics of sample.

	Recruitment Survey Participants, <i>n</i> = 151	Interview Participants, <i>n</i> = 17
<i>Gender Identity</i>		
Agender	1	0
Cisgender Female	76	11
Cisgender Male	48	6
Genderqueer	1	0
Prefer not to answer	1	0
<i>Ethnic Identity</i>		
Hispanic, Latino/a/x, or Spanish origin	91	4
Non-Hispanic, Latino/a/x, or Spanish	26	11
Prefer not to answer	31	2
Prefer to self-identify	3	0
<i>Racial Identity</i>		
Asian	57	3
Black or African American	5	2
Middle Eastern or North African	4	1
Multiracial	9	1
White	45	10
Prefer not to answer	28	0
Prefer to self-identify	3	0
<i>Disability Status Identification</i>		
A learning disability	8	1
A mental health disorder	15	2
A sensory impairment	3	1
Multiple disabilities or impairments	5	1
Does not identify with a disability or impairment	82	11
Prefer not to answer	38	1
<i>Sexual Identity</i>		
Asexual	3	1
Bisexual	17	5
Heterosexual/Straight	90	8
Homosexual/Gay/Lesbian	5	2
Prefer to self-identify	3	0
Prefer not to answer	33	1

3.5. Analysis

Qualitative data analysis began at the beginning of the study and continued throughout. This was intended as a process of “making sense of the data... [which] involves consolidating, reducing, and interpreting what people have said and what the researcher has seen and read—it is the process of making meaning” [61] (p. 178).

Immediately after conducting each interview, the interviewer wrote an analytical memo about the conversation. These memos serve as “written records of analysis which document the analytical and methodological steps taken by the researcher” [62] (p. 7). Once all interviews were completed, the interviewer listened to each of the audio recordings and “pre-coded” the data, or highlighted participant quotes that stood out as potentially significant “codeable moments” [57] (p. 26). The interviewer then wrote a second analytic memo; these analytic memos served as a “code- and category-generating method” that allowed us to obtain a broad sense of participants’ experiences and to begin to draw comparisons across students’ experiences [57] (p. 50).

The interviewer then examined and descriptively coded each interview transcript; “descriptive coding summarizes in a word or short phrase... the basic topic of a passage of qualitative data” [57] (p. 76). This process allowed us to identify the basic concepts present

in the dataset, building a vocabulary of our data [57]. For instance, during this initial coding phase, we coded for any barrier to participation that students cited as a reason they had never visited or never returned to the makerspace. This step helped us gain a deeper sense of our participants' experiences and informed the next phase of focused coding.

We then used “focused coding” to categorize the data according to our theoretical framework [50,54,57]; “focused coding searches for the most frequent and significant initial codes to develop the most salient categories in the data corpus” [57] (p. 156). Here, the interviewer both deductively coded the data using a priori codes from the Social Boundary Spaces framework and inductively coded the data for emergent themes across the dataset. Focused codes enabled the us to identify specific barriers to participation and instances of boundary crossings, interactions, and processes, etc. [50,54,57].

Table 3 details the theoretical concepts from the Social Boundary Spaces framework and the accompanying codes from this process [50,54]. These codes and memos included raw data, with the explicit intention of keeping the participants' voices and meanings present in analytical outcomes.

Table 3. Codes aligned to Social Boundary Spaces framework.

Framework Concept	Codes	Definition
<i>Boundary Crossing</i>	<i>Boundary Crossing</i>	“The process of negotiating and combining ingredients from different contexts to achieve hybrid situations”
	<i>Barriers</i>	Barriers to crossing the boundary into the makerspace
	(1) <i>Time</i>	Students not having enough time to visit
	(2) <i>Purpose</i>	Students not feeling they have a purpose to visit
	(3) <i>Requirements</i>	Students not knowing the requirements to visit
	(4) <i>Technical Skills</i>	Students finding the makerspace intimidating because of the technical skillsets associated with the space
<i>Brokers</i>	(5) <i>Social Barriers</i>	Students finding the makerspace intimidating for social reasons
	(6) <i>Design of Space</i>	Students finding the design of makerspace intimidating
	<i>Brokers</i>	“People who cross boundaries”
	<i>Never Visited</i>	Students who had never visited the makerspace
<i>Boundary Interactions</i>	<i>One-Time Visitors</i>	Students who had visited the makerspace once
	<i>Return Visitors</i>	Students who had visited the makerspace repeatedly
	<i>Interactions</i>	“Interactions between the actors of different practices”
<i>Boundary Practices</i>	<i>Makerspace Interactions</i>	Interactions between students and people within the makerspace
	<i>Peripheral Interactions</i>	Interactions between students and others on the outside of the makerspace
<i>Boundary Objects</i>	<i>Boundary Practices</i>	“A sustained form of collaboration emerging from interaction between two sites”
<i>Boundary Processes</i>	<i>Objects</i>	“Objects that cross boundaries”
	<i>Identification Processes</i>	“Identification of the intersecting practices, whereby the nature of practices is (re)defined in light of one another”
	<i>Coordination Processes</i>	“Coordination of both practices in the sense that minimal routinized exchanges between practices are established, to make transitions smoother”.
	<i>Reflection Processes</i>	“Reflection is a more profound effect of boundary crossing. It is about learning to look differently at one practice by taking on the perspective of the other practice”.
	<i>Transformation Processes</i>	“In the case of transformation boundary crossing leads to changes in practices or even the creation of a new in-between practice, for example a boundary practice”.

3.6. Limitations

We recognize several limitations to this study, including the opt-in participant recruitment component of the study methodology. Due to the focus of this study on specifically targeting students with little to no experience with the makerspace on campus, the pathways of non-dominant students who have successfully found a space for themselves in the STEM makerspace are not represented here. This work is a part of a dissertation, and

therefore Madison was the only interviewer and only coder analyzing the data. However, interview memos, codes, and analyses were thoroughly discussed with members of Madison's dissertation committee. Finally, these analyses represent findings from one site and one university at one point in time and may not be broadly generalized to other university makerspaces; for instance, compared to national statistics on engineering undergraduate degree attainment, the recruitment sample shows over- and underrepresentation of several student groups.

4. Results

Students' pathways into and away from the STEM makerspace can be sorted into three categories: (1) students who have never visited, (2) students who visited once but never returned, and (3) students who have visited repeatedly. Students who visited the makerspace are classified as brokers, or people who cross boundaries [50,54]. The majority of interviewees were either non-visitors (i.e., non-brokers) or had visited only once, due to the focus of and strategic sampling of this study. We begin by describing students' accounts of (un)successfully boundary crossing, and then, in the following section, detail six categories of barriers that students experienced. The students described instances of identification processes, coordination processes, and reflection processes, but no instances of transformation processes.

4.1. *Crossing the Boundaries of the STEM Makerspace*

4.1.1. One-Time Visitors

Six students had visited the makerspace once, with a mix of students visiting on their own accord (i.e., voluntary boundary crossing) and students who visited as a part of a course requirement (i.e., mandatory boundary crossing). Two of these students visited the facility as a part of a building tour but never returned. Two other students independently sought out the makerspace but found out that they needed to complete training modules in order to use the equipment and never returned; these are examples of interactions on the boundary of the makerspace that did not lead to engaging in boundary practices or sustained forms of collaboration between sites.

The remaining two students in this group had both visited the makerspace because of course requirements. Callie is a 4th year ECE student who identifies as a bisexual, Latina woman with a learning disability. Callie was required to take a tour of space and complete training on the 3D printers and laser cutters as a part of a first-year design course; she described her first visit as "a really great start to being introduced to the maker space" but never came back because "once that opportunity to be with somebody who, you know helps me out in the makerspace was done, it was, you know, scarier to go back". Callie was able to boundary cross when she felt she had the support of the student staff during initial interactions, but after her first visit, she did not feel that scaffolding was there any longer. Another 4th year ECE major, Julie, who identifies as a bisexual, white woman, also visited the space to complete a course project. One of Julie's team members was already certified on the laser cutters in The Invention Space; when they visited the makerspace together, Julie watched her teammate laser cut the team project. In this case, Julie boundary crossed but did not engage in any boundary practices.

4.1.2. Repeat Visitors

Two students had visited the makerspace repeatedly, but due to several negative experiences in the space, only one of these students intends to continue visiting regularly. This student, Raymond, is a 1st-year ECE major and identifies as a straight, Black man. He has completed training on the laser cutter and wants to complete training on all of the equipment in the makerspace by the end of the school year. Raymond feels that these certifications will serve him well on the job market, or in other words, Raymond has identified value in the practices within the makerspace with respect to his professional interests and feels he can successfully continue to coordinate with the existing makerspace practices.

In contrast, Sanya, who is a 2nd-year ECE student and identifies as a bisexual, Asian woman, has also had negative experiences in the makerspace after successfully boundary crossing. Sanya and her friends used to use the space regularly for their group project in a humanitarian engineering class. She originally visited the makerspace as a requirement for this course and completed soldering training with her friend; the next time they visited the makerspace, they faced gender-based discrimination from the student staff members. Sanya's friend's student ID card was not working on the door to the soldering room, despite being certified on the equipment, and her friend spent the next half an hour trying to convince a male staff member that she had, in fact, completed the required soldering training to be in the room. After this negative boundary interaction, Sanya and her friend kept to themselves when they visited the makerspace, never asking for help from any of the staff members.

Sanya and her friend were both temporarily successful brokers and demonstrated both coordination and reflection processes in merging the practices of their course and the makerspace, and then later re-examining the way they were interacting with those within the makerspace. After they became aware of a lack of coordination between themselves and other participants in the space, they chose to disengage from the making community by minimizing their interactions with hostile actors.

These narratives illustrate that participating in a STEM makerspace is not as simple as simply visiting or not. Students experience barriers to participation and discriminatory experiences even after successfully boundary crossing into the makerspace; next, we detail the six categories of barriers that students face before visiting a makerspace.

4.2. Barriers to Participation in the STEM Makerspace

In reflecting on their reasons for not visiting or returning, students interview responses illustrated several barriers to successfully crossing the boundary into the STEM makerspace. While most barriers to participation were at the boundary of the makerspace, some occurred once students had already crossed the boundary and were engaging in boundary interactions and boundary practices within the makerspace.

Barriers to participation included (1) not having enough time, (2) not having a need or purpose to visit the space, and (3) not having or knowing how to obtain the proper certifications for using the equipment. Additionally, students find approaching makerspaces to be intimidating because of (4) the design of the space itself, and (5) the perceived technical skillset of the students already in the spaces. Additionally, non-dominant students face (6) barriers rooted in the hegemonic, marginalizing social norms prevalent in engineering. Table 4 details students' academic characteristics and which of these six barriers each participant listed as part of their experiences with the makerspace. Then, we describe the experiences of each of these categories of barriers.

Table 4. Student participants and the barriers they faced.

Pseudonym	Major	Year	Visitor Type	Barriers Faced ¹					
				(1)	(2)	(3)	(4)	(5)	(6)
Jerry	Computer Science and Math	3rd year	Non-Visitor	x	x	x		x	
Theo	Chemical Engineering	3rd year	Non-Visitor	x	x	x		x	x
Michael	Electrical Engineering	1st year	Non-Visitor	x	x			x	x
Carmen	Pre-Med	4th year	Non-Visitor		x	x	x	x	
Annie	Mechanical Engineering	2nd year	Non-Visitor	x	x				
Julian	Electrical Engineering	3rd year	Non-Visitor	x	x		x	x	x

Table 4. Cont.

Pseudonym	Major	Year	Visitor Type	Barriers Faced ¹					
				(1)	(2)	(3)	(4)	(5)	(6)
Maribel	Electrical Engineering	4th year	Non-Visitor				x	x	x
Jennifer	Biomedical Engineering	1st year	Non-Visitor		x			x	x
Hayden	Mathematics (Applied)	2nd year	Non-Visitor		x	x	x	x	x
Noura	Aerospace Engineering	5th year	Non-Visitor	x		x			x
Callie	Electrical Engineering	4th year	Visited Once				x	x	x
Neal	Biomedical Engineering	2nd year	Visited Once	x		x		x	
Cooper	Chemical Engineering	1st year	Visited Once	x		x	x	x	x
Selena	Chemical Engineering	3rd year	Visited Once		x		x	x	x
Julie	Electrical Engineering	4th year	Visited Once	x	x			x	x
Roger	Electrical Engineering	1st year	Repeat	x			x	x	
Sanya	Electrical Engineering	2nd year	Repeat				x	x	x
Totals				10	10	7	9	15	12

¹ (1) Time, (2) purpose, (3) requirements, (4) design of space, (5) technical skills, and (6) social barriers.

4.2.1. Students Do Not Have Enough Time to Visit Makerspaces

Not having enough free time outside of classes, completing coursework, and participating in extracurricular activities, social activities, etc. was a thread in many of the conversations we had with students. A few students talked about having an interest in and plans to visit the makerspace at the beginning of the semester, but as the semester progressed and their workload increased, visiting the makerspace became less and less of a priority for them; later in the semester, the time required to complete the training and the certifications processes that would pre-date their ability to use the space freely seemed like a much heavier lift than it had at the beginning of the semester.

However, lack of time was never cited as the sole reason that students had not made their way into the makerspace on campus and students' perception of the space as a workplace influenced their desires to spend time there. In explaining her lack of interest in spending time in the makerspace, Annie, a second-year mechanical engineering student who identifies as a straight, white woman with a mental health disorder, commented that she sees the makerspace as solely an academic area. Annie said, "going to The Invention Space would not be on the top of my list of things that I would like to do outside of school hours because I don't do a lot of personal engineering hobbies, and I know that some people do, but what I do outside of school is probably not engineering based". Here, Annie was indicating that she perceived the makerspace as equivalent to her academic work and would not want to spend her free time doing more school.

4.2.2. Students Do Not Feel They Have a Reason to Visit Makerspaces

The majority of interviewees described looking into the makerspace and seeing what they presumed to be engineers working on important projects, often describing the space with words like "high-tech", "functional", "a workplace", "a laboratory", etc. Jennifer, a 1st year biomedical engineering student who identifies as a white, lesbian woman, reflected that "it looks like it's efficient, and it, it looks like it's people who were asked to be there,

or they have to be there for a class or something. Like I've never seen anyone walking around touring it". This perception of a sense of mandatory productivity in the space was incredibly common amongst interviewees and was often directly linked to students' not feeling comfortable going to explore the facility.

Similarly, many students thought of the makerspace on campus as a place where "engineers are making stuff" for their class or research requirements; this contributed to a broad sentiment of students not feeling like that have a purpose to visit the. In all, students (1) identified the makerspace as a workplace where you need to be productive rather than idling, (2) preferred to be required to visit the space as a part of a class project, or (3) to have a specific project in mind before visiting, but (4) did not feel comfortable visiting the makerspace to work on a personal rather than academic project, and often felt that visiting the space as a novice or for personal projects would be (5) taking away resources and materials from students they felt "actually" needed the facility.

Simply put, students did not see space for themselves to be learning in a space where they felt 'real engineers' were working; Jennifer explicitly described the makerspace as "pretty intimidating. I feel like it would be hard for me to be a part of a space like that if it wasn't required for a class or something like that". Several students shared this view, saying they would feel more comfortable visiting for the first time if it were part of a class assignment: one interviewee, Cooper, who is a 1st year chemical engineering student who identifies as a white woman, had been assigned a makerspace project in her introductory engineering design course, but like Julie (Section 4.1.1), one of her teammates already knew how to use a 3D printer and seized control of the project, despite Cooper expressing interest in learning how to 3D print alongside her teammate. This experience of being sidelined during formal opportunities to visit the makerspace was especially common amongst the women interviewed.

Other students struggled to identify how they might use the makerspace for something outside of class or were simply unaware that they could use the makerspace for nonacademic projects. Michael, a first year ECE major who identifies as a straight, Latino man, felt visiting the space to work on a personal project would be "taking away from someone else that actually needs to use it". Julie also commented that this directly influenced her desire to visit the makerspace, saying that she would be more likely to visit the makerspace after learning that that was an option, and even more likely to visit if she felt the majority of the students in the space were working on personal rather than academic projects. Julie described multiple barriers to visiting the space, remarking, "So A. There's the whole, I have to go learn how to do it. But B. There's the well, 'Do I really want to take up a machine printing out key chains for people when there's this whole big group of people that are working on their final projects'. I think it's because my perception is that it is primarily an academic space, and so it would feel a little weird to do a personal project in there".

4.2.3. Students Do Not Know What Is Required of Them before Visiting Makerspaces

Training requirements also deterred students from visiting the makerspace. When thinking about what he might use the makerspace for, Theo, a 3rd year chemical engineering student who identifies as a straight, Latino, multi-racial man, said that "if I do come up with an idea that I'm like, 'I want to 3D print that!', then I definitely will [visit]. But also, I feel like the lack of knowledge of how to use some of the equipment down there... I'm not sure if they have classes for it". This sense of confusion about whether training was available and how to get trained on the equipment was common throughout our conversations with students. Many interviewees noted that they would not even know who to ask or where to look for additional information, with most not knowing that the space has a website with training appointments sign-ups.

In one case, Noura, a 5th year aerospace engineering student who identifies as a straight, Black woman with a mental health disorder, had taken the time to find the website to sign up for training on the sewing and embroidery machine with her friend. However, the website was not being properly maintained there were no appointment slots available

for sewing training (all other equipment had available appointments). Neither Noura nor her friend had attempted to visit the space since; this illustrates that the journey into a makerspace can be quite precarious and initial interactions on the boundary hold a lasting power over students' interest in the space.

4.2.4. Students Find Makerspaces to Be Intimidating Because of the Design of the Space

Further, students find the design and appearance of the makerspace itself to be a deterrent towards participation, using words like “clinical”, “musty”, “chaotic”, “overwhelming”, “intimidating”, “gray”, and “industrial, which is not my preferred atmosphere”. Callie, a 4th year ECE major who identifies as a bisexual, Latina woman with a learning disability, was aware of The Invention Space but chose instead to go visit the fine arts makerspace on campus, because it was “more approachable [and] feels warmer, I guess. Like the lighting, the colors, the décor”. She liked “the vibe” of that facility much more than the engineering-oriented makerspace. Similarly, Carmen, a 4th year pre-med student who identifies as a bisexual, Latina woman, felt the design of The Invention Space was counterintuitive to its purpose—“in a maker space, you’re going to be creative, so you want color around you, for inspiration, or just to spark your creativity”. Several students felt a display of student projects within the space could be a source of creative inspiration and greatly improve the aesthetics of the facility.

4.2.5. Students Find Makerspaces to Be Intimidating Because of Technical Skills

When describing the makerspace, many students noted the technology and equipment housed inside the space as a source of precaution towards visiting the space, both due to safety concerns about the machines themselves and the fear of making mistakes amongst peers who seem to know what they are doing. In describing his opinions of the space, Jerry, a 3rd year computer science and math major who identifies as an asexual, white man, calls it “interesting, but not inviting. . . I would say, inviting in the sense that I would like to go there and explore, but not inviting as if I would want to go and use the machines—aside from the ones I’m already familiar with”. Similarly, Carmen noted she “would be scared to have that in my hands, and not know how to properly use it, because I know that some of the stuff will be dangerous”.

Further, students are also especially nervous about learning how to use the equipment in front of the other students in the space, whom interviewees perceived as already in community with one another. More than half of the interviewee participants felt that the students who were already in the makerspace were experts on all the equipment; Michael thinks the makerspace “looks very cool, maybe a little bit intimidating, because I don’t exactly know how to use any of that” equipment and “I figure that those people that are in there, they seem like they know what they’re doing. I don’t know it just it’d be a huge gap, you know what I mean, the experience there”.

Several interviewees echoed these feelings of imposterism and feeling like they had to know how to use the equipment before they visit in order to match the perceived technical skillset of the students already in the makerspace. For instance, Maribel, a 4th year ECE major who identifies as a bisexual, Latina woman with a mental health disorder, felt she did not have enough experience to visit, but thought students in the makerspace were “really cool, because they like expressing their creative side, and they’re just using the resources that the engineering school provides for them. But um, maybe in the past, they were given like more room to have that space to create and, make and were, I guess, like pushed to do those things”.

She was interested in visiting the makerspace but felt behind her peers who may have already been afforded training opportunities in less high-risk environments.

4.2.6. Non-Dominant Students Face Social Barriers Rooted in Marginalizing Norms

These feelings are further compounded by Maribel's experiences with discrimination in engineering spaces; Maribel, like several other interviewees, faces additional social barriers rooted in the hegemonic, marginalizing norms prevalent in engineering.

Maribel has not been spending much time in the electrical engineering building lately, after having a traumatizing experience during the office hours for one of her courses. Her TA committed a macroaggression against her in front of her classmates; Maribel did not want to get into the details of the incident but reflected that ever since she's felt "less welcomed in the engineering building" where the makerspace is housed. She no longer likes spending any time in there because she "feels intimidated" and "now I see the [building] as not too safe of a place. And since the makerspace is there, I kind of associate it with that feeling too". Her traumatic experience with her TA made her feel constantly "aware that I'm like different than a lot of people in engineering". She "would be anxious [in the makerspace] because it's an engineering space, and after the experience with the TA, those would be the thoughts that I'd be having going into the space. . . like I don't belong here, or those kinds of emotions". Maribel is now seeking out other spaces on campus where the culture of engineering is less prevalent, because she feels safer outside of engineering environments.

Sanya similarly chose to end her participation in the makerspace because of experiences of gendered harassment. Sanya identifies as Asian but does not feel like her racial identity is as salient to her as her gender identity in the space because the people she sees working there are "not just a bunch of white guys. There's a lot of different guys, but I feel like I don't see as many girls of any racial identity". For Sanya, gender played a role in the types of activities she did in the space, noting that it felt like "if you're doing something not a conventional way. . . it just seems like I'll get judged, and I feel like part of that is because I'm a girl, and guys will just assume that I don't know what I'm doing". Despite an interest in learning how to sew, Sanya said "I don't think I would ever go sew unless I was with someone else, because I would hate to do that alone . . . I wouldn't want to be sewing in that space alone". Her biggest recommendation for improving students' experiences in the space would be to "make sure [the staff] don't say things that they shouldn't. When you do work on projects, there's already that stress of the project. So just like being questioned is just not great".

5. Discussion

Research shows that makerspaces can be valuable places for strengthening engineering students' competencies, interest, and efficacies [13,15,21,28,29,38] but we also know that the modern making movement systematically excludes some students and practices [7,40–42,44,47,48], and thus, not all students have access to these benefits. Despite acknowledging this, researchers have previously investigated equity and inclusion in makerspaces through studies that sample students who have already opted into making experiences.

These analyses of non-dominant students' experiences on the boundaries of STEM makerspaces reveal the nuance engrained in students' choices of whether to participate in university makerspace. This decision is not as simple as visit or do not visit, and it is not merely dictated by students' lack of interest or lack of time. We know that undergraduate students do not participate in every campus offering available to them, and this can be because of time constraints from part-time jobs, studying, etc., or a lack of interest in the activity available to them. In this study, we are able to see the variety of social and spatial factors that are also at play when students are considering visiting a makerspace. Further, deciding (or being required to) to visit a makerspace once or a few times does not guarantee continued participation, nor does it guarantee a positive or beneficial experience there. As in any other (pseudo)academic setting, students need a variety of supports to feel comfortable participating and require ongoing support to facilitate positive and safe learning experiences.

5.1. Connections to Boundaries & Participation Pathways in the Prior Literature

One other study has used the framing of Social Boundary Spaces [50,54] to explore learning in makerspaces, but these authors investigated boundary types within the makerspace rather than the boundary between participants and non-participants [56]. The authors identified seven boundary spaces within university-based makerspaces, including several that were echoed in our participants' experiences relative to the makerspace—the boundary between “novice and expert users” and “academic/professional and personal activities” [56] (p. 10). Relative to boundary processes, Choi et al. [56] also report a lack of transformation processes in student's experiences in academic makerspaces; it is our position that transformation in the context of an engineering makerspace is something that takes time and power to achieve, or in other words, something that may only be privileged to those who are already validated members of the community, rather than to newcomers.

Adjacently, Tomko et al. [10] investigated how undergraduate women navigated engineering makerspace Communities of Practice (CoP). While their focus was largely on those students who were able to successfully become members of the makerspace CoP, they detail a few instances of failed articulations (i.e., failed boundary crossings) on their pathways into the university makerspace; sentiments which mirror Sanya's experiences in The Invention Space.

“For one participant, though, her first encounter with this community was unsettling enough to preclude future use. . . This encounter with the men who were overseers of the 3D printing room was both daunting and aggravating. She felt outnumbered as the lone woman and also categorically assigned the role of know-nothing woman needing help—a deficit role she was unwilling to embrace” [10] (p. 708).

For several participants in their study and in our own interviews, early encounters with the makerspace were actually deterrents and “disincentive(s) to further engagement with that CoP, particularly when those experiences are not successfully mediated by full members” [10] (p. 709). While some students simply felt the requirements for further participation were too intensive or not worthy of their time yet, several students faced marginalizing experiences in the makerspace that influenced their interest in further participation and mediated the forms in which they were willing to engage with other makerspace participants. Some of these students chose to withdraw from the makerspace community, where they felt unwelcome and unsupported. These narratives, along with the other accounts of students facing barriers before and during their initial visits to the makerspace, highlight the importance of fellow students, makerspace staff, and university administrators providing ongoing support to facilitate positive and safe learning experiences.

5.2. The Maker Workplace

Counter to the narrative espousing makerspaces as hubs of creativity with the potential to increase access and broaden participation in STEM degree programs and career pathways [3], the majority of students interviewed shared that they perceived the university makerspace as an engineering workplace meant for technical experts—not a multidisciplinary creative center for exploration, growth, or the expression of self.

The imagery of a hard, industrial, laboratory like facility communicates to students that this space is a space for mass and mandatory productivity, exclusively for academic and so-called entrepreneurial endeavors that align with capitalistic values. Students do not feel comfortable working on personal projects in a space they see as meant for academics or “high-tech” projects. This acts as a barrier to participation for those students who (a) do not already have the expertise in the machines they see in the space or (b) have interests that they see as outside of the scope of making appropriate for an engineering makerspace. Students do not feel comfortable trying to learn in front of peers they view as experts, and projects that might serve as literal building blocks towards technical competencies are looked down upon by makerspace administration and the academic discourse of making

(see “KeyChain Syndrome” in Blikstein and Worsley [63]; and a rebuttal of the term in Worsley and Bar-El [48]).

Views of the makerspace as an engineering workspace act in combination with a perception of technical expertise amongst those students who already in this space, further deterring students from taking (what they view as) the risks of first entering the makerspace and then trying to learn in it while their ‘expert’ peers watch. Newcomers to the space see the students who are already participating there as a community of regular users that would be socially challenging to break into and who they would be bothering if they asked for help.

5.3. *Marginalizing Experiences on the Boundary*

Students who have had the privilege of developing these skills and confidences earlier in life, or students who do not face stereotype threat and microaggressions while navigating the makerspace, are further privileged in these spaces that require incredibly high activation energies to cross the boundary line into. For instance, if Maribel still wanted to visit the makerspace, she, and other non-dominant students who are already marginalized in engineering spaces, would have the extra burden of overcoming the trauma of prior micro- and macro-aggressions associated with engineering spaces. While the majority of barriers described here by interviewees were gender-based, it is likely that other elements of students’ identities that are marginalized in STEM spaces may become salient to students as they try to participate in the makerspace.

Makerspaces can act as a form of anticipatory socialization for engineering students, where they can learn and develop skills relevant to professional engineering practices, but in doing so, students are also faced with the hegemonic, marginalizing cultural norms prevalent in STEM disciplines which limit both who opts in to participating in these spaces and what types of activities they do there. Students’ concerns about being exposed in the makerspace are real, not just imagined—microaggressions from staff members are a real and ongoing threat for students. As researchers, educators, and policymakers, we must work to “confront and transform—rather than reproduce—educational inequities” inherent in makerspaces [41] (p. 210).

Next, we explore a hypothetical pathway towards boundary crossing into an engineering makerspace, identify barriers faced along the way, and make suggestions for policies and practices that may alleviate these barriers and offer students the necessary support to feel legitimized in a makerspace.

5.4. *Ways to Alleviate Barriers to Participation and Offer Continuing Support to Students*

Imagine you are a student encountering a makerspace for the very first time. At every step towards the space, there are barriers facing you and exit ramps available that may push you away from participation. While every student’s experience will differ, in Table 5, we explore one version of what may be required for students attempting to boundary cross into a makerspace and make suggestions for practices that may alleviate these barriers and offer students the necessary support to feel legitimized in the makerspace.

Table 5. Steps towards boundary crossing and opportunities to support students.

Initial Experiences	Barriers Faced ¹						Opportunities to Alleviate Barriers and Offer Support
	(1)	(2)	(3)	(4)	(5)	(6)	
1. Seeing the space	X	X	X			X	· Including information about opportunities to participate in the space on exterior doors or windows, and on an official makerspace website · Making the space colorful and welcoming
2. Seeing the staff, students, and equipment in the space	X	X		X	X		· Offering handouts and tutorial projects for each piece of equipment, including asynchronous training opportunities when possible · Showcasing example student projects with a range of complexity and a variety of personal and more academic projects near doors and windows · Creating marketing materials that are intentionally inclusive, rather than exclusionary
3. Trying to find out more information about it and learning from a peer that the space is ‘some lab’	X	X	X	X		X	· Hosting tours, open house events, and group training events routinely · Having a clear website stating the makerspace’s aims, culture, norms, and explicit DEI statements and pledges to support inclusivity there · Advertising the purpose of the makerspace on the outside of the facility itself, but also through departmental listservs, student services, courses, etc., and outside of only the engineering college
4. Being required to visit the space for an academic group project	X		X	X	X		· Creating inclusive making curriculum (see [48]) · Developing faculty workshops to support making content and pedagogy · Working in tandem with professors to dedicate class time to taking the students over to the makerspace to complete individual assignments · Requiring faculty members to attend workshops and complete trainings on the makerspace equipment themselves before assigning students to do so
5. Walking into the makerspace and trying to find help	X		X	X	X	X	· Using uniforms or signs to clearly identify staff members and advertise that their role in the makerspace is to help students · Positioning a staff member or welcome desk at or outside the entrance · Including visuals (such as a map or painted pathways) and resources (handouts, QR codes, etc.) that guide students who walk in the first time · Developing multiple ways for students to sign up for and access trainings

Table 5. Cont.

Initial Experiences		Barriers Faced ¹						Opportunities to Alleviate Barriers and Offer Support
		(1)	(2)	(3)	(4)	(5)	(6)	
6.	Interacting with a staff member	X		X	X	X		· Having student and professional staff members participate in sensitivity and diversity trainings as a part of their hiring process · Offering regular and continued DEI professional development for staff · Making sure these opportunities are productive for staff, not punitive · Conducting new student audits where an undercover student navigates the space and completes a report about their experiences for management · Constantly working to understand student experiences in the space by providing opportunities for visitors to anonymously report incidents or provide feedback about their experiences to management
7.	Trying to find out requirements for training on the equipment	X			X	X		· Including information about opportunities to participate in the space on exterior doors or windows, and on an official makerspace website · Regularly reminding staff members about training procedures and how they can best direct new students towards these resources
8.	Completing online and in-person training modules	X			X	X		· Ensuring that the makerspace website stays up to date with training appointment sign-up slots, allowing walk-ins and group sign-ups, asynchronous and synchronous options, etc.
9.	Going back to the space to complete your group assignment	X				X		· Offering student–student staff partnerships for students who are returning for the first time after completing a training module · Ensuring students’ training records are kept up to date in a system that easy to use and access for staff who are verifying training requirements · Providing feedback to faculty members about students’ experiences with group projects in the makerspace, including how to best support students’ varying levels of expertise
10.	Thinking about whether to visit the space again	X	X		X	X	X	· Including example student projects with a range of complexity and a variety of personal and more academic projects throughout the space · Showcasing those projects that may be outside of the range of what students see as “engineering making” in an “engineering makerspace” · Hosting a variety of events (rather than only a hack- or make-a-thon) to encourage engagement within the space (e.g., Newcomer’s Night, Laser Cut your favorite Literary Character Night, BYO T-Shirt Embroidery Hour, partnership events with student organizations that support non-dominant students, etc.)

¹ Barriers Faced: (1) Time, (2) purpose, (3) requirements, (4) technical skills, (5) social barriers, and (6) design of space.

5.5. Implications

Some methods for supporting students' interest in visiting makerspaces are simple questions of advertising and operating logistics. For instance, using as many modes of advertising as possible to communicate information to students about the space may reach broader audiences and reduce misinformation about the purpose of a makerspace and the requirements for visiting. Makerspace administrators and departments housing makerspaces should consider not only posting information about the makerspace outside of the facility itself and on an official makerspace website, but also pushing out information through other channels like departmental listservs, student service offices, and flyers in the building, and embedding information in places students will be required to engage with the material, like training modules in first-year courses, or tours of the facility during first-year orientations. Displays and purposeful advertising of examples of students' personal projects (sometimes seen as outside of the scope of traditional engineering making) could counteract students' feelings of having no purpose in the space; partnering with university-wide marketing departments, rather than engineering-specific creators, could be one avenue for creating more inclusive marketing materials, which could highlight a broad range of projects, advertise in every department, and have an explicit goal of not reinforcing stereotypes about engineers and what they do in the space.

Students shared that they have the most time to explore extracurricular options like the makerspace at the beginning of semesters; makerspace should offer and promote tours, group trainings, open house events and special events like 'Newcomer's Night' frequently during the early weeks of a semester. Outside of providing additional opportunities for students to take their own initiative to visit the space, requiring students to learn and participate in the space via tours, class projects, club meetings, etc. has some potential for increasing students' comfort with the space, but also comes with the risk that a domineering team member will simply complete the project on their own. Still, prior research suggests that requiring students to visit may mitigate students' fears and increase their likelihood of returning [58].

During students' early experiences with the space, it is essential that makerspace administrators and staff members are careful and intentional in communicating the values of the space; we must all thoughtfully work to "change the narrative of who makers are, what making is, and who belongs in makerspaces to reduce barriers and create inclusive making communities" [10] (p. 700). As a start, makerspace leaders can promote opportunities to engage with a wider variety of projects, such as the "everyday practices that have been the historical domain of women" [41] (p. 212) like crafting and sewing, and they should place relevant materials and equipment prominently within the space (i.e., not sidelined as lesser than). Further, students' own "powerful forms of knowledge and practice" [7] (p. 763) such as "the vernacular engineering of Latino car designers" [41] (p. 207) should be valued and respected in these facilities.

Meaningful making does not need to include a large-scale and technocentric project that spans an entire semester or school year (e.g., engineering senior design projects); instead, educators should offer more varied points of entry to making, as research indicates that students can thrive with more flexibility during making activities [44]. Smaller, less-time-consuming, or "uncreative" projects [48] (p. 20) such as 3D printing a box to learn how to use the software and the machine—projects that might serve as literal building blocks towards technical competencies—should not be trivialized as lesser than. Educators should encourage "more craft-oriented forms of making" [48] (p. 7), rather than dismissing them as "irrelevant to anything educational" [10] (p. 710).

Makerspaces, or the departments that house them, should offer regular DEI professional development for professional and student staff; these conversations need to explain concepts like implicit bias, and include examples of students in makerspace who are approached or not trusted because of how they look. Additionally, makerspaces should regularly solicit feedback about student experiences from their participants (and especially

from students who are opting not to participate) and offer opportunities for visitors to anonymously provide feedback about their experiences in the space to management.

6. Conclusions

In this paper, we investigated perceptions of makerspaces amongst non-dominant undergraduate students using the lens of Social Boundary Spaces [50,54,55]. In reflecting on their reasons for not visiting or returning, students' interview responses illustrated several barriers to successfully crossing the boundary into the STEM makerspace, including (1) not having enough time, (2) not having a need or purpose to visit the space, and (3) not having or knowing how to obtain the proper certifications for using the equipment. Students find approaching makerspaces to be intimidating because of (4) the design of the space itself and (5) the perceived technical skillset of the students already in the spaces. Additionally, non-dominant students face (6) barriers rooted in the hegemonic, marginalizing norms prevalent in engineering.

We can help alleviate barriers to participation and support students' continued involvement in STEM makerspaces by offering learners flexibility and varied points of entry into making. Meaningful making does not need to include a large-scale and technocentric project and smaller, less-time-consuming projects like 3D printing a box should not be trivialized. Outside of providing additional opportunities for students to take their own initiative to visit the space, requiring students to learn and participate in the space via tours, class projects, club meetings, etc. has some potential for increasing students' comfort with the space. That said, students' early experiences in the space can be critical moments, where negative or confusing experiences may actually deter future engagement there. It is essential that makerspace administrators and staff members are careful and intentional in communicating with makerspace participants and are actively working to foster an inclusive and welcoming learning environment.

We note a few avenues for future work. While students' sexual identities and disability identification statuses were collected as part of the survey-based recruitment strategy, neither of these social identities were prevalent components of our discussions with students; future work should consider investigating barriers specific to these identity groups, especially since makerspaces are an informal education setting that may be largely outside of the scope of formal accessibility accommodations provided by universities. Further, this work was specific to only one university makerspace, but some interviewees had had experiences in multiple makerspaces; research investigating students on the boundary of multiple makerspaces could provide more generalizable recommendations for supporting inclusivity in these spaces.

Author Contributions: Conceptualization, M.E.A.; methodology, M.E.A.; software, M.E.A.; validation, M.E.A. and A.B.; formal analysis, M.E.A.; investigation, M.E.A.; resources, M.E.A.; data curation, M.E.A.; writing—original draft preparation, M.E.A.; writing—review and editing, M.E.A. and A.B.; visualization, M.E.A.; supervision, A.B.; project administration, A.B.; funding acquisition, A.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by a grant from the National Science Foundation (#2044258). Opinions reflect those of the authors and do not necessarily reflect those of the granting agency.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of The University of Texas at Austin (Project 2018020093, approved 15 May 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is unavailable due to privacy restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Interview Protocol

1. Can you start by just telling me a bit about yourself?

2. Can you define what “making” means?
3. In what context did you first hear or learn about making?
4. Are you interested in making?
5. Can you think of a time when you’ve made something?
6. Do you have any hobbies or participate in any student orgs here?
 - a. Which ones?
 - b. Do you think of any of those as “making”?
7. Do you know anyone else who “makes”?
8. Can you tell me again what you think of the makerspace?
9. Have you visited the space since you took the survey?
10. Do you have any interest in visiting the makerspace?
 - a. If yes, why haven’t you visited?
 - b. If no, why not?
11. What do you think happens there?
12. What do you think it would feel like to go into the makerspace for the first time?
13. If you could design your ideal makerspace, what would you want to see in the space?
14. Is there anything else about making or makerspaces that you think is missing from this conversation?
15. Do you have anything else you’d like to add?

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