



Article

Understanding Equity of Access in Engineering Education Making Spaces

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Abstract: The goal of our exploratory study was to examine how management and staff in engineering education making spaces are enacting equitable access amongst their users (e.g., students). We examined six different making space types categorized by Wilczynsky's and Hoover's classification of academic makerspaces, which considered scope, accessibility, users, footprint (size), and management and staffing. We reviewed research memos and transcripts of interviews of university makerspace staff, student staff, and leaders/administrators during two separate visits to these places that took place between 2017 and 2019. We inductively and deductively coded the data, and the findings suggested that equity of access was situational and contextual. From the results, we identified four additional considerations needed to ensure equitable access for engineering education making spaces: (a) spaces designed and operated for multiple points of student entry; (b) spaces operated to facilitate effective student making processes and pathways; (c) threats to expanded access: burdens and consequences; and (d) elevating student membership and equity through a culture of belonging. Together, the findings point toward a need for developing a more nuanced understanding of the concept of access that far supersedes a flattened definition of access to just space, equipment, and cost.

Keywords: access; equity; makerspaces; engineering; making spaces



Citation: Villanueva Alarcón, Idalis, Robert Jamaal Downey, Louis Nadelson, Yoon Ha Choi, Jana Bouwma-Gearhart, and Chaz Tanoue. 2021. Understanding Equity of Access in Engineering Education Making Spaces. *Social Sciences* 10: 384. <https://doi.org/10.3390/socsci10100384>

Academic Editor: Nigel Parton

Received: 1 September 2021

Accepted: 6 October 2021

Published: 13 October 2021

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1. Introduction

Makerspaces are commonly described as physical spaces where individuals come together to creatively make products and artifacts (Halverson and Sheridan 2014). In university settings, makerspaces have been designed to support collaborations between and among students. Frequently, collaborations between students occur through course activities (e.g., projects) that require the creation of products developed from tools and resources provided within these spaces (Lande et al. 2013). In engineering, the accreditation requirements of the field necessitate that these spaces are designed to support elements of the undergraduate engineering curriculum, such as designing and prototyping (Hira et al. 2014; Lande et al. 2013; Wilczynski 2015). While the naming of the spaces may vary (e.g., machine shops, prototyping centers, makerspaces) (Youmans et al. 2018; Youmans et al. 2019), they can be very useful for enhancing engineering students' knowledge of the profession (Bouwma-Gearhart et al. 2021; Youmans et al. 2018). Through sustained engagement in these making spaces, it is believed that students develop a sense of membership and belonging (e.g., Nadelson et al. 2019). For the purpose of this work, we

will primarily use the term “making spaces” over makerspaces; this is connected to our prior work (Bouwma-Gearhart et al. 2021; Nadelson et al. 2019; Youmans et al. 2018; Youmans et al. 2019) situating a need for the purposes of a makerspace, which is to generate community-wide connections (academic and non-academic) versus making spaces that are disciplinary, have specified goals, and catered to a particular audience (i.e., engineering) to gain pre-established learning goals and skills (e.g., technical skills) (Youmans et al. 2018; Youmans et al. 2019).

Even in recognizing the need to rename academic makerspaces, at least for engineering, criticisms have arisen. Recent literature has suggested that the learning environments created in these spaces are tailored to white, male, and middle-class groups, and exclude minoritized groups, hindering efforts to increase equitable participation in engineering (Barrett et al. 2015; Greene et al. 2019; Martin 2015; Roldan et al. 2018; Wilczynski 2015). Furthermore, even though making spaces are increasingly being integrated into engineering preparation curriculum, we have little understanding of how these spaces are designed for equity in access, particularly for individuals from underrepresented and minoritized groups. Our research addressed this gap in the literature by seeking to understand the following research question: *In what ways are the designs and operations of an engineering education making space influencing access among its users (i.e., engineering students)? What additional access considerations for engineering making spaces need to take place to allow for equitable access among its users?*

2. Literature Review

Making spaces in engineering education programs are typically organized differently compared to community makerspaces. Makerspace categorization provides important information about how the spaces are designed for access, resources, and staffing (Hira and Hynes 2018; Roldan et al. 2018). For example, community makerspaces are designed for the public so that its participating citizens can holistically make/create and have equitable interactions between people, means, and activities (Hira and Hynes 2018; Roldan et al. 2018). In contrast, making spaces in engineering education programs are designed for a specified population (engineering students) with the purpose of enhancing learning transfer between course work and the profession. Despite this recognition, the terms makerspaces, academic makerspaces, and making spaces are used interchangeably. As such, the literature sections below reflect the fluctuating use of terms and classifications.

2.1. Categorizing Makerspaces

There have been multiple approaches to categorizing the purposes of makerspaces. For example, Hira and Hynes (2018) developed a conceptual framework for K-12 education makerspaces situated in what the authors defined as *people*, *means*, and *activities* to elucidate the educational foci of these spaces. Hira and Hynes (2018) maintain that people-focused makerspaces serve as a space informed by “the goals of individuals or the community of individuals the space serves” (p. 5). The emphasis of means-focused makerspaces is on the tools and technologies that support the process of making (e.g., prototyping centers). Activities-focused makerspaces are designed to support an activity or event (e.g., library-sponsored event). Hira and Hynes (2018) posit that educational makerspaces are typically considered activities-focused, where the means (i.e., tools and technology) become integral to the events taking place in these spaces. The categorization of makerspaces becomes useful when considering the resources, funding, and staffing of these facilities (Wilczynski and Hoover 2017).

Within higher education, Wilczynski and Hoover (2017) developed a five-attribution model for classifying academic makerspaces (see Table 1). The model is based on: (1) the scope of higher education (an assessment of the relative extent to which the space is integrated into a campus): S-1 to S-3; (2) the accessibility of makerspaces (the degree by which a user is permitted to use the space): A-1 to A-4; (3) the number of users (a measure of the energy, engagement, and impact of a space): U-1 to U-4; (4) the footprint (a measure

of the physical areas of the makerspace): F-1 to F-4; and (5) the management and staffing (an assessment of who is leading and operating the spaces): M-1 to M-3. When these categories are taken into consideration by administrators and leaders in the planning and maintaining such a space, its operation will likely reflect the values and missions of the institution, which in turn, influences the types of learning activities students might engage with in these spaces (Wilczynski and Hoover 2017).

Table 1. Summary of the Wilczynski and Hoover classification of academic makerspaces (Wilczynski and Hoover 2017).

Classification	Parameters	Description
Scope	S-1	A program that is within its first 2 years of existence
	S-2	A program supporting a minimum of one university mission
	S-3	A program supporting three or more university missions
Accessibility	A-1	Access restricted to students enrolled in department courses
	A-2	Access restricted to individuals from sponsor department
	A-3	Access restricted to individuals in a specific school
	A-4	Access provided to the entire university
Users	U-1	Less than 100 users
	U-2	100 to 1000 users
	U-3	1000 to 3000 users
	U-4	>3000 users
Footprint	F-1	<1000 sq.ft. (<93 sq. m.)
	F-2	1000–5000 sq.ft. (93–465 sq. m.)
	F-3	5000–20,000 sq.ft. (264–1858 sq.m.)
	F-4	>20,000 sq.ft. (>1858 sq.m.)
Management and Staffing	M-1	Mainly student-managed and staffed
	M-2	Faculty/professionally managed and professionally staffed
	M-3	Faculty/professionally managed with hybrid (student/professional) staffing

To better understand our sites, we categorized our six sites using the Wilczynski and Hoover's classification system of academic makerspaces (2017), as shown in Table 2. We found that the accessibility and footprint (physical size of the space in square footage or square meters) did not correlate with each other, as a larger space did not necessarily equate to increased access. For example, as shown in Table 2, there was one A-3 site that had an F-4 footprint and one A-4 site that had an F-3 footprint.

Table 2. Classification of the six engineering education making spaces (at the time of this study) using Wilczynski and Hoover's classification of academic makerspaces (2017).

Site	Accessibility	Footprint	Scope	Management and Staff
Site 1	A-3	F-3	S-1	M-3
Site 2	A-3	F-4	S-2	M-3
Site 3	A-3	F-3	S-2	M-3
Site 4	A-4	F-4	S-2	M-3
Site 5	A-4	F-3	S-1	M-3
Site 6	A-4	F-4	S-3	M-3

2.2. Designs for Engineering Education Making Spaces

The physical, climate, and programmatic features of a making space have recently been associated with engineering students' individual sense of comfort and belonging to the space (e.g., Bouwma-Gearhart et al. 2021; Choi et al. 2021; Lenhart et al. 2020). In six engineering education making spaces across the United States, Bouwma-Gearhart and colleagues (2021) identified barriers, such as the cost to students and requirements for students to be eligible to access the space (e.g., technical experience, hours of operation, location), as limitations to creating a truly inclusive space. Similarly, it was suggested

that while engineering education making spaces serve as a space for community-building, there is a potential for a shift to the common focus on the individual or isolating learning experiences in traditional engineering instruction (Lenhart et al. 2020). Villanueva Alarcón and colleagues (2021) have pointed to the need to understand the culture of belonging created in engineering education making spaces and how they support or do not support equity of access.

Furthermore, Fasso and Knight (2020) detail how intentional designs of school makerspaces can support the professional identity development of their students. Fasso and Knight (2020) found that intentional designs of makerspaces that include an intertwining of making activities with students' needs, interests, and backgrounds will help create socio-cultural spaces "where making, interaction, modelling, and narrative explicitly scaffold and support identity-building" (p. 290). Fasso and Knight (2020) suggest that creating a balance between structured and open-ended activities within these makerspaces supports how students negotiate and develop identities as professionals. This observation from Fasso and Knight (2020) has also been suggested to enhance students' access to academic makerspaces (Greene et al. 2019; Franzway et al. 2009; Hui and Farnham 2017; Kafai et al. 2014).

Building upon the framework of McMillan and Chavis (1986), Roldan and colleagues (2018) have detailed situations where the intentional design of academic makerspaces took into consideration issues of equity. Roldan and colleagues (2018) explored how a sense of community might be achieved for underrepresented engineering students through four intentional mechanisms: (1) membership, (2) shared emotional connection, (3) fulfilment of needs, and (4) influence. Membership, through member acceptance, is the feeling that one belongs because the individual is aligned with how the community defines itself. Shared emotional connection, either through perspective-taking or members' signals of approachability, results in individuals being able to relate to others' shared experiences and time within the space. Fulfilment of needs via structured help-seeking activities is the assurance that individual needs are met by the accessibility of resources for members of the community. Influence occurs when the individual inspires the community, and the community impacts the individual. Of the four mechanisms, membership is believed to influence academic achievement, social acceptance, and persistence most strongly in engineering (Hui and Farnham 2017; Kafai et al. 2014; Roldan et al. 2018). Membership requires belonging (Roldan et al. 2018) and belonging requires access (Roldan et al. 2018; Villanueva Alarcón et al. 2021). Even cultures of belonging cannot co-exist with equitable systemic practices for access (Villanueva Alarcón et al. 2021). Without understanding the connections between these constructs, it will be difficult to situate the experiences that users could have within these making spaces. Consequently, our understanding of how groups' marginalization or support structures are enacted in these making spaces is severely limited. Our research focused primarily on the equity of access in engineering education making spaces and was viewed as a critical indicator of the culture of belonging being created (Villanueva Alarcón et al. 2021).

2.3. Working Definitions of Access from Engineering Education Making Spaces

Informed by the work of Roldan and colleagues (2018), Hira and Hynes (2018), and Fasso and Knight (2020), we wanted to summarize current views of access for engineering education making spaces. We wanted to understand if engineering education making spaces were intentionally designed and operated for equity of access. We posit that leaders, administrators, instructors, and staff in making spaces influence equity of access by creating environments where students interact with other people, resources, and activities that may or may not nurture a sense of belonging in engineering. In our earlier work, we defined the student's sense of belonging in engineering making spaces (e.g., Nadelson et al. 2019) as requiring the motivation or a need to be part of the community to complete personal and/or professional goals. It seems, therefore, important to understand how leaders and staff in these making spaces envisioned, developed, and continued to modify

these spaces for equity of access. Again, the focus of the research for this manuscript was on equity of access, with a ‘sister’ study and publication focusing on the culture of belonging (Villanueva Alarcón et al. 2021).

For our research, we developed a working definition of equity of access based upon work from prior authors (Fasso and Knight 2020; Hira and Hynes 2018; Roldan et al. 2018). For this manuscript, our working definition for *equity of access* consists of the affordances, histories, relationships, structures, communities, and individuals that draw upon the broad contexts, activities, and experiences of making for the purpose of exchange and mutual growth. At the same time, we want to clarify that we understand that access and membership (through belonging) are not mutually exclusive, but rather interactional and dependent upon each other (Roldan et al. 2018). In Table 3, we present prior definitions of access for engineering making spaces, include some examples, and then synthesize these to develop the working definition provided earlier in this paragraph.

Table 3. Prior definitions and examples of access to develop a working definition of equity of access for engineering education making spaces.

Term	Prior Definitions	Examples
Access	“... the activities that students in school Makerspaces partake in are contingent upon the affordances allowed by the existing curriculum and resources spent ...” (Hira and Hynes 2018, p. 8) “Includes individual and community narratives that draws together the materials, activities, and relationships to establish new ideation of one’s identity” (Fasso and Knight 2020, p. 281)	“... understanding the history of the making community with its roots in white, male, middle-class activity and the history of marginalized students hoping to get involved ... shape their relationship with the community” (Roldan et al. 2018, p. 753) “The purpose of such spaces is to serve as venues for activities of a particular kind ... education activities” (Hira and Hynes 2018, p. 5–6) “Broad range of situations, materials, and activities designed for diverse, gendered, and cultural preferences” (Fasso and Knight 2020, p. 287)

3. Materials and Methods

3.1. Study Sites

Our study is part of a larger National Science Foundation project exploring the experiences of faculty, staff, and students at engineering education making spaces. The goal of the larger project was to explore issues of access, success, persistence, and belonging on students’ professional identity development as engineers in these making spaces (e.g., Bouwma-Gearhart et al. 2021; Choi et al. 2021; Lenhart et al. 2020; Nadelson et al. 2019; Villanueva Alarcón et al. 2021; Youmans et al. 2018; Youmans et al. 2019). From this work, we collected survey responses, interview data, observational data, and researcher memos/field notes. For our research study, we used interview data and researcher memos/field notes as our data sources. All engineering education making spaces originated and were housed in a College of Engineering within doctoral universities with high research activities (Indiana University Center for Postsecondary Research 2017). However, the level of access of the space varied, as indicated in its mission and location (Wilczynski and Hoover 2017). Two of the sites were in the Southwest region of the U.S., one was in the Midwest part of the U.S., and the remaining sites were in the Western part of the U.S. We used Wilczynski and Hoover’s (2017) classification of academic makerspaces to classify our sites (see Table 2). It is important to note that we did not explore A-1 and A-2 levels of access in our study, since we wanted to only focus on those engineering education making spaces that had affiliation with a college or department of engineering, which according to Wilczynski and Hoover’s classification (2017), are A-3 and A-4 sites. For this study, we had three sites classified as A-3 and three additional sites classified as A-4. Data analysis and findings were based on the aggregation of these sites per classification.

3.2. Research Questions

We hypothesized that if an engineering education making space was intentionally designed for access, then the culture created in these spaces would be more equitable to their students. Thus, the research questions (RQs) are the following:

In what ways are the designs and operations of an engineering education making spaces influencing access among its users (i.e., engineering students)? What additional access considerations for engineering making spaces need to take place to allow for equitable access among its users?

3.3. Data Collection

For our exploratory study, we applied a phenomenological/phenomenographical approach (e.g., [Daly 2008](#); [Dringenberg et al. 2015](#); [Youmans 2020](#)) to better understand the essence of individuals' lived experiences with access and compare the differences that varying classifications of access may afford. From 2017 to 2019, members of the larger research team conducted two sequential visits to six different university-based engineering education making spaces. In these sites, we conducted semi-structured interviews with a total of 45 faculty, 29 staff, and 148 students working within and having used the spaces. Our prior research explored the experiences from management (director, assistant director, with and without instructor roles) and staffing (staff—industrial or machining specialists—with instructor roles, student-staff) in these sites ([Fasso and Knight 2020](#); [Nadelson et al. 2019](#)), and of students (e.g., [Lenhart et al. 2020](#); [Nadelson et al. 2019](#)). However, we have not explored these interviews of the former population through the lens of access. For this study, it is important to mention that we did not analyze the student interviews in depth, although they have previously been explored among our research team from the lens of affordances, motivation, and professional identity development ([Lanci et al. 2018](#); [Nadelson et al. 2019](#)). This is to say that our primary focus was on faculty and staff and the ways in which they viewed and/or create equitable access and belonging.

The site interviews of interest were further collapsed by the level of access (A-3, open to a college of engineering or school—a total of three sites; A-4, open to the university at large—a total of three additional sites) using [Wilczynski and Hoover's \(2017\)](#) classification of academic makerspaces. These transcribed A-3 or A-4 interview clusters were constantly compared against each other in the form of versus coding (e.g., [Daly 2008](#); [Dringenberg et al. 2015](#); [Youmans 2020](#)), and findings were corroborated through the student interviews for member-checking purposes ([Birt et al. 2017](#)). Researcher memos and reflection discussions took place between the first three authors, and refinements were discussed with the remaining authors. All authors contributed to the interpretations and representative examples presented in this manuscript.

4. Results

From the qualitative data, we identified four themes connecting to equity of access in engineering making spaces: (a) spaces designed and operated for multiple points of student entry; (b) spaces operated to facilitate effective student making processes and pathways; (c) threats to expanding access: burdens and consequences; and (d) elevating student membership and equity through a culture of belonging.

4.1. Spaces Designed for Multiple Points of Student Entry

Leaders in the three A-3 sites and the remaining three A-4 sites recognized that the affordances of the spaces themselves (e.g., [Bouwma-Gearhart et al. 2021](#); [Choi et al. 2021](#); [Lenhart et al. 2020](#)) would help create equity of access by increasing the use of materials, activities, and types of projects developed or made available in these spaces ([Fasso and Knight 2020](#); [Hira and Hynes 2018](#); [Roldan et al. 2018](#)). In addition, the leaders at both A-3 and A-4 sites increased the physical size of the facilities (square footage), the time of operation, and the available equipment for making as another way to increase access:

*“And it’s like we have policies and procedures and stuff like that, but we want you to feel limitless . . . I think that, you know, one way that that happens is that **we allow like the personal project thing**. We don’t sit here with a clipboard being like, “Well, what is this used for?”. You know, like students print D&D figurines, or make wild contraptions”.*

(Director, A-3, Site 2)

*“I think that this sort of space, you know sort of transformed the class...so just having **access to 3D printers**, allows the students to make the design... I think that one of the challenges that kind of the students face is the **operating hours** and the like you know you have to be here for the entire time of your print, so it does limit the time you can assign to students, you know cause realistically, like the hours were **10 am-8 pm**, and for most of the semester it is now **8 am-8 pm** . . . ”*

(Staff, A-4, Site 4)

However, the leaders of the A-3 and A-4 sites had different thoughts about what would be required for engineering students to have equitable access to their making spaces. For A-3 sites, the leaders recognized access as including policies and procedures to ensure that prospective and current undergraduate engineering students could use the space. In addition, the leaders acknowledged that access to the spaces expanded opportunities for students to be engaged in engineering activities (such as rapid prototyping) in their early undergraduate coursework. The leaders shared that access was seen to both open student entry to the profession and create a sustainable pathway of future student workers to the space. At the same time, leaders of some A-3 sites maintained specific restrictions or requirements before students were permitted to access and utilize the space (e.g., computer-aided design drawing expertise, completing machine use tutorials). For A-3 sites, access was limited to students who were enrolled in an undergraduate engineering degree program.

*“But to back up a little bit, so kind of before this [site], we started the freshmen design program. There were other schools that were doing a freshmen engineering design program but we found here [in site] is that we were bringing prospective students through here constantly the junior level high school level whatever. And they were like, “**This is great, I want to go to [site], so I can play in a design [site]**”, and we would be like, “**Yeah, but you’ve got to wait three years before you can**”. And it just wasn’t flying, so now we have an **elective level introduction to engineering design**...[...]. So we started capstone, but we added freshmen and then we added different courses that you’ll seen in here that all ultimately sort of lasted so that student can get the engineering design minor... **About half take that um, and then we will have students just dive in, and then they become our lab leaders, and then they end up doing our summer seed internship program** and sometimes we have, we do international design programs and sometimes they do those things and so those that dive in and do it, do so in a really big way”.*

(Instructor, A-3, Site 3)

*“And it’s like we have **policies and procedures and stuff like that, but we want you to feel limitless**. That most of the limits should be on you and your willingness to invest the time. Because, in reality, that’s like the best case...that’s the best scenario and that’s, in reality, what your real limit is you. Like how much time you’re willing to put into it.”*

(Director, A-3, Site 1)

“I don’t think they’re very nice to people who are outside of the school, outside of the engineering school. It’s like, they don’t think the same. Because you have to have drawings, CAD drawings before you use these services. If you’re in the art school, you’re not gonna know how to do that, or probably be familiar with what CAD is”.

(Student-Staff, A-3, Site 2)

For A-4 sites, there was recognition from the leaders that their spaces needed to widen their admissions to a greater variety of students and to not just engineering, and suggested that the name “makerspace” itself cued exclusion. It is important to mention that there was recognition for the need to be more faithful to the original intent of makerspaces (e.g., [Hira and Hynes 2018](#); [Youmans et al. 2018](#); [Youmans 2020](#)) and allow other disciplines from other colleges (e.g., science, business, and art) to interact with engineering. They also acknowledged that, in order to achieve this type of access, making spaces management and staff had to create new curriculum outside of the walls of engineering education in traditional classrooms. In other words, access was viewed as breaking barriers of disciplines, curriculum, and opening interdisciplinarity, which, in some cases, led to a re-imagining how to utilize the space and attend to more profound pedagogical questions.

*“You don’t have to be a design major, you don’t have to know how to sketch, you don’t need to know anything about design thinking or be an entrepreneur in order to be an entrepreneur, or **you don’t have to be an engineer in order to appreciate working with engineers**”*

(Staff, A-4, Site 6)

*“So, that’s another way because it’s like, okay, you can only go so fast working with current faculty. Why don’t we try to **offer up our own course that is very a la carte**? So, it doesn’t really have an agenda besides the very general mission of like hands-on learning and stuff like that”.*

(Director, A-4, Site 1)

“Yeah, I think that’s one thing right there. When I think of a makerspace, it could very well be a hacker kind of club that is exclusive to particular people or a particular type of people go there and it’s hard to get in there and be a part of the group, I suppose . . . ”

(Staff, A-4, Site 5)

4.2. Spaces Operated to Facilitate Effective Student Making Processes and Pathways

Both A-3 and A-4 site leaders viewed ‘Process’ as a developmental integration or supplementation of engineering curriculum, either through training, certifications, or course offerings. On the other hand, ‘Pathways’ was viewed by the leaders as including considerations for student competency-building beyond technical skills to include professional skills (e.g., teamwork, communication). In short, processes were viewed as the technical skills that one acquires, whereas pathways consisted of the means by which said technical and professional skills are acquired. However, leaders, instructors, and staff in these engineering making spaces agreed that intentionality in creating a curriculum that will support these process and pathways is essential.

*“...but the best thing is they help create curriculum for trainings, so they sort of come up with the **curriculum or the process** or procedure or the repressor guides or whatever they know **best how to communicate with students** and how to get students to **understand the equipment so they get a promotion** they get paid more and then we have a student leader manager and he is sort of like he does our scheduling he does whatever.”*

(Director, A-3, Site 3)

At the same time, there were nuances in how processes and pathways were approached by the A-3 and A-4 site leaders. For A-3 sites, there was a more significant focus on ensuring that the engineering curriculum was attended to, although there was a recognition from the leaders and staff that personal projects are an important way to motivate students to participate more meaningfully in projects and activities in the space. As a result of the balance these A-3 sites had to strike, there appeared to be limits on who could use the space (e.g., first-year students versus senior; undergraduates versus graduates). Additionally, a lot more emphasis was placed on skills needed to support the engineering curriculum rather than allowing users to explore their own ways to engage with the space. Finally,

in recognizing the need to supplement the engineering instruction, these A-3 site leaders required accommodation to the timeline needs of engineering faculty:

“And they do offer workshops for CAD stuff. But in my opinion, I think that’s just too involved for someone who’s not looking for something like that. If I wanted to make something and I was not in the engineering school, I wouldn’t be like, “Wow. I better make this on CAD first and then have a technical drawing of this””.

(Student-Staff, A-3, Site 2)

“They don’t allow graduates to utilize the space unless they have an undergrad on their team. They have a pretty wide-open beginner course which is curtailed to and for newbies—and not just engineering students, but to all.”

(Staff, A-3, Site 3)

*“So, that’s another way because it’s like, okay, **you can only go so fast working with current faculty.** Why don’t we try to offer up our own course that is very a la carte? So, it doesn’t really have an agenda besides the very general mission of like hands-on learning and stuff like that.... **The academic credit is good. It’s also a pathway for people outside engineering.** Because otherwise, it’s like, “Well, how do we let them come in?” Yeah, it’s like really good”.*

(Director, A-3, Site 1)

*“I think that, you know, one way that that happens is **that we allow like the personal project thing.** We don’t sit here with a clipboard being like, “Well, what is this used for?” You know, like students print D&D figurines or make wild contraptions”.*

(Staff, A-3, Site 1)

For A-4 site leaders, a more prominent focus was given to expanding the curriculum beyond traditional norms of engineering education. There was a larger recognition that seminars and certifications might be a way to equip users to use the space rather than to supplement engineering instruction:

*“You don’t have to be a design major, you don’t have to know how to sketch, you don’t need to know anything about design thinking or be an entrepreneur in order to be an entrepreneur, **or you don’t have to be an engineer in order to appreciate working with engineers.**”*

(Instructor, A-4, Site 6)

“Oh yeah, just to have the large space, we did all kinds of movement explorations and things that we wouldn’t be able to do unless we were in here. Then they also performed their own performances, and they used the whiteboards. They all had to use some kind of object. They had to think about how they were presenting it in space and how it was framed. They did all things, they used the table, they used the whiteboards, they used chairs to create little mini performance spaces.”

(Instructor, A-4, Site 6)

4.3. Threats to Expanding Access: Burdens and Consequences

It is important to mention that, for many spaces, particularly those that aimed to expand access (A-4 sites), there was a recognition by its leaders that the way to enable access is through the people occupying these spaces.

*“...So now **I’m not talking this is really about the maker space.** I’m talking about the people in the maker space, which is part of what makes the whole construct if you will. So **it’s human interactions.** At the beginning I was not part of the group, and then I was”.*

(Student/Staff, A-4, Site 6)

At the same time, people working in these spaces (e.g., staff, student staff) expressed concerns about the inequitable threats to expand the access that the space leaders envisioned. For example, many A-4 site leaders discussed the need to expand access by buying more equipment or increasing the size of the space. With those types of expansions, questions arose from the staff and leaders about ways to balance the costs of expansion with the fixed funds that they may receive from endowment or business donations and partnerships. Leaders spoke about balancing the budgets by not hiring student teaching assistants or student workers to become coaches. At the same time, these same leaders expressed concerns of the consequence to student belonging that may be compromised if student teaching assistants or student workers are not present in these spaces and the burdens it may pose on their current staff.

"We can now build this course at scale without requiring 20 TAs, which would be too expensive. Instead, we can use one to two TAs and many coaches and one instructor".

(Leader, A-4, Site 5)

Interviewer: "Yeah, so staffing is an issue?"

*Staff: "Staffing is a huge issue. But, regardless, I think I could propose something that has a couple people and just say this is what I want to do and propose it to the engineering people and see if they...the issue with those classes is you can only have like four or five people in those classes, and they're one-credit classes, and they come, and they meet three hours a week or whatever, and they come and build something, and you've got to be ready to help all four of them or five of them or whatever. When I was doing those classes, I did one called Intro to Rapid Prototyping where I taught them all the maker machines, and now that we had a 3D printing laser cutting, they built a project, they learned how to solder some just basic stuff, but the issue was they wanted me to do 20 people, and I think I've got like 10 usually. **It was about the most I get, but the college really wanted more people, and I'm just like why.... Only one of me and those classes really one person almost isn't even enough for 10 people.**"*

(Leader, A-4, Site 5)

4.4. Elevating Student Membership and Equity through a Culture of Belonging

Both A-3 and A-4 site leaders recognized that student belonging could be created if the culture around the making space messages membership (sense of community) and equity to the students. However, both A-3 and A-4 leaders had different views of what community-building and this form of messaging entails. For A-3 sites, most site leaders and staff equated belonging with binarized views of gender and did not speak to or about other domains of diversity, such as race, ethnicity, and disability, among others.

*"And um cause I started collecting that data just a few years ago so when they register they can um it's an option that they can **select a gender and so we can kind of keep those statistics**, and it is very interesting because something very natural happened about that here and it's that we really the technicians the staff most of the faculty **we really do not see gender in here at all**. I mean I joke that there are **all the same annoying students in here to me**".*

(Staff, A-3, Site 3)

*"...maybe **women do this more this more than guys** [sic] but certainly tell themselves how much more prepared everyone else is. And so um putting them in a situation to where they can see you know he is struggling to make a square cut as much as I am or whatever I think is a really good thing and then now our TAs our Lab, I would say we had 4 years of our lab leader program where we actually designated one of them as the head and have them pick leaders from the other group and **really lead that group, and it has been 50/50**".*

(Staff, A-3, Site 2)

In A-4 sites, on the other hand, leaders and staff spoke about the need to look beyond the four walls of a space and consider the contextual factors that may influence the students entering the space. However, again, no mention of other domains of diversity (e.g., race, disability, ethnicity, etc.) was noted. This omission of other domains of diversity and their intersectionalities was predominantly shared amongst self-identified minoritized student/staff workers, who mentioned the need to decolonize these spaces intentionally.

Interviewer: "So do you think [this site] supports diverse identities, diverse genders, diverse people? Do you think [this site] helps?"

Student/Staff: "I think there might be the potential to do that? I don't think I could say they do ... Anyways, so even though I do see the potential that make spaces have, I do think that the moment they are being used now might be some form of neo-colonialism for some contexts".

(Student/Staff, A-4, Site 6)

While these student workers offered no suggestions to improve the space, there was a recognition of a need for individuals who work and lead the space to consider the mindsets and personal challenges that students may carry with them when entering the space.

*"But at the beginning, it was like, fitting in the community. It's like, okay, there's social interactions. That's how we work, right? **There was an established community [in this site], and I was not part of the community yet.** So, at the beginning I was super... **I'm coming from [country of origin], I also have this or used to have this colonized mind,** however you want to call it. So, I was very scared of using machines that I didn't know how to use and mess up. And one of the people there was initially... **I was very intimidated about the person there, the manager or whatever.** So, **after a while I was actually, I don't know how it happened, but I made it into the group, and now I felt very comfortable about being been in the space and having friends and talking and whatever, but it was not immediate**".*

(Student/Staff, A-4, Site 6)

"Just a lot of mental health stressors on that. When they come in a classroom like this, and they realize "well my knowledge, my way of knowing is valuable," and all of a sudden they feel value themselves and can find a major that supports that or equally could contribute to [inaudible 00:31:08] and that imposter syndrome can fall away and go well "I have knowledge, my teacher there she likes to dance, she has value, there is value in this, she's a smart person that's contributing to the ideas of the team"

(Instructor, A-4, Site 6)

5. Discussion

In this exploratory study, we wanted to understand how the leaders, instructors, and staff of engineering making spaces ideated and designed for access, and if these views changed across different levels of access for and within these spaces. We also explored what additional access considerations could be acknowledged in engineering spaces for making. While this study may not be generalizable, we believe that many of the findings that we presented may be transferrable for different contexts and types of engineering spaces such as these.

In our study, we found that *equity of access* was situational and contextual and, as such, served to expand the existing definitions from Roldan and colleagues (2018) about access to include added considerations for: (a) spaces designed and operated for multiple points of student entry; (b) spaces operated to facilitate effective student making processes and pathways; (c) threats to expanded access: burdens and consequences; and (d) elevating student membership and equity through a culture of belonging.

For the first theme, multiple points of student entry, we found that while some A-4s are technically open to all students, the in-roads (points of entry related to the curriculum and course offerings) are limited. As a result, the classes provided within these spaces may not necessarily translate to other disciplines. This parallels what we found in our previous work regarding the affordances and boundaries created in these spaces for students and faculty (Choi et al. 2021; Lenhart et al. 2020). Expanding who can use the space, without restrictions to prior certifications or trainings (e.g., CAD experience), may help move these spaces toward the original intent of makerspaces that consider people, purposes, and means (Hira and Hynes 2018), and may influence processes and pathways stemming from these spaces in engineering. At the same time, we recognize that safety is an important consideration for engineering education and do not recommend its complete removal but rather its re-imaging for equity of access.

For the second theme, spaces operated to facilitate effective student making processes and pathways, it was evident that there is a need to create disciplinary-crossing opportunities in the engineering curriculum. One notable exception to this suggestion was found in one of the A-4 spaces, where engineering students partnered with the arts/theatre department as part of a course. Due to the openness of the space, moveable tables, and whiteboards, along with accessibility to the machines (without prior certifications or trainings), students were allowed to create novel designs while pushing the traditional boundaries of pedagogy in both art/theatre and engineering classes. At the same time, by re-imaging and humanizing the experiences of engineering education in these spaces, the process and pathways of engineering education expanded the philosophical notions of learning and how these are assessed in these spaces. Consequently, if opening access is viewed in terms of the process and pathways, where not only material products are created but where the process of becoming “fully human as social, historical, thinking, communicating, transformative, creative persons who participate in and with the world” (Salazar 2013, p. 126) occurs, more equity could be present in these spaces.

Threats to expanded access: burdens and consequences was the third theme. We found that many of these spaces equated access with more equipment, money, or physical size (square footage or square meters). This aligned with Wilczynski and Hoover’s classification of academic makerspaces (2017). However, what is missing from this classification is how budgetary restrictions or funding restrictions may result in unintended consequences to the staff or individuals who are part of the space or how reduced involvement from student workers in the space may change the dynamics of the space for students. As leaders and administrators consider balancing cost with the operations of the space, the potential cultures and environments that could be created due to leadership decisions need to be considered.

Within the fourth theme, elevating student membership and equity through a culture of belonging, we find that equity of access is inextricably linked to belonging and the present culture in these spaces (Villanueva Alarcón et al. 2021). Exemplified by and within the data, it is suggested that the cultures created conveyed messages to students that cued to them a sense of belonging consistent to the norms of the space, like the hidden curriculum of engineering (Villanueva et al. 2020). Another aspect of access that is not easily found within the simple definition presented by Wilczynski and Hoover’s classification of academic makerspaces (2017) is the notion of whom access is provided to/by. These spaces tended to operate within a closed loop that limits the access of different identities beyond the omnipresent white men in engineering; the dearth mentions of race served as evidence of this phenomenon. The only reference of diversity was that of being connected to gender, and even those sources of evidence alluded to binarized views of gender (male/female). What was most concerning was that other domains of identity diversity (e.g., race, disability, ethnicity, etc.) were never recognized by the space leaders and staff. An ahistorical understanding of diversity and the subsequent colorblind mentality and language through the lens of gender within engineering making spaces deflects and obfuscates responsibility for creating genuinely equitable and accessible spaces for all. This limited view was

summarized by one A-4 leader that stated, they fostered diversity by “make[ing] it a very inviting and warm feeling. That’s why we have the light blue walls and the tan flooring. We asked quite a few females on our staff, you know what color you like, and so it was alright we are going with this” (Site 4). While we agree that environmental factors have a significant effect upon access and belonging (Hira and Hynes 2018), we argue that more intentionality is needed to design and ideate these spaces to be truly inclusive and equitable and not to reinforce a learning environment tailored to white, male, middle-class groups who continue to exclude and restrict equitable participation in engineering (Bouwma-Gearhart et al. 2021; Choi et al. 2021; Greene et al. 2019; Lenhart et al. 2020; Roldan et al. 2018; Nadelson et al. 2019; Villanueva Alarcón et al. 2021). Studies are beginning to show that when a sense of community and belonging is created in an engineering space, students’ academic success is drastically improved (Nadelson et al. 2019; Lenhart et al. 2020; Wilson et al. 2008; Wilson et al. 2010). Thus, we call leaders and designers of these spaces to consider the decisions that they make more critically as they develop their spaces for equitable access to all in engineering.

6. Recommendations

To assist our readers in identifying ways to attend to equity of access in these engineering making spaces, we present some recommendations. Although these recommendations are not meant to be prescriptive, we understand the importance of providing tangible starting points to facilitate ideation and customizable solutions. As we have stated before, access and belonging are intertwined and interactional (Villanueva Alarcón et al. 2021). As such, we invite our readers to read our sister publication on the topic of the culture of belonging in engineering education making spaces (Villanueva Alarcón et al. 2021), which outlines recommendations based on the acronym of ACCESS (Ambient belonging; Critical hires; Community engagement; Equity; Sponsorship; Student-centered). In the same vein, we present recommendations for equity of access in this manuscript using the acronym BELONG (Bridging; Engaging; Longevity; Openness; Nuanced; Goal-oriented). In this way, we emphasize that equity of access cannot happen without a culture of belonging, and vice versa.

Bridging. While we acknowledge that processes and pathways seem to be treated separately in most other spaces, from the findings, we suggest that, for more accessibility to happen, paradigms need to be bridged. To remind the readers, in our study, processes are the technical skills that one acquires, whereas pathways are how said technical and professional skills are acquired. One way to achieve this this is to re-envision traditional pedagogy in engineering in ways that seek the professionalization of engineering students outside of the walls of their curriculum. As a recommendation, seek to create spaces where students’ assets and life experiences can be shared in ways that push the pseudo-boundaries of knowledge and expertise. Develop activities or events where students across different disciplines (engineering and non-engineering) can collaborate on, whether through a project or promotional events (e.g., contests, outreach, etc.) so that knowledge can be exchanged with each other.

Bridging also signifies the connections between technical and professional skills. While we understand that there are strong foci in professionalization in engineering curriculum, making spaces can be another platform by which these skills are encouraged and bridged. Possible activities could include hosting job interviews or preparation sessions in the spaces, oral presentation contests, or even community nights where students communicate in laymen terms how different making space equipment works or showcase products created in these spaces.

Engaging. By creating making spaces that are more interdisciplinary, intentionality is leveraged to celebrate difference in thought, background, and expertise. Engaging students in activities that are meaningful and motivational for them requires an intentional understanding of students’ interests, hobbies, and skills. As we stated in our sister publication (Villanueva Alarcón et al. 2021), finding ways to highlight or include students’ authentic

ways of being can connect students to the space and open opportunities for students to draw upon multiple contexts and experiences. For example, consider hosting gaming, hobbyist, or cultural events where students can share products created in the making space that are connected to their backgrounds. In addition, consider identifying ways to market and highlight student products throughout the school year to help other students connect with the space.

Engage the outside community (schools, parents, donors) to visit the space and connect with current or former engineering students to help all members to build trust and work together in the process of making. This will be especially important in connecting with at-risk youth through maker activities (Somanath et al. 2016).

Longevity. The longevity of an engineering education making space will strongly depend on its leadership, its succession planning, and the purposeful inclusion of diverse identities in the space. This recommendation is like the critical hires recommendation of our sister publication (Villanueva Alarcón et al. 2021), with the additional concept of ‘sustainability’. To sustain an engineering education making space, their policies and procedures must always be adapting to the needs and realities of its users. Equity of access is not just delimited to user access, but is also in the hiring of staff, personnel, and leaders that can meaningfully and sustainably ignite action and change in their spaces over time.

Openness. Alongside longevity, there must be an openness for equity of access. This cannot happen unless the leadership, policies, and procedures are open to adaptation and change. Openness happens when leaders, staff, faculty, and students listen to each other’s concerns genuinely and the needs of all parties are considered. This means finding ways to gather and collect perspectives of all parties, either through surveys or interviews throughout the academic year, with a commitment to continually refine and adapt the curriculum, activities, events, or other connected venues in the engineering education making space.

Nuanced realities. Equity of access includes an understanding of the realities of each making space, in terms of resources, infrastructure, and needs. Accordingly, situating resources, such as trainings, certifications, and opportunities for knowledge-sharing, and sharing these across different users or leaders will be important to consider. At the same time, we cannot solely rely on the engineering curriculum and engineering faculty content holders to solely guide how these nuances are addressed. There has to be intentionality to opening access to other knowledge-holders, such as advisors, librarians, and graduate students, among others, to help inform the contexts and unique needs of the students. The more information you may have about your users, the better situated you will be in designing opportunities for all students’ needs to be addressed in contextually appropriate and nuanced ways.

Goal-oriented. Finally, if the words *equity of access* or, by extension, *culture of belonging* (Villanueva Alarcón et al. 2021) are not terms that are brought to the forefront of discussions and designs/modifications of engineering education making spaces, all recommendations will simply be an afterthought. Consider bringing experts on diversity, equity, inclusion, and access into your engineering education making space meetings. Create book clubs or brown bag sessions to discuss ways to improve the environment for future and prospective users. Bring forth meeting talking points connected to equity of access and facilitate opportunities to re-evaluate existing policies and trainings. Being goal-oriented for equity of access in the design and operation of an engineering education making space can engender trust and strengthen the purpose of these spaces to meaningfully attend to the users it intends to serve, in the present and in the future.

7. Conclusions

In our study, we found an overall need to re-define equity of access to/for engineering education making spaces that superseded a flattened definition of access to just space, equipment, and cost. The environments created by this limited view of access inherently assumes that all identities are on an equal playing field and that, by having the door

open to all, that automatically access is created. As we have provided in this paper, we recommend that additional considerations of equity of access can serve as a starting point to ideate and design engineering education making spaces that are accepting of more non-traditional, non-binarized, and racially/ethnically diverse identities into their engineering programs. In addition, including more outreach, activities, and opportunities that expand beyond engineering disciplines can promote more engagement with the space and influence environments that nurture a culture of belonging and acceptance for engineering by its student body, staff, and leaders.

Author Contributions: Conceptualization, I.V.A., R.J.D., L.N., Y.H.C. and J.B.-G.; Data curation, L.N., Y.H.C., J.B.-G., I.V.A.; Formal analysis, I.V.A., R.J.D. and C.T.; Funding acquisition, I.V.A., J.B.-G. and L.N.; Investigation, I.V.A., J.B.-G., Y.H.C., L.N. and C.T.; Methodology, I.V.A., L.N., J.B.-G. and C.T.; Project administration, I.V.A., J.B.-G. and L.N.; Validation, I.V.A. and R.J.D.; Visualization, R.J.D. and I.V.A.; Writing—original draft, I.V.A., R.J.D.; Writing—review & editing, I.V.A., R.J.D., Y.H.C., L.N. and J.B.-G. All authors have read and agreed to the published version of the manuscript.

Funding: This material is based upon work supported in part by the National Science Foundation (NSF) EEC-1664271, 1664272, 1664274, and 2113755. Any opinions, findings, and conclusions or recommendations expressed in this material do not necessarily reflect those of NSF.

Institutional Review Board Statement: Ethical review and approval for this study was provided by the Institutional Review Board of University of Florida (IRB202003240) approved 06 January 2021 upon I.V.A. institutional move from Utah State University. It is important to mention that the Institutional Boards of Oregon State University (protocol code 2019-0052 approved on 16 April 2019), University of Central Arkansas (IRB #18-138 approved 22 August 2018 with an institutional agreement with Utah State University), were also approved and active during the entire study and grant period.

Informed Consent Statement: Per Institutional Review Board guidelines, all participants provided consent to be in the study.

Data Availability Statement: The data presented in this study are available upon written request with the corresponding author. The data are not publicly available due to confidentiality concerns for participants.

Acknowledgments: We would like to deeply thank the six sites that participated in this study and its participants for allowing us to visit and interact with the people in the spaces. A special thanks for Drs. Sarah Lanci, Adam Lenz, Kate Youmans, Cindy Lenhart, Taya Carothers, Darcie Christensen, and all the undergraduate research assistants who have provided their time to the execution of this project throughout the years.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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