What is an Equitable Academic Makerspace?
6th International Symposium on Academic Makerspaces

ISAM 2022 Paper No.: 74

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Introduction

To create a workforce that can develop innovative solutions to complex problems, participation from diverse groups is necessary [1]. Research suggests that academic makerspaces, rapidly growing in number since the early 2000s, help students develop their professional identities and skills in engineering, and therefore equip the future generation of engineers that enter the workforce [2], [3]. Academic makerspaces have been seen as potential drivers to increase diverse participation, due to the increased access to tools and knowledge. For example, a White House report suggested that academic makerspaces can provide the opportunity to level the playing field for all Americans, even those that are traditionally underrepresented and marginalized in higher education [4]. However, this promise is yet to be realized, with an emerging body of work critiquing the notion they are delivering equitable benefits to all students [5]–[7]. Recent studies suggest that academic makerspaces exhibit inequitable differences, where historically underrepresented students do not reap the same benefits as the dominant population [8]. The design and programming of academic makerspaces have been critiqued because they are "tailored to white, male, and middle-class groups, and exclude minoritized groups, hindering efforts to increase equitable participation in engineering" [9].

To realize the full democratizing potential of these spaces, research has been conducted to understand how to equitably build makerspaces. Research suggests that the inequity within these making spaces will be perpetuated unless intentional and conscious action is taken by the faculty, administrators, and staff of the academic makerspaces to create a truly inclusive and equitable space [5]–[7], [9], [10]. Therefore, it is important to understand the work that has been conducted to better understand the inequity present within these spaces and the practices that can be engaged to create an equitable space. This systematic literature review functions to synthesize the work on equity within makerspaces, to support the design and programming of makerspaces that seek to reach equitable participation and to potentially identify new research areas.

Methods

In this section, we provide a detailed description of the review method. We include the following key information: inclusion and exclusion criteria, search and selection process, analysis, and coding.

A. *Inclusion and Exclusion Criteria*

The first step in the review process was to determine the inclusion and exclusion criteria and the keywords for the search terms. The following initial criteria were used:

- Include articles published after January 1st, 2005
- Include articles that contain one of the following terms in the title or abstract: makerspaces, hackerspaces, or fablab
- Include article focused on engineering or STEM
- Include articles with makerspaces housed in academic institutions with undergraduate students as users
- The written language of the article must be English
- Article must be peer reviewed
- Exclude articles focused on 3D printing, other high-end technology, or on biomedical research
- Exclude articles that focus on makerspaces that were housed in libraries or museums
- Exclude articles that focus on K-12 maker education

Then, we conducted a systematic computer-based search using all of the databases on ProQuest. The Journal of Engineering Education and the International Journal of Engineering Education were also hand searched for relevant research papers. To try and not exclude relevant articles the following search terms, or keywords, were used: makerspaces, hackerspaces, fablabs, engineering, STEM, higher education, undergraduate, community college. The following Boolean logic was used to search through ProQuest:

(ab(makerspace OR makerspaces OR "making spaces" OR fablabs OR fablab OR hackerspace) OR ti (Makerspaces OR "making spaces" OR fablabs OR fablab OR hackerspace)) AND (undergraduate OR community college OR college OR undergrad OR higher education) AND (engineering OR STEM OR engineering education)

We were given 3 relevant research articles from an expert in the field that were not found using ProQuest or the two hand searched journals. The 3 articles were not included in any of ProQuest's databases or either journal that was hand searched.

B. *Selection*

The search yielded 298 unique articles after 28 duplications were removed. The down-selection process was comprised of two stages, depicted in the figure below. First, the titles,

abstracts, and full texts of the articles were scanned for relevance and checked against the inclusion criteria which resulted in 53 articles that were part of the knowledge base. The third stage of screening was to determine whether the article was Equity centered, which yielded 14 equity-oriented articles. To be considered an equity-centered article, at least two of the following criteria had to be met:

- Mentions or centers the voices of the focal population that is impacted by inequities
- Depicts makerspaces as replication or extension of engineering culture
- Mentions the body of work that critiques the idea that makerspaces are democratizing spaces or explicitly critiques it
- Includes more than one of the following terms: equity, equitable, inequity, equal, marginalized, underrepresented, underserved, inclusive, access, identities, disparities, barriers, diversity
- Mentions inequities that occur in the makerspace
- Uses a lens/theoretical framework of equity

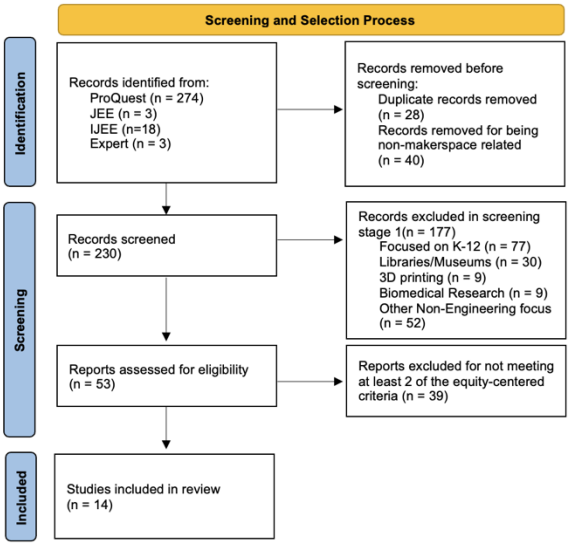

Fig.1 Screening and Selection Process

C. *Analysis*

For the analysis of the papers, on an Excel sheet, the following questions were answered to get an understanding of how equity was conceptualized within the articles:

- What research questions are posed?
- How central was equity to the study?
- Who are the participants/subjects?
- What is the context of the Makerspaces studied?
- What evidence was collected on equity?
- How is equity defined?
- How is inequity present in the makerspace?
- What are the barriers to equity?
- What are the dimensions of equity of focus?
- Whose voice is centered in this work?
- How can equity be achieved?

The centrality of equity to the study was determined based off the equity-centered criteria mentioned previously in the selection section. The context that was considered for the makerspaces was in terms of location, size, year created, type of access to the space. These questions were used to inform the coding scheme.

D. *Coding*

The codebook was created inductively through multiple rounds of reading and analyzing the 14 included articles, with multiple readers. The codebook includes the different dimensions of equity, access, and full participation that were identified in the literature based on empirical evidence and theories. The codes provided a general map of the literature in terms of the dimensions of equity, access, and full participation that are commonly used the literature. The papers were also understood in terms of the date issued, methods used, and for interview-based studies the participants.

Table 1 Codebook

Equity	Welcoming/Inclusive Environment
	Diverse Participation
	Equal Distribution of Benefits
	Disrupt Barriers
	Moving Towards an Expansive Definition of Making
Access	Eligible Based on Major
	Eligible Based on Knowledge/Skillset
	Eligible Based on Student Characteristics
Full Participation	Membership/Sense of Belonging
	Shared Emotional Connection
	Fulfillment of needs
	Influence

The sections that follow will describe the dimensions of equity, access, and full participation in further detail. The barriers and factors that impact access and full participation, both facets of equity, are also discussed in the writing to

come.

Results

The following results represent a mapping of the engineering academic makerspace literature. First, characteristics of the academic makerspace literature focused on equity are described, followed by definitions of the key concepts documented in the dataset. Then, factors impacting equitable participation within the makerspace are discussed.

A. *Dataset Characteristics*

The dataset consisted of 14 articles determined to be equity-centered. Of these 14, nine were empirical research articles, two were theoretical articles, two were opinion essays, and one was a documented case study. The publication dates for these equity-based papers ranged from 2016 to 2021. The largest number of equity-centered articles published per year occurred in 2020 with 6 articles.

Papers in the dataset were published in engineering education journals, such as the International Journal of Engineering Education, Harvard Educational Review, Education Research International, Journal of Pre-College Engineering Education Research, Journal of Engineering Education, Education Sciences, Technology and Engineering Teacher, Journal of Learning Spaces, and Social Sciences, as well as engineering design journals, such as the Journal of Mechanical Design, the International Journal of Engineering Sustainability, and Artificial Intelligence for Engineering Design, Analysis and Manufacturing : AI EDAM. The International Journal of Engineering Education was the only journal to publish two articles in the equity-centered knowledge base.

Figure 2 shows the frequency of the study focal group across the dataset. Note that there were four papers with overlap, focusing on both women and underrepresented groups.

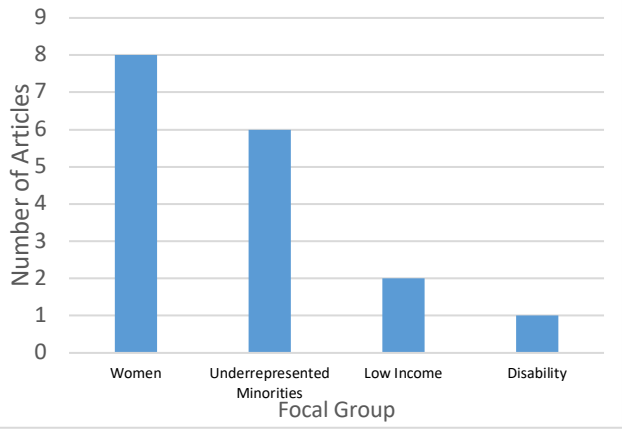

Fig.2 Equity-Centered Articles Focal Group

For the subset of interview-based work, the participant role gives important insight on who the authors believed carried knowledge or experience of value. Of the seven articles that conducted interviews, two interviewed staff, two interviewed students, and three interviewed both staff and students. Only two of the articles included demographic information for their participants. Of the articles that interviewed both students and staff, the demographics of the students were not mentioned. Women makers in academic makerspaces were interviewed for 3 papers specifically targeting women.

B. *Definitions of Equity*

The most notable finding from the review was the lack of explicit definitions for the term equity. Although attempts were made to describe the features of an equitable makerspace, the dataset lacked a precise definition. Combining dimensions from a number of the works, this study will define an equitable makerspace as a welcoming and inclusive environment that encourages diverse participation with equal distribution of benefits from using the space to all students. Table 2 shows the identified dimensions of equity and the containing articles.

Table 2 Equity Dimensions

Dimensions of Equity	Articles that mentioned it
Welcoming/inclusive environment	[2], [6], [9], [11]
Diverse participation	[1]–[3], [9]–[13]
Equal distribution of benefits to all students	[2], [3], [10]
Disrupt barriers	[5]–[7], [11]
Moving towards an expansive definition of making	[5]–[7]

In describing equitable makerspaces, a number of articles in the dataset make the distinction between representation and full participation [1], [9], [10]. Diverse representation, in which a space's user group consists of a diverse pool of participants, based on their backgrounds, identities, and histories, is seen as a necessary but not sufficient condition for equity [9]. Equitable participation begins with access to the makerspace, but full participation, or a deep sense of belonging for all users, is required to create equitable outcomes. In the following sections, access and full participation will be further defined, including the barriers to access and factors that impact full participation.

a. *Access*

From the literature, access can be understood as being eligible or permitted to use the space based on a student's major or enrollment status, prior knowledge, and characteristics. Access based on one's position as a student in a class or university was discussed in 6 articles. One of the distinctions used to classify different makerspaces is their level of access, as showcased in the classification system created by Wilczynski and Hoover [14]. Access levels can range from access for all university students to only those enrolled in certain department courses [14]. The boundaries placed on access implies the presence of an intended audience, which highlights the designed purpose or function of the

makerspace. Community makerspaces have open access to the public with the aim of giving all equitable access to the people, means, and activities within the space [13]. University makerspaces in engineering education programs are accessible only to engineering students, and function as outlets for students to improve their professional engineering skills [10].

A certain set of skills or prior knowledge may be required to gain access and use the makerspace, which was mentioned by 8 articles. Doors may be closed to students that are interested in using the space but do not have the background in making to support their entry based on the eligibility requirements [1]. Roldan et al. believes that the expectation for a student to have basic making skills before becoming a member of the space can be intimidating, especially for those that have lower engineering self-efficacy, like women and underrepresented minority students [1]. From the work of Roldan et al., an example of this form of access is when students are allowed to use a tool if they have the required knowledge in creating a computer aided design CAD file [1]. It was found that if students did not have the knowledge, most of them would decide to not use the space at all, labeling it as inaccessible [1]. Access also pertains to the user's ability to use the space and the tools provided safely. Accommodating and modifying the makerspace for students to safely navigate and use the tools allows them to reach a higher level of access. The one article that mentioned this form of access emphasizes the importance of accommodations or modifications to create a "user-friendly" environment that encourages student participation [15]. An example of an accommodation is an area within the makerspace that has permanently fixed stations, with non-moveable/non-wheeled tables, for visually impaired students to navigate the space easily and safely [15].

The included literature argues that cost, eligibility requirements, hours of operation, physical location, and size of the makerspace as barriers that can severely limit diverse participation in these spaces [2], [1], [2], [9], [10]. Financial barriers have the potential to disproportionately impact students that are low income and a part of communities of color [2], [9], [10]. Research also suggests that high requirements for eligibility pose as barriers to by excluding those that are interested and willing to learn, yet not have the required prior knowledge or skillset [1], [2], [9], [10]. Another study found that hours of operation can pose a challenge to students, by not matching the feasible hours students are able to work, which may limit the participation of students that work part time alongside their classwork [10]. The physical location of makerspace can provide access to all students, not just engineers, should position themselves in a centralized location [2]. The physical capacity of the makerspace is a barrier to widespread participation from students because only so many people can enter and work within the space.

Access goes beyond being able to walk through the doors to use the facility, it has multiple levels that gives the user the opportunity to engage in the makerspace. All students that are allowed to walk into the makerspace should be able to use the space safely, even those with a limited making background or those that require accommodation. To increase access equitably, barriers that limit participation from underrepresented students must be eradicated.

b. *Full Participation*

For a user to have the opportunity to realize the benefits of using a makerspace, the identified works found that users must fully participate as members within the makerspace community. Following the critique detailed in Vossoughi et al., this body of literature shows that access is not enough for equity [7]. Equity is not a single individual succeeding in the current system but rather equitable spaces which redefine the system, constantly seeking to eliminate inequities and to ensure that they are not implicitly or explicitly rooted in the experience of dominant populations [7]. Research in this area defines full participation in a space as characterized by a participant's sense of community and belonging.

Roldan et al. used the sense of community theory to understand whether the makerspace is creating a positive environment and therefore encouraging full participation [1]. The four attributes that describe or define a sense of community are: membership, shared emotional connection, fulfillment of needs, and influence [1]. In this framework, the user feels they benefit from the community and the community benefits from their membership. Membership is one's sense of belonging to a community based off one's coherence of characteristics to the boundaries of the group [1]. Shared emotional connection occurs when members of the community relate to one another through sharing their experiences [1]. Fulfillment of needs is described as the belief that one's needs will be met by being a member [1]. And lastly, influence is understood as one's ability to matter or influence the community and vice versa [1].

The analyzed work identified membership as the key attribute for sense of community. Membership, or the sense of belonging, is defined as a person's feelings of being an integral part of an environment where they are involved [16]. Research states that one's sense of belonging is correlated to one's feelings that their characteristics fall within the boundary of how the community defines itself [1]. The perceived boundaries of membership within the space are suggested to be impacted by the projects, activities, and social interactions that occur within the environment [9]. Villanueva Alarcon and colleagues posit that the external cues, making activities, and social interactions impact one's sense of belonging, and therefore perceived membership [9],[13]. In summary, full participation is defined as when makerspace users feel a deep sense of belonging to their makerspace community. The surveyed literature repeatedly called for the intentional design of makerspaces to create equitable learning environments where diverse populations not only had access but were able to fully participate [1]–[3], [7], [9], [10].

C. *Factors Impacting Full Participation*

Given the centrality of full participation to the construction of an equitable makerspace, many of the papers in the dataset investigated the factors impacting full participation. The following section categorizes these factors into three areas: people, staff practices, and pedagogy and programming.

a. *People*

Social interactions that occur within the makerspace can influence the creation of a sense of belonging [9]. Staff members play the role of knowledge bearers in the space. Within the makerspace environment, typically filled with dangerous machinery, staff can also act as mentors to students to guide and train them on correct and safe making practices [2], [1]. Therefore, staff members appear to play an essential role in student's access to learning resources and the makerspaces' sense of community [1]. Specifically for students that are underrepresented within engineering and makerspaces, the presence of staff members or leaders in the space that have diverse backgrounds and identities are signal markers that indicates diverse participants are valued [1]. Villanueva Alarcon et al. recommended that makerspace leaders hire critical staff members that carry complex identities and experiences that can aid in the creation of a culture of belonging [9]. From the work of Tomko et al., the presence of women role models in the makerspace is emphasized with the purpose of drawing in more women participation [11]. Other research suggests that an individual's sense of community can be strengthened through creating emotional connections, typically with those that have similar lived experiences [1]. However, while an important factor, the incorporation of knowledgeable staff members with diverse identities alone does not ensure equity within the makerspace [9].

b. *Staff Practices*

Papers in the review found that a number of practices staff members employ within the makerspace environment can also play a role in a user's sense of belonging. First, Tomko et al. stated that an effective makerspace must support asking for help [11]. To ensure equitable distribution of aid and guidance to students, Roldan and colleagues found that staff members must practice signs of approachability to reduce anxiety around asking for help and building new connections [1]. Presenting students with ways to receive structured help, where students can understand how to best approach asking for help and how to receive helpful constructive responses from leaders of the space, can lead to a reduction in the number of conflicts and negative help seeking experiences are decreased [1]. Appearing supportive and approachable opens more opportunities for students to share emotional connections with leaders or members of the makerspace, and therefore strengthen the student's sense of community in the space [1]. Second, research suggests that an open and welcoming makerspace is one that invites failure and harbors a culture of learning where students can experiment [2], [11] Villanueva Alarcon and colleagues stated that a fail-forward culture, or a culture of trust where students are free from anxiety of participating and making mistakes, is at the heart of equity [9]. Third, students should be regarded by the leaders and staff of the makerspace as carriers of knowledge to expand their learning opportunities and possibly impact their self-belief. One instructor in the makerspace environment postulated that students value themselves once they realize that their knowledge, and way of knowing, is valuable [10]. To support this claim, Lenhart et al. suggests that students viewing themselves as contributors to the space enhances their identity and belonging in the space [3]. Finally, the literature urges makerspace leaders and staff to have open conversations about diversity and equity, to move towards the proposed goal of having equitable participation [1]. Other research has suggested the importance of training staff in acknowledging the histories of discrimination that occur within the makerspace environment [7]. Staff must consider the personal challenges that students carry with them, that could be due to their backgrounds and pervious lived experiences [10]. To help new students feel comfortable and welcome in the space, staff members must reflect on the experiences and histories of underrepresented students to make progress towards their equity and diversity initiatives for the makerspace [1].

c. *Pedagogy and Programming*

Faculty that work within academic makerspaces can bring formal learning structures into the informal learning environment. The role of these educators is to provide students new learning opportunities and activities that are applicable to their disciplinary knowledge and professional development [3]. The analyzed studies found that programming for the academic makerspace should address the pedagogical needs of students, especially those a part of the working-class and communities of color, bringing the space closer to achieving full participation [7]. This body of work, typified by Huber et al., argues that the true democratizing potential of makerspaces can be felt once programming focuses on the individual users' identities and communities [5]. For example, minority students were found to have a greater sense of belonging when accounts of diverse identities were considered throughout the physical design and programming of an academic makerspace [5], [7]. Vossoughi and colleagues go on to mention that educational injustices shape the lived experiences of students and therefore the pedagogical needs of these students, hence it is important to consider the histories of injustice and experiences of marginalized students to meet their needs [7].

Alongside the consideration of student's diverse identities and histories onto the curriculum of educational making spaces, the research suggests the incorporation of diverse methods of making within the pedagogy. Vossoughi et al. recommend building design activities on the everyday practices of marginalized students, rather than the pedagogical design activities that are based on dominant cultural norms[7]. Efforts to expand participation from different groups through the insertion of culturally and historically relevant forms of making that already occur in the lives of students moves towards full participation. Rather than pushing for diverse participation in a space where the narrative of making is

rooted in the experiences of dominant populations, expanding what counts as making can legitimize different identities and practices [6].

For example, one paper noted the emphasis placed on advanced manufacturing and expensive tools, such as 3D printing, associated with makerspaces, juxtaposed to the forms of making that do not benefit from the dominant economic structures that are deemphasized [7]. Examples of these alternate forms of making are repairing and repurposing items, making as a social or artistic practice, and "crafting" processes such as sewing [7]. The various historical and cultural forms of making that are not legitimized in the mainstream maker movement should be incorporated into these spaces as valued forms of making that would encourage diverse participation.

Discussion and Conclusion

This systematic literature was conducted with the aim of understanding the current state of equity-centered research on academic makerspaces. This is an emerging area in makerspace research, as instances of equity-oriented research have increased over time. As research continues to affirm the benefits from using makerspaces, it is imperative that work to design equitable makerspaces continues in order to realize their democratizing potential. From the 14 articles analyzed in this review, equity was conceptualized through multiple dimensions. An equitable makerspace was characterized as one that has a welcoming and inclusive culture, where diverse participation is present and benefits from using the makerspace are equal among all students. The welcoming and inclusive culture for the equitable space is not possible without the disruption of barriers and the expansion of boundaries on what it means to make things.

There are a number of key findings from this literature review on what it means to be equitable and corresponding recommendations to move towards the design of equitable makerspaces. The main result is that equitable makerspaces require access and full participation for a diverse set of users. To achieve this goal, the process to create an equitable makerspace must be characterized by intention. The design of the makerspace, along with the pedagogy, must be reflected upon and throughout of carefully to ensure that the space does not reproduce inequities and is not rooted in the experiences of the dominant population. The choice of hiring diverse staff members, the training of the staff, and the choice of the staff to employ equitable practices to students in the space are all intentional with the goal of creating a welcoming, inclusive, and equitable environment a reality. Academic institutions seeking to create new inclusive makerspaces, can use the identified dimensions of equity and the factors impacting full participation to guide their design decisions.

Although the research focused on application to makerspace practice, many of the findings also apply to makerspace research. If it is important to consider the experiences and histories of students to create an equitable makerspace, it is equally important to consider the experiences and histories of students when conducting research on equity within these spaces. Obtaining firsthand anecdotal evidence from student makers will give researchers a better understanding of what inequities are present within the space, what barriers exist that limits participation, and what it means for a space to be inclusive and equitable. From the empirical equity-based articles, eight conducted interviews with students or staff members of the makerspace. From the mapping of the literature, there is a clear lack of focus on students with varying ability. To obtain a broader, more accurate understanding of the equitable makerspace environment, the insights, and experiences of all students, especially those that are underrepresented, should be considered.

Beyond the addition of underrepresented voices, analyzing and contextualizing the anecdotes from students with the history and background of their identities is important to have a clear picture of their experiences in the makerspace. From the women-centered articles that disclosed the demographics of students, women of color were present within the pool of interviewees, yet their intersecting identities were not discussed in the findings. There is a gap in the literature on analyzing the equitable nature of the makerspace using Intersectionality as a framework. Expanding beyond the fact that users are women makers, understanding the nuances that occur with the intersection of being a woman of color within the space offer interesting opportunities for future work. Analyzing the interview-based evidence with a framework of intersectionality will give us a broader perspective of what occurs within these spaces and how to effectively deliver equitable support for students.

Lastly, the systematic review findings indicate a lack of empirical testing of recommendations that were asserted in the literature. Much of the equity-based literature included a set of recommendations for makerspace designers and leaders to employ to reach an equitable makerspace. None of the papers in the dataset tested the identified recommendations. Future research should focus on determining best practices for creating an equitable space as defined in this work.

In conclusion, an equitable makerspace requires intentional design and redesign of the environment, programming, and practices that occur within the space. Access is described in the literature as the entry way to using the makerspace that affords students many benefits. Getting students through the door, to use all the resources available to them, is not enough. For students to reap the full benefits of using the makerspace, students must fully participate in the makerspace environment as a member of the community. Therefore, to support diverse groups of students with different backgrounds and histories requires consideration of their needs, experiences, communities, and backgrounds such that they experience a deep sense of belonging. Increasing access and encouraging full participation from a diverse pool of students is the key to creating equitable makerspaces capable of training and inspiring our future engineering workforce.

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