Barriers and Benefits: The Path to Accessible Makerspaces

Katherine H. Allen
kat.allen@tufts.edu
Dept. of Mechanical Engineering,
Tufts University
Medford, MA, USA

Audrey K. Balaska
audrey.balaska@tufts.edu
Dept. of Mechanical Engineering,
Tufts University
Medford, MA, USA

Reuben M. Aronson
reuben.aronson@tufts.edu
Dept. of Computer Science,
Tufts University
Medford, MA, USA

Chris Rogers
chris.rogers@tufts.edu
Dept. of Mechanical Engineering,
Tufts University
Medford, MA, USA

Elaine Schaertl Short
elaine.short@tufts.edu
Dept. of Computer Science,
Tufts University
Medford, MA, USA

ABSTRACT

Motivated by the philosophical overlap between makerspace culture and the needs of assistive technology users, we investigated the ways that makerspaces can support the development of new technologies by and for disabled makers. Using eleven semi-structured interviews with makerspace operators and disabled makerspace users, we identified five categories of barriers to makerspace participation: recruitment/outreach, physical access, financial, access to information, and belonging. Based on these interviews, we highlight ways makerspaces can better welcome makers with disabilities: enabling members to create adaptive technologies for the space ("makerspacing the makerspace"), making the physical space and information within the space accessible, and fostering belonging by building relationships with the disability community. Overall, our work contributes to our understanding of the possibilities and challenges of connecting the disabled community with the maker community and suggests new directions for collaboration, especially towards building hybrid makerspaces that provide multiple modalities for connection and creativity.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility theory, concepts and paradigms**; **Accessibility design and evaluation methods**; *Accessibility technologies*; **Accessibility systems and tools**.

KEYWORDS

accessibility, makerspaces, hackathons, co-design

ACM Reference Format:
Katherine H. Allen, Audrey K. Balaska, Reuben M. Aronson, Chris Rogers, and Elaine Schaertl Short. 2023. Barriers and Benefits: The Path to Accessible Makerspaces. In *The 25th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '23), October 22–25, 2023, New York, NY, USA.* ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3597638.3608414

ASSETS '23, October 22–25, 2023, New York, NY, USA

ACM ISBN 979-8-4007-0220-4/23/10.
https://doi.org/10.1145/3597638.3608414

1 INTRODUCTION

Makerspace culture, with its emphasis on bespoke creativity, iterative design, and personal customization, is a promising match for the needs of disabled people, especially for the design of customized assistive technology. Unfortunately, while the makerspace movement has opened up the practice of engineering and design worldwide, there remain barriers that prevent disabled people from participating. Even discussions around assistive technology development in maker communities can exclude the disability community. For example, accessibility "hackathons"[1] typically operate on a "service" model, where people with disabilities are included as "clients" for whom a team of makers develop solutions. While clients are often involved with defining challenges or answering questions about their needs to drive project design, they typically do not get to participate directly as makers[13, 33].

This client-service model is better than developing assistive technologies in isolation from disabled people entirely, but it is inadequate as a model for disabled participation in makerspaces. As Ladner [29] argues, while it is essential to include the perspectives of people with disabilities in designing technology, it is better still to enable people with disabilities to participate in all aspects of the design cycle, including fabrication and prototyping ("Design for Empowerment"). The makerspace ethos is ideal for this sort of fully-integrated design process, where learning new skills is ongoing and makers draw inspiration from their own experience.

To identify some of the barriers preventing disabled makers from participating in makerspaces as makers rather than clients, we conducted a series of interviews with both makerspace operators and makers with disabilities, with the goal of illuminating design considerations for an inclusive, accessible makerspace. In addition to investigating physical makerspaces, we discussed the benefits and drawbacks of digital makerspaces, and the ways that digital collaborations enable disabled makers to work in community even when they are physically unable to work in the same space. From these investigations, we developed guidelines for accessible makerspaces focused on assistive technology, and aligned these with the broader recommendations from prior work for makerspace accessibility in

[1]Events where makers rapid-prototype assistive devices over a short period of time, ranging from a few hours to a few weeks

Figure 1: A visualization of the themes from our 11 interviews with makerspace operators and disabled makers. Word size and color/saturation indicate the prevalence of the code across all interviews.

general[4]. We also identified ways that makerspace designers and operators might best use hybrid digital-physical spaces to get the advantages of both.

2 BACKGROUND AND RELATED WORK

2.1 Terminology

For the purposes of our study, we define a *makerspace* as any physical or digital space in which people come together to create things or share tools and advice for creating things. This definition includes classic engineering spaces as well as digital-only online communities, local yarn shops, sewing circles, etc. *Makers* are people who engage in creating things, whether or not they self-identify with the Maker Movement[19] and whether or not they engage in that creation in a social or collaborative way.

There is significant debate in and between the academic, medical/service, and disability advocacy communities about the language to use when identifying people with disabilities. There is no consensus in academic literature for how to choose between person-first language (i.e. person with visual impairments, person with autism) and identity-first language (i.e. blind person, physically disabled person) [20, 44]. Here, we use the preferred language of participants when quoting them directly, and otherwise use identity-first language in keeping with the preferences of the disabled members of the research team.

Finally, although our participants include women, men, and nonbinary people, we use the pronoun "they" for all participants to protect their anonymity.

2.2 Makerspaces, Inclusivity, and Assistive Design

One of the goals of the Maker Movement[19] was to open up design and fabrication capability to a large segment of the population who had previously been excluded from the conception and creation of new products or services [37]. But despite those grand inclusive ambitions, the makerspace community struggles with diversity and inclusivity, and it predominantly serves a mostly-affluent, mostly-male core community highly focused on a specific subset of tools and processes[8, 22, 46, 47] These failures have led to prominent voices in education excepting themselves from the label "maker"[15], while others provide recommendations for reform on inclusivity principles[27, 41, 42].

Member recruitment, retention, and effectiveness are discussed in prior work, along with attempts to define what qualifies as an effective makerspace. Specific case studies of individual makers or maker communities identify critical factors of makerspace structure [37]. Reviews of the existing literature look at makerspaces and the idea of making as an entire enterprise, both from an academic perspective (journal articles and published books) and a social one (blog posts and magazine articles)[6, 31, 47, 48].

Makerspace inclusivity research has focused on recruiting people to the makerspace who do not fit the stereotypical makerspace demographics (STEM college-educated men)[27, 28, 46]. This work has typically not focused on people with disabilities but on women, people of color, and/or people with lower income[7, 41, 45]. Although the target demographic for these interventions was different, many of the conclusions translate directly to our work. In particular, financial concerns and issues of belonging were identified as factors influencing participation in our interviews as well as in prior work [28, 46]. Other work has found that the language used by experienced makers when answering novice questions was often unintentionally unwelcoming by trivializing things novices found challenging [37]. We build on this work by connecting with the disabled community to identify specific considerations necessary to include them in makerspaces and maker culture.

When discussing inclusivity, it is important to consider online makerspaces, not only physical ones. It has been demonstrated in multiple case studies that virtual makerspaces have more even gender ratios and broader geographical footprints compared to in-person makerspaces[36, 38, 45]. However, Litts et al. found that,

in an online community associated with a physical makerspace, in-person participants produced the majority of the online interactions, despite the population of the online community being more far-reaching[30]. Our work includes interviews with members of online makerspace communities to specifically discuss how disabled people interact with these communities and what barriers might be there.

Prior work has included disabled people in assistive technology design and development, both as collaborators and as developers themselves[9, 25, 29, 40]. There is substantial evidence of the creation and sharing of DIY-AT on general-purpose maker websites like Thingaverse[12], but the researchers also found that it was difficult to locate the small percentage of projects relevant to AT. Many products made through hackathons end up unused or the projects unfinished[34], motivating the development of makerspaces that support long-term projects. Assistive technology developed by the users themselves has also been found to improve the adoption process[26]. There are online projects dedicated to assistive technology, like "Makers Making Change"[2] and "AT Makers"[1], which include both disabled and non-disabled participants who may be making assistive technology for themselves or for others, but which do not provide all of the community, mentoring, and skill development of a makerspace. In addition to the more general AT-making communities, there are also numerous disability or device-specific communities dedicated to making AT devices more functional, improving aesthetics, or both. Prior work[11, 23, 40] indicates that participation in these communities provides numerous benefits, including social, disability identity and disability advocacy benefits, but more work is needed to connect these device-specific communities with community makerspaces.

3 METHODOLOGY

The 13 participants for this study were composed of eight adults who operate a makerspace (makerspace operators, designated MO), and five adults who have one or more disabilities and consider themselves "makers" under the definition in Section 2.1 (disabled makers, designated DM). The majority of the interviews were 1:1 and conducted over Zoom, with two conducted as in-person interviews and one conducted as a multiparty Zoom with a team working on overlapping sets of makerspace-related projects (MO-5, MO-6, and MO-7). Participants were recruited through direct emails to contacts of the first and last authors, as well as secondary contacts recommended by other participants and contacts. The first author conducted all the semi-structured interviews using the questions in Appendix A, which were developed based on initial discussions with makerspace users and disability advocates. Each interview lasted between 45 and 75 minutes. Participants were compensated for their time and their privacy protected via a process approved by the Tufts University Institutional Review Board.

3.1 Qualitative Coding

We extracted an initial set of 568 open codes based on the content of the transcripts and interview notes. These open codes were grouped thematically by the research team in a collaborative process using both spreadsheet annotation and thematic grouping using Miro, resulting in a list of 33 codes in six general categories. Two researchers separately coded all interview notes and transcripts, then summarized the results on a per-interview basis. The coders collaboratively reviewed the resulting codes to resolve ambiguity in code definition between raters and produce a final set of encodings for the dataset. An analysis of the dataset is included in Table 1. We report statistics based on the two categories of participants (MO, makerspace operators, and DM, disabled makers) and the number of participants in each of those categories who discussed each code in their interviews. For coding and statistical purposes, MO-5, MO-6, and MO-7 are treated as a single interview.

Table 1: Qualitative codes.

Category	Codes
Accessible Space	building infrastructure, cleanliness, ergonomics, pathways, storage, tools, transportation, safety
Barriers	accessible information, accessing additional services, assumed disinterest in inaccessible tasks/information, community labor, financial, operating hours, physical access, sensory issues, support for remedial access/skill building, time, recruitment/outreach
Belonging	awareness, community, identities, permission
Culture	adaptability, atmosphere vs. accessibility, beginner-friendly vs. expert-welcoming, bespoke design vs. universal design, brave space vs safe space, inclusion, invitation-only vs open-to-all
Digital	challenges and advantages of digital media, digital vs physical spaces
Other	getting started/first experience

4 FINDINGS

Our findings are divided into four sections. We briefly review participant roles and demographics. Second, we discuss the synergies participants reported between makerspace culture and design of assistive technologies. We then explore five classes of barriers that prevent disabled makers from participating in collaborative makerspaces: recruitment, physical access, financial, access to information, and inclusivity. Finally, we collect recommendations from the participants that reinforce and expand on prior work in making makerspaces accessible, including exploring the role of digital makerspaces in democratizing access to collaboration. Figure 1 illustrates the themes of our findings, and Figure 2 illustrates the relative importance of various codes broken out by the two types of participants.

4.1 Participant Demographics and Roles

We report aggregated demographics in Table 2 to protect participant privacy. Many participants have more than one affiliation within the category. Demographic information was not formally collected (a limitation of our methodology), but were mentioned in

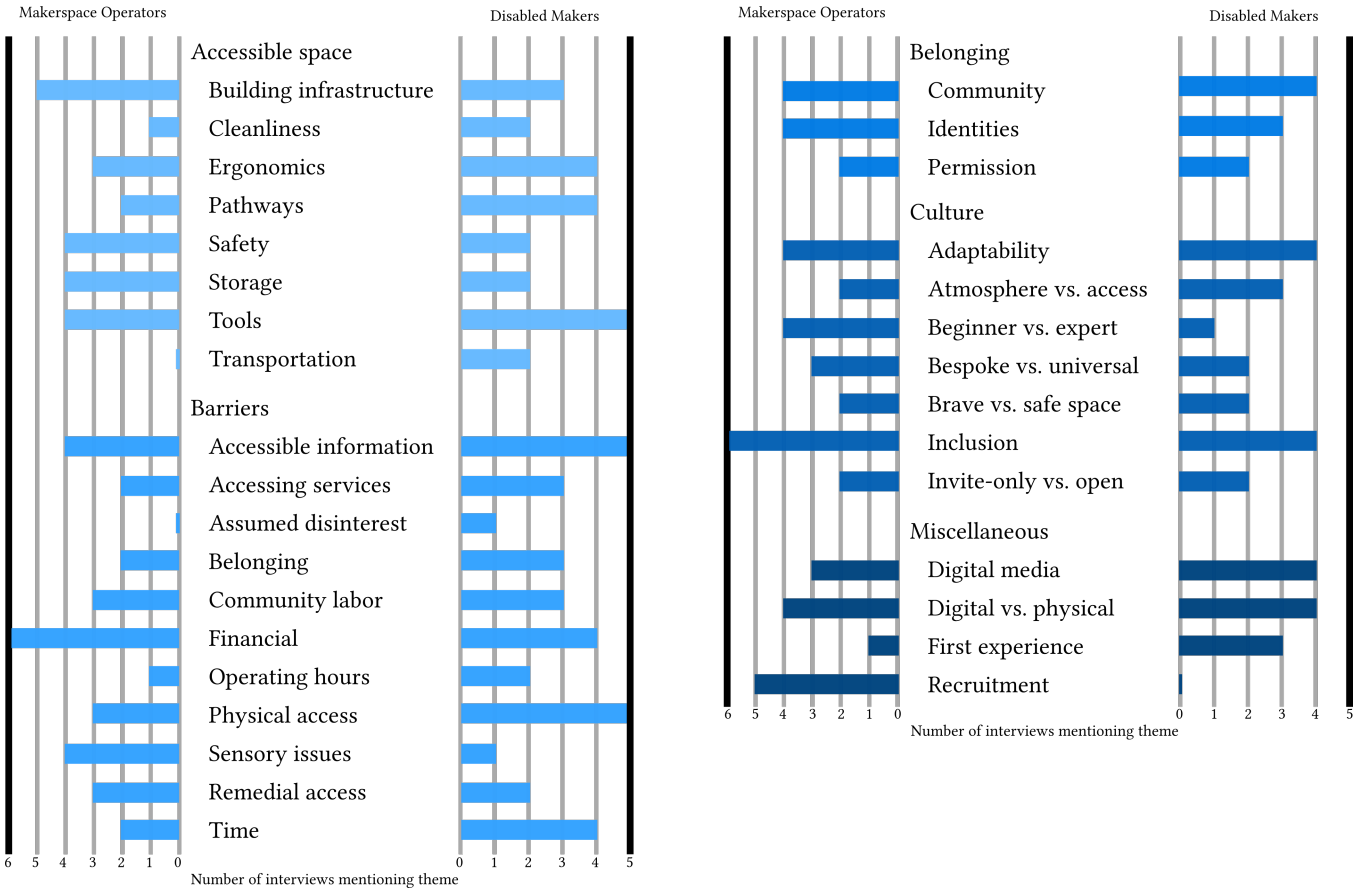

Figure 2: Predominant themes in interviews with makerspace operators and disabled makers, measured by the number of interviews of each type (makerspace operators, N=6 or disabled makers, N=5) in which the theme was discussed. Chart data is given in text in Appendix B.

some of the interviews as relevant to participants' experiences. Participants included male, female, and nonbinary interviewees, and some participants discussed the intersectionality between disability and their experiences as gender or racial minorities in their interviews. Access challenges that were part of participants personal experience included ADHD, autism, blind/low-vision, Deaf/hard of hearing, hypermobility, learning difficulties, mobility limitations, muscular dystrophy, neurodivergence, noise sensitivities, sensory sensitivity, and wheelchair use. Access challenges primarily observed by participants discussing the challenges of others included colorblindness, ESL communication, fine motor skills challenges, general neurodivergence, and sensory sensitivities.

4.1.1 Positionality. We recognize that our personal and professional identities and lived experiences affect our research, especially for human-centric investigations. While we strive to be both objective in our analysis *and* to empathize with participants with other lived experiences, our positionality defines the context in which we work. To provide some of that context, we note that the authors include 3 women and 2 men, who are all either White or multiracial White and Native American. The authors include disability advocates, makers both of assistive devices and other types of projects, and people with access challenges including mobility impairments and neurodiversity.

4.2 Synergy between Makerspace Culture and Accessibility

> Makerspace culture lets me suggest [adaptations] in a non-judgmental way—isn't this a cool hack—building their identity as makers. Of course you would make things better!
> This is my 'master plan': people get used to their identity as makers, as engineers, they make things—and then they can ask their professors for the accommodations they now know are possible.
>
> Participant DM-5

Maker culture and the ability to rapidly prototype tools and designs opens up numerous opportunities for bridging the everyday access challenges for people with disabilities. All of the the disabled

Table 2: Overview of participant affiliations and involvement with makerspaces. Note that categories do not sum to $N = 13$ due to participants being in multiple categories.

Category	Participants
Role	
Makerspace operator/creator	8
Singly- or multiply-disabled	5
Educator	6
Affiliation	
University	4
Community-based makerspaces	4
Online community	6
Home-based	6
Media	
Digital	3
Physical	11
Audience	
Young adults	7
K-12 children	4

makers interviewed create projects for both themselves and others. Participants adapt tools for hobbies (like off-road beach scooters, adaptive mountain bikes, or screen-reader friendly DJ software), artistic pursuits (like Halloween costumes involving crutches and wheelchairs or banners using tactile interfaces) and activities of daily living (like faucet handle extenders or wheelchair-to-bike lifts), represented in Fig. 3. One participant leads teams that adapt electronic toys for children with mobility-related disabilities, so that they can trigger the "buttons" with whatever mobility they have, whether that is a joystick, an eye-motion sensor, or a brainwave-activated EMR sensor. Another participant adapts wheelchairs and other mobility devices that come to their clients secondhand, to bridge the gap between discovering a need and having funding for a custom device. Almost all of the participants also create artifacts unrelated to their disabilities, but related to their other interests, like digital films or music-driven LED displays.

Creating the culture in which these creative projects can flourish relies on defining the ways participants engage with each other in the space. DM-2 argued that the most important thing for developing makerspace culture is to encourage participants to step out of their comfort zones and engage with new challenges. "We have safe spaces where we can be ourselves and not have to worry about being challenged, and maybe those are where we go to talk about the experience of being a blind programmer in a sighted world. And then we have brave spaces that are supposed to respect people, but might be more intersectional, and where we might well feel challenged and vulnerable and uncomfortable, but it's a space that is supposed to support that and make it OK for us to approach our limits." They observed that both of these are valid types of space, but *brave spaces*[5], where people are encouraged to approach their limits, are more suited to design and engineering. According to MO-1, for a space to be a brave space, the ability to walk in and try something new is critical: "Anything we have here, you can actually find a better version of it somewhere else on campus. But here, you can just walk in and get started. And if you find that you need a bigger something, you can go over to this specialized place that is maybe a little more intimidating". Creating a brave space with low barriers to entry and room to grow your skills provides space for makerspace culture to flourish.

Multiple participants noted that building makerspace culture includes "makerspacing the makerspace". Participant MO-1 chose to buy cheap 3D printers as a kit for their makerspace, and make the students learn to fix them to "minimize cost while maximizing exposure of students to being an engineer." When a wheelchair user started participating in their local makerspace, DM-5's students started doing cord management and built an adaptive lever for the faucet so that it was accessible from wheelchair height. When a makerspace user could not use the controls on a CNC machine because they were too high up, Participant MO-2's students attached a mouse and keyboard, allowing them to control the machine from a comfortable position—although they also noted that not every machine is able to be modified, and serious or off-label modifications often void the warranty and make the machine difficult to get repaired.

The makerspace movement bridges a gap between commercially available solutions and what disabled people actually need. DM-1 explained why they find it important to have the capacity to make things for themselves: "I'm making custom devices, for myself, solving problems that nobody else has solutions for, because even when I'm starting with a device designed to be accessible, like my adaptive mountain bike, it was designed for paraplegics who have really great upper body strength that I just don't have." DM-4 does the same types of work for themselves and for others. "I see a lot of people getting equipment second-hand, and it's not suited to their needs. So a lot of the work that I do with community members is finding ways to pull together [...] accessories or [make] modifications to their devices until they can get a custom-fit device". MO-4 noted that often, insurance companies won't cover custom devices (especially DIY custom devices) and clinicians are reluctant to recommend them over devices already on the market. Unfortunately, what is on the market is limited, because commercialization of assistive technology is very difficult. DM-4 talked about the challenge of getting good ideas turned into commercial products: "I want to make a white cane device that works with a manual wheelchair. I have designs, but big companies are really hesitant to adopt things they see as niche but that have needs in the community. Right now, people switch to power chairs so they can use a straight cane, and there's no in-between". The limited commercialization possibilities for devices with small numbers of users drives the need for bespoke adaptive tech. Although anecdotally and through the testimony of end users, these devices provide substantial quality of life improvements, challenges with incorporating DIY-AT into clinical practice have been documented in prior work[25], and there are few solutions in the literature for how to reconcile the "fail fast and often" approach to DIY-AT with the more conservative approach preferred by clinicians. MO-5 explained that "What would really help me is published research into the effectiveness of custom devices in AT, or the speed to market of co-designed engineer/clinician devices. Or research that people who are involved in the design of their own solutions are more successful. We need to show clinicians and insurance companies how beneficial this technology is, how

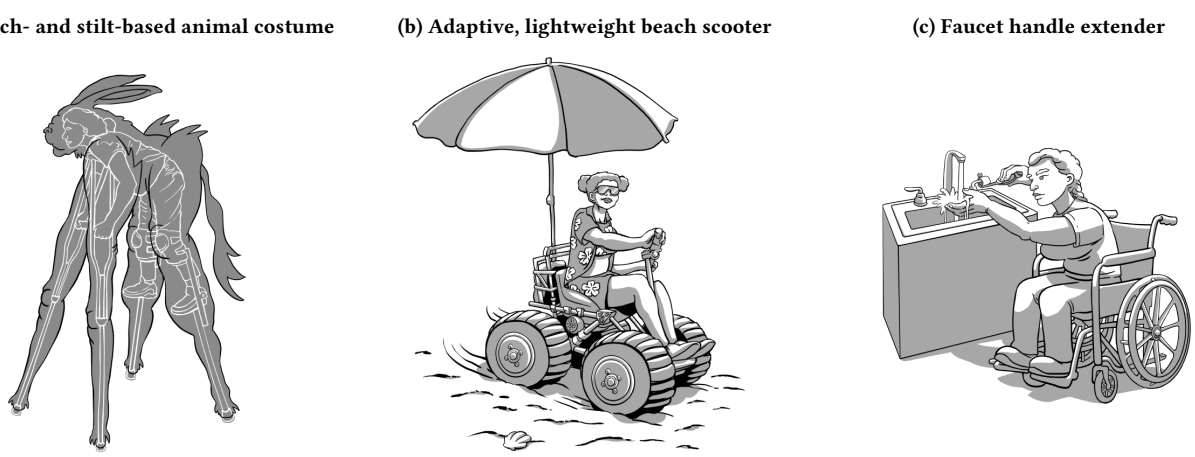

Figure 3: Artist's rendition of a sampling of participant projects. Details of the projects and features of the makers have been changed to protect their anonymity.

beneficial this co-design process is, so that we can get things that really work in the hands of more people."

4.3 Barriers to Participation

While makerspace culture can naturally support the access needs of people with disabilities, our participants identified several barriers to the actual use of makerspaces by people with disabilities. We classify these into five categories: Recruitment and Outreach, Physical Access, Financial, Access to Information, and Inclusivity/Belonging.

4.3.1 Recruitment and Outreach. In our discussions with makerspace operators, they noted that building an accessible space was not enough to recruit disabled participants. This was a primary concern for makerspace operators, with 5 of 6 discussing issues related to recruitment and outreach. MO-1 noted that the first barrier to makerspace use is knowing that the space exists, which drives their university makerspace's outreach programs. Within the university environment, MO-1 leverages the connections of their student staff members. Each staff member is required to partner with other student groups to run workshops for students who might never have been in the engineering buildings—but this does not improve outreach to disabled students unless there is already representation among the makerspace staff. To make the impact of this outreach broader, MO-3 intentionally recruits diverse staff members. "I hire people who have at least one solid making skill, but who are mostly selected to be good teachers and to be experts in safety and inclusion." MO-2 noted that challenges in outreach are also a barrier to letting people know that the makerspace has various accommodations available. MO-3 agreed and noted that they have found university disability services unwilling to advertise on their behalf or partner with them. MO-1 noted that this can lead to accommodations appearing unused: the lift into their makerspace has been used only a handful of times in the last several years. If these accommodations are not maintained, however, it can compound the challenges of recruitment. A reputation for *inaccessibility* can drive disabled people away from the makerspace, and even from the idea of community makerspaces in general. DM-4 related how the reputation of a local makerspace discouraged them from trying to work there. "I had spoken with with a standing, disabled person that I know who is connected to one of the maker spaces here, and they really discouraged me from trying to get in touch with the maker space downtown because there's an elevator to get in the building and it breaks down all the time and then once you're in the building, there are stairs—there's not an elevator into the actual maker space, and it's pretty similar across the city." This experience pushed DM-4 away from the makerspaces in their community—and even if the physical access issues with the makerspace had been repaired, there is no incentive for them to re-examine their participation. Building a reputation as a space that cares about accessibility is key to recruiting and retaining people with disabilities.

4.3.2 Physical Access.

> Makerspace culture is great for bridging accessibility gaps because the attitude is 'I don't know, let's make this work'—but you have to get inside before you can makerspace the makerspace.
>
> DM-5

Perhaps the most obvious barrier to participation for disabled makers is physical access, which was discussed by 100% of the disabled maker participant group and 50% of the makerspace operators. Small-scale physical access issues can be a primary target for "makerspacing the makerspace" but some barriers are beyond the reach of makerspace users to change without help.

Transportation issues push many makers with disabilities away from engaging in community makerspaces. DM-5 discussed the difficulties of physical access for wheelchair users when the approach to the building or the transit from parking spaces is inaccessible. "So the makerspace is on a hill, in a building close to the top of that hill,

and street parking is in the multiple blocks around the makerspace. The path up the hill is steeper than ADA ramps allow, and then there are doors without automatic openers on both the building and the makerspace itself. And, of course, the nearest bathrooms are outside the makerspace, but once [the wheelchair user] is inside they can't even leave independently, so they need help even to get to the bathroom". The challenge of providing access includes not only providing access within the organization or institution, but also ensuring that the entire route from wherever your participants live is accessible. DM-2 told the story of how a seemingly small barrier to physical access, entirely outside the control of the creative space, had dramatic consequences: "One of the things that substantially impacted my education, and really my whole life, was this one intersection [in the middle of the university campus]. Basically, I found that intersection really hard to get across, and the [research buildings] were all on the other side of that intersection. I never did normal graduate research things because I never conquered that intersection, effectively. And so that was one of the factors that pushed me away from academia." DM-1 prefers their home makerspace because it is easy to get there, which allows them more time and energy for making things. "I'm not gonna get on the train and like, go an hour into the city and go to this super cool wood shop. I'd have no strength by the time I got there. When it is in my home, I don't have to spend a lot of energy to get to the shop and start using it." DM-3 noted that this is especially true in more rural areas. "If I can't drive, what am I going to do? There might be a transit service I can call... but [...] figuring out how to get there might use up all my social and logistical energy for the day". Because of transportation issues, DM-4 often brings their assistive technology projects to the homes of their clients or takes the devices to their own home. Their clients are mostly in dense urban areas, but the shop space they use is in the suburbs—beyond the capabilities of their clients to travel on a regular basis. "It has to be really worth it to go that far, even for me." The difficulties of transportation push these disabled makers towards using their home-based spaces, but that also limits their capabilities. DM-4 says their projects are "pretty much limited to what I can do with hand tools and like what can be housed in my house. I don't have the capacity to cut wood. I don't have the capacity to weld. I don't have the capacity to do any electrical work or learn how to do it." Transportation barriers to makerspace access limit disabled makers' skill growth, access to mentoring, and the complexity of their projects.

Cleanliness and organization is also a significant concern for physical access to the space. Both operators and makers mentioned the challenges of keeping storage organized to preserve clear pathways for mobility devices, but several (DM-1, DM-5) also noted the challenges in keeping the floor clean so that makerspace users do not slip. DM-5 also noted that having adequate wheelchair access requires not only lifts, cable management, and wheelchair-height tables, but also logistical support like having a place the wheelchair user can stop to clean slush or dirt off their wheels in bad weather. DM-5 mentioned that smocks and other protective gear are not typically designed for wheelchair use, so it becomes difficult to keep dust, paint, and other materials off of a wheelchair, cane, or other device that it could damage. And multiple makers (DM-4, DM-5) observed that in order for disabled participants to regularly use the space, there must be pathways for multiple disabled makers to be present simultaneously, potentially with assistants or interpreters, and that assistants/interpreters will also require makerspace safety training. DM-3 mentioned that this is an advantage of fully-digital makerspaces (discussed in more detail in section 4.4.2) since "the overhead of a physical space becomes a barrier for accessibility in a way that online spaces don't have".

Once inside the makerspace, access to tools and machinery is a major barrier for disabled makers. DM-1 summarizes it as an ergonomics problem: "It comes down to needing better-than-average ergonomics—what makes a space difficult for someone else or uncomfortable might make it impossible for me." The challenge of accessing physical switches, controls, and machinery was mentioned by both makerspace users and operators. MO-1, DM-1, MO-3, DM-2, DM-4, and DM-5 all discussed how machine shop tools like presses and lathes are typically built assuming the physical capabilities of a standing 6' tall man, and noted their frustration that tools with table heights are typically not adjustable, putting a small standing person at a disadvantage, and a wheelchair user in a very dangerous position. This can be a place where "makerspacing the makerspace" requires thinking creatively about what it means to "use" a tool: DM-5 noted that a disabled maker directing the use of someone using a machine shop tool is still "making" the device, in the same way they would be if they were using a CNC tool, and MO-4 noted that they will frequently "be the hands" for one of their collaborators who is quadriplegic, to instantiate the things their collaborator designs. This type of interdependence has potential for cross-disability solidarity and community building[10, 18, 24]. DM-5 further observed that while universal design principles are a good starting place for accessible design (as many people have different reasons for needing a tool but can use the same tools), adaptations beyond universal design will be required for each new combination of disabilities, and funding should be allocated for creating that access.

4.3.3 *Financial Barriers .*

> It's a 3-way optimization tradeoff: we have to triangulate accessibility, finance, and environmental factors, and they are in tension with each other
>
> MO-3

Funding and financial barriers are highly interconnected with disability access issues. The intersectionality of poverty and disability is well-documented and bidirectional: a household containing an adult with a disability that prevents them from engaging in paid work requires, on average, 29% more income than a household of the same size with only non-disabled adults[32], and the conditions associated with poverty can cause or exacerbate conditions that may result in disability[21, 35, 39]. In addition, many disabled people require customized hardware (for example, a special mouse or keyboard for computing tasks), increasing their cost to participate. Because of this, financial barriers (which may affect non-disabled makerspace users as well) compound the barriers facing disabled makerspace users.

Given this correlation, it is unsurprising that financial barriers to participation were discussed by all makerspace operators and almost all disabled makerspace users. MO-1 discussed at length the impact of material costs on both student project quality and

makerspace usage: "It turns out that most students don't really want to come up to you and say, [...] 'please buy me something to make my project'. Instead, they'll say 'Yeah. Well, I didn't have the right materials to do this cool project, I don't have a good piece of wood, but I found this piece of wood in the dumpster, so I'll just make my project out of that." MO-1 adapts their budget to reduce the financial barriers and break down barriers to belonging in the makerspace: "We have all these 3D printers, and we just make using them free. We probably spend $5000 to $10,000 per year on filament, but that is maybe 10% of one student's tuition for the year, it's like nothing compared to the budget of the university. And it means that people are a little less careful, they print trinkets... but it's also a gateway drug into printing something for a project, and then designing something yourself, because you feel comfortable in the space and with the tools". Providing funding or free materials for makerspace users can significantly improve their experience within the makerspace and break down some of the barriers to the participation of disabled makers.

Unfortunately, funding is still often a challenge, especially outside of large institutions. Multiple participants discussed the idea of a trade-off between accessibility and budget. MO-2 noted that one of the makerspaces they worked with had to move multiple times for financial reasons. "In the community spaces I saw as a member, it all came down to money. What can we afford, what will our rent be, and is this sustainable? If we have to have higher dues, will people stay?" DM-3 noted that economic conditions stress makers in multiple ways, by both pushing them towards paid work and limiting what they can pay to use community spaces—which impacts the makerspace's budget and what they can afford to do in terms of making the space accessible: "In this economy, hobbies have become luxuries, people are working multiple jobs. So we don't have the time to go to these spaces or money to pay dues. And so, because of that, maker spaces are being forced into inaccessibility just to keep the lights on." Community makerspaces need to connect with funding for accessibility initiatives—but while funding for accessibility initiatives does exist, amassing the time and knowledge to access that funding can be challenging.

Access to financial support for accessibility tools is a challenge for community makerspaces and for individuals. DM-4 discussed the difficulty of helping their collaborator bootstrap into collaborative spaces when remedial access was not provided. "We spent most of our digital filmmaking residency trying to get one of the participants a laptop that they could use, so they weren't trying to call in and edit a film on a phone as a quadriplegic who didn't know how to use VoiceOver." They noted that typically, this sort of support is not budgeted into programs, so it excludes people unintentionally—and noted that government support programs don't always help: "Disability services is reluctant to fund things like keyboards and trackpads, but [a computer] isn't going to be accessible as-purchased." Something has to bridge the gap between equipment provided to disabled makers and what is needed for them to be able to use the equipment. MO-1 noted that while funding exists for students on scholarships to pay for books and class materials (which could potentially cover these peripherals as well), accessing them is logistically challenging and may be beyond the reach of a student struggling with an intensive curriculum. Often, these gaps between institutional and government support and the needs of people with disabilities are bridged with community labor—frequently by other people with disabilities either helping out friends or volunteering on an official basis with community outreach organizations. DM-5 explained the burden this places on people with visible disabilities in mentoring roles. "Your energy gets wasted on all this access stuff, and it takes away from your ability to do technical work. I probably lose a conference paper per year to helping students get the access they need". The burdens experienced by DM-5 are not unique to this context: see Shinohara et al. [43] for a study of this "burden of survival" among doctoral students. To bridge the gaps between what support is provided and what is needed, makerspaces will need to identify those gaps and allocate funding and staff member time to address them.

4.3.4 *Access to Information .*

> It's great if you make things accessible to me the way I'd like to think about them, but if I am actually going to create and learn, I need to understand the way you think about the world, because all the [prior work is] from that perspective. And so to actually be able to participate in the community of creation and research, I need to be able to understand how you see the world, not just how I see the world. Technologies that allow me to 'see' a sighted world are much more critical in a creative environment than they would be in other environments
>
> DM-2

100% of disabled maker participants and 66% of makerspace operators mentioned access to information as one of the most critical barriers to makerspace participation. DM-2, MO-4, and MO-8 emphasized the value of digitized information, noting that most people (disabled or not) have worked out some way to access the Internet, and once the information is digitized effectively and accessibly, it can be used to empower people with control over their environment in dramatic ways. For example, the first tool MO-4 builds for all their clients is a remote control for their garage door: "That seems minor to you and me, but if you don't have that, you've got to give your caregivers a key to your home. That causes so many issues. Whereas if you have the ability to open your garage door from your phone, when they get there they can text you and say 'I'm outside, let me in', and you can open the garage door and *you can secure your home*. It's an absolutely enormous thing to give somebody, and any maker can connect a button to that switch—we just have to make a button that matches the capabilities of the end user." DM-2, who is blind, explained how the digitization of books allowed them to become an avid reader: "A pocket dictionary in Braille is 62 volumes of full-sized pages, really big hardcover books. I was really fast at reading Braille, but that's like a book a week or maybe a book a month. Whereas in contrast, I can read 120-130 [digitized] books a year." The accessible digitization of information is a powerful tool for disabled people, since it makes it possible to reshape the information in a way that is accessible within their limitations and use it to control their surroundings.

Permission to access the information is also critical. Copyright and intellectual property restrictions may limit how a text can be translated or reformatted, preventing it from being adapted for a

disabled person's use. DM-4 noted that Right to Repair (a political campaign usually framed around access to diagnostic information from the computers in cars[3]) is also very relevant to access to information for assistive technology. "Diagnosing issues in a power chair is similar to diagnosing a car, you need the computer that will do the automatic diagnosis of the error codes. More and more, there is a monopoly of a handful of chair companies, purchasing even the accessory companies and making them less interoperational between brands of chair." Tool user manuals and diagnostic information need to be provided in a free and open way, so that they can be adapted for the use of people with disabilities.

Even for information not restricted by copyright or intellectual property law, participants discussed the challenges of translating information into the appropriate languages or a format that they can interact with. DM-2 relies on digitization to address the lack of availability and limitations of Braille, but observes that many informal systems in makerspaces and community organizations are still paper-based. They note that this limits not only participation but volunteerism, a critical part of community-building and belonging: "A lot of the volunteer jobs are things I could do if it was on a computer, like checking people into the space, but a lot of people still take that information down on paper. Going and looking at schedules that are printed on posters, that sort of thing, is impossible for me". DM-4 observed that tool manuals are frequently in small print and not digitized, or the PDF versions are not accessible, which makes it difficult to learn to use new tools. MO-6 and MO-8 use multilingual facilitators to ensure everyone has access to the same information, but observe that "translations need to be culturally and technically aware, which is a big problem" (MO-8). DM-5 noted the additional difficulties of using an interpreter for technical work in a makerspace, where the noise levels add to the already large challenge of interpreting technical vocabulary. They also observed that access to interpretation ties into physical access: even in an ADA-compliant space, there may not be room for the instructor, the interpreter, and the student to all be in the space at the same time safely. Accessible digitization can bridge some of the gap towards information accessibility and translation, but physical access still needs to be provided and provision for the safety of all participants needs to be made, and translation/interpretation still requires human input for technical and cultural context.

Support for skill-building was another challenge discussed by multiple participants: half of the makerspace operators and one-third of the disabled makers observed barriers to skill-building for disabled participants. DM-4 mentioned that part of this barrier is in people's assumptions of disinterest—the assumption that a disabled person can't or won't want to repair or maintain their own equipment. "In my youth, I had also done a lot of bicycle maintenance with my father. He was very adamant that if we had a thing we needed to know how to take care of it, so that applied to bicycles, cars—anything that we owned that had any kind of motor or machining to it. So that as soon as I got a wheelchair I was like, this is a tool, why aren't you teaching me how to take care of it? I should know that!" DM-2 observed that, even when it is benign in intent, this assumption prevents disabled people from exploring new skills: "There were things I couldn't do that I steered away from rather than analyzing consciously, because it's kind of frightening to admit that you're not able to do the things that the people around you can do. In [my supportive maker] communities, I never had someone questioning the things I thought I could do—they were supportive of viewing me the way I wanted to be viewed but not pushing further. It takes yourself to basically sit there and go 'Is this one worth actually finding a solution to even if it's hard?' ". Reducing these barriers is important, but since it will always be at least somewhat more difficult for disabled makers to access training and information, it becomes even more important to preserve their access to the help, mentorship, and community collaboration of the makerspace—which makes it critical to address issues of inclusivity and belonging.

4.3.5 *Inclusivity and Belonging.*

> The barriers in expressing needs in the first place, in getting to "I do belong here" is the hardest part.
>
> DM-5

Belonging was a significant part of all interview discussions, becoming four separate codes all of which were extensively discussed both groups of participants. Impostor syndrome was mentioned by nearly all participants as an issue, either for themselves or for members of marginalized groups (mostly gender, ability, and racial minorities, but age and lack of prior experience were also mentioned as factors). Isolation was also a concern for several participants, especially when they were excluded from community makerspaces. DM-4 noted that "Outside of working directly with other disabled people, [being a disabled maker] feels kind of isolating". MO-1 and MO-3 observed that this is another part of the recruitment and outreach issue, and another reason to recruit diverse student staff members, present information in multiple formats, and ensure that physical access pathways can accommodate more than one disabled maker at a time. MO-1's makerspace includes both on-the-spot laminated written documentation and tutorials at major tools, a "Genius Bar" where the student staff members sit so that people can easily find them when they need help, an online collaboration space, and scheduled but drop-in training sessions, so that participants can access the information in whatever format they feel most comfortable (an overlap of belonging and access to information). They also think carefully about how to present shop safety rules to encourage makerspace users to feel comfortable working in the space and changing the space. "We have people who are very strong rule followers, and if they don't know what the rules are they don't want to do something. [But if] there's a sign that tells me a whole bunch of things I shouldn't do, [...] I'll get this general vibe that I shouldn't *do things* at all. So I try not to have signs like that." Participants who feel comfortable in a space and feel ownership of the space are more likely to be open to "makerspacing the makerspace" when they encounter an accessibility gap.

The assumption of neurotypicality in creative spaces can also be a barrier to participation. "As a person with communication differences [...] I always feel like I'm on the verge of doing something wrong. And it's because we communicate in different ways" (DM-3). Prior experiences colored the expectations and recommendations of participants and their assumptions about whether a space open to both disabled and non-disabled people would be welcoming and supportive. While some participants expressed the opinion that they would only participate in spaces with leadership that have similar

disabilities, others feared that participating only in spaces with a monoculture of disability would lead to difficulty participating in the research and innovation happening outside that community, and therefore slow progress towards true universal accessibility. DM-2 noted that "my most valuable accessibility tool [...] is absolutely that I can just use a random computer, and that exists partly because people like me participate in developing and open source projects". The mixed recommendations suggest that a careful approach is necessary to reap the benefits of a heterogenous makerspace, and create a makerspace culture that is supportive without dismantling the "brave space"[5] ethos that supports makerspace culture.

4.4 Connecting across the Accessibility Chasm

4.4.1 Providing Access with Bespoke Design: Design for Empowerment and Makerspacing the Makerspace.

> Anticipating everything isn't possible—that leads to anxiety or overwhelm. And pre-optimizing/universal design doesn't take into account the needs of the real people who really come to the makerspace.
>
> DM-5

One advantage of a heterogenous space is that it potentially provides access for multiply-disabled people in a way that a set of homogenous spaces would not. However, creating that access may be more difficult than just providing access for one disability at a time. DM-4 observed that people with multiple disabilities have a more difficult time connecting with existing maker communities, even online, and that additional resources will be required to recruit them into a community: "I'd love to have people who have multiple disabilities be able to connect with this community, to give them the access I have. But that will require a pretty big tech provision budget for both the devices themselves and the peripherals, [and a] vocational specialist who can devote the time to teach them how to use the computer". It can be difficult to prepare for every combination of disability and the surprising ways they overlap. To address this, participants suggested that universal design is insufficient: allocating additional support for meeting access needs as they come up was mentioned by 40% of disabled makers and 33% of makerspace operators. DM-5 also discussed the potential benefits of meeting with everyone who wants to use the space and interviewing them to discuss their needs, an idea they call "Session Zero" and credit to J. Calvert[14]. DM-5 believes this idea has promise to improve accessibility if translated to education-focused makerspaces. "If this 'Session Zero' could be mandatory for all students, because everyone needs adaptations, the curriculum could be adapted to the student's personal goals.[...] It reinforces the maker/hacker culture of adaptation and creating custom, framing all of this not as 'special disability sauce' but 'this is makerspace culture'—this is engineering culture, this is just how we do things around here." This 1:1 orientation to the makerspace would be time and resource-intensive, but the combination of early identification of access needs, inducting new makerspace participants into makerspace culture, and giving them ownership over making changes to the makerspace provides benefits that should outweigh the initial costs.

4.4.2 Digital Makerspaces .

> The Internet reduces the barriers to access.
> This is why internet-centered accessible makerspaces are just so much more probable.
>
> DM-3

Participants agreed that digital spaces are an enormous advantage to accessibility in general and for makerspaces in particular. All of the disabled participants use digital spaces in some form for connecting with maker communities, and four of the five use online makerspaces as their *primary* space for collaboration. Digital makerspaces aren't just for disabled makers: MO-4 noted that they communicate and collaborate almost entirely online with their community of both abled and disabled makers, and with their assistive technology clients across the country and around the globe, since it eliminates both building access and geolocality barriers. DM-3 noted that that lack of geolocality is both the best and most challenging part of participating in a digital makerspace. "It's a double-edged sword, really—I can't borrow tools, and my best friends are on the other side of the world, they can't help me when I'm sick and need groceries or need a ride to the doctor. But they're [in the space] at 2 AM when I need someone to talk to, because it's not 2 AM in Australia".

Digital spaces also provide a natural boost to information accessibility. While digital information can be used in physical spaces (multiple participants described using phones or tablets to access magnification or transcription services while in a physical collaboration space), it is natively available in digital spaces. This lowers the barrier for access to information (see section 4.3.4), and allows information to be translated more easily into different languages and formats (including Braille and ASL), although it does not necessarily solve the issue of culturally and technically-aware translation.

Digital spaces, however, are not a panacea for all the ills of physical makerspaces. DM-4 noted that the barrier of getting to the space applies even to online spaces: "Sometimes, people don't even have access to the Internet itself – people with spotty internet access or who are relying on Tim Horton's or Dunkin' Donuts WiFi —to be really inclusive, your online program needs provision for a hotspot or to pay for Internet access so they can upgrade enough to access your materials." MO-8 has found that what computing tools they provide also really matter for access to digital spaces: for example, different operating systems are better or worse at localization or screen-reader access. Allocating funding to bridge access gaps and addressing online accessibility gaps will still be necessary.

Digital spaces also do not fully solve the problems of inclusion and belonging. DM-3 noted that the digital spaces they use most often, like Discord and Slack, are invitation-based, and people whom the community identifies as having high support needs are often excluded. They identified a "public health risk" in having the moderators and organizers of these communities be primarily young people, who have the freedom to donate their time, and noted that there is a need for support to prevent burnout in community organizers and online moderators. DM-1 noted that their invitation-only online community intentionally excludes beginner makers to focus on project sharing and collaboration among experts. "I don't want

Table 3: Key recommendations for makerspaces.

Theme	Key Recommendations
Accessible Space	• Ensure that the door-to-door pathways are accessible • Prioritize shop cleanliness (especially floors): provide space for all makerspace users to clean their shoes/wheelchair/crutches to keep the space clean • Be prepared to adapt tools which may have bad ergonomics or inaccessible controls, or to provide alternate access and "be the hands" for someone else when the tool or space is inaccessible (without taking away their design authority)
Breaking Down Barriers	• Digitize information to make it easier to translate and adapt • Support disabled makers in skill-building • Eliminate gatekeeping: connect makers with free materials and support • Be mindful of volunteer burnout, provide support with paid staff where possible • Put plans in place to support users at all skill levels, including remedial access
Fostering Belonging	• Build a reputation as a space that cares about accessibility • Partner with relevant community organizations • Hire staff members who are focused on building the right culture, not just technical skill • Reduce the barriers to getting started in the space • Store tools so they can be easily found and no one "looks lost" • Hire diverse staff members, so new people to the space see someone they can identify with • Make the rules clear, but encourage people to adapt the space to their needs and empower them to make changes ("makerspacing the makerspace") • Foster a "brave space"[5] where people can be supported in approaching their limits, but hold space for affinity groups where makerspace users can be supported by those with similar access challenges • Set aside space for both beginners and experts, to allow experts to choose when they engage in support and mentoring and when they want to focus on their own projects
Other	• Use digital collaboration to reduce friction to join a community and to keep makers engaged if they are unable to participate in-person for a period of time • Include discussion of access challenges and learning goals in makerspace orientation, ideally 1:1 with new participants as a "Session Zero"[14] prior to starting in the makerspace

to sound exclusionary, but I put work into giving people advice, and I want to be able to get stuff out at the same level and amount. That's really satisfying for me, and makes me want to participate in the community". To keep expert users engaged in the makerspace, support, community, and growth opportunities must be provided for expert makerspace users as well as for beginners, and the ability of expert makers to pursue their own projects (rather than just being a resource for new users) must be protected. To enable the support of high-needs individuals and mitigate the burden on volunteers in a digital makerspace, funding might need to be allocated for user support staff.

5 DISCUSSION

While makerspace culture aligns strongly with the needs of disabled people looking to customize assistive technology, we find that disabled makers encounter many barriers in using existing makerspaces. The disabled makers we interviewed found value in creating custom tools themselves instead of having to convince a corporation of their market viability. Our key recommendations based on all interviews are listed in Table 3. Many of these results are consistent with prior recommendations[4], but beyond those guidelines, we highlight the issues of door-to-door accessibility (including the pathways from transit stations or parking lots), providing free or low-cost materials to democratize the experience of creating things in the makerspace and foster a sense of belonging, and the potential for "makerspacing the makerspace" to both improve accessibility and participant's feelings of ownership in the space. We note that the experiences discussed by our participants are individual, and may not reflect the full spectrum of accessibility challenges experienced by other people with the same disability, nor do they reflect all possible disabilities and combinations of access challenges. We believe that building a culture of "makerspacing the makerspace" will allow makerspaces to adapt to new participants with different needs, but also recommend that makerspaces work with their target populations directly to identify specific needs, and that the makerspaces provide funding to adapt the makerspace to address the identified needs. Future work could add detailed recommendations for specific projects by surveying a larger group of disabled makers about the types of DIY AT and non-AT projects that interest them, to identify specific interventions (e.g. [16, 17]) that would be high-value to a large number of disabled makers.

The interconnection of the barriers to makerspace access is evident: barriers in physical space or information accessibility lead to a lack of belonging, which discourages disabled makers from using the space and consequently makes it more challenging for

makerspace operators to acquire funding to break down access barriers. One promising direction for the future of makerspaces may be *hybrid* makerspaces that combine the best features of a digital and physical makerspace. Digital makerspaces have lower barriers to entry and can bypass some of the challenges associated with physical spaces, but have unique barriers like a lack of geolocality that prevents tool sharing. Physical makerspaces may be inaccessible or periodically inaccessible to participants (for example if they have a period of time where they are easily fatigued, or if they are not geographically convenient to the makerspace). Adding digital elements to a physical space can support community interactions, foster a sense of belonging, and facilitate collaborative "makerspacing" of the physical space to enhance access. Overall, our results suggest that thoughtfully-designed hybrid makerspaces could provide a best-of-both-worlds option, and further research into accessible hybrid technical communities is warranted.

In addition, future work should explore more fully themes that came up in our research that were not directly related to makerspace design. One of those is how to accommodate community members with access conflicts, such as a maker with ADHD who requires music to work and a maker who needs background noises kept to a minimum to allow their cochlear implant to work effectively. Of course, the disability community has long experience in this type of negotiation; integrating more disabled people into makerspaces may also bring expertise relevant to this problem. Future work might also explore the details of adapting the "Session Zero"[14] concept to makerspaces and other technical communities: meeting 1:1 with all participants in the space, not just those who identify as disabled, to ensure that their needs are met and to develop custom access plans. Other future work might look into how more documented, organized "engineering-style" making could enable one-shot bespoke assistive technology, addressing the concerns with the "fail fast and often" tinkering approach observed in prior work[25].

6 CONCLUSION

There exist numerous barriers to the participation of people with disabilities in makerspaces. Based on our interviews with makerspace operators and makerspace users with disabilities, we have identified some of these barriers and proposed potential solutions, including both specific, actionable changes to make to move towards universal design, and a mandate for makerspace operators and designers to maintain a culture of adaptability and "makerspace the makerspace" to find solutions to accessibility gaps. We observe that digital makerspaces, while they have access challenges and limitations of their own, provide a lower barrier to entry than in-person makerspaces and provide the community necessary for disabled makers to feel that they belong in the makerspace. Hybrid digital-physical makerspaces may be a way to connect makers with in-person communities with the accessibility features of digital spaces, but a focus on making the space accessible, making information accessible, breaking down barriers, fostering belonging, and encouraging a culture of "makerspacing the makerspace" are the most important parts of creating a space where disabled makers can work to create their own accessibility technology.

ACKNOWLEDGMENTS

The work described here was supported in part by the US National Science Foundation (IIS 2132887) and the Clare Booth Luce Fellowship program of the Henry Luce Foundation. Special thanks to Jason Wiser for the artistic renderings of participants' projects.

REFERENCES

[1] 2016. ATMakers: About Us. http://atmakers.org/about-us/
[2] 2021. Makers Making Change: About Us. https://makersmakingchange.com/about-us/
[3] 2022. The Repair Association: About Us. https://www.repair.org/aboutus
[4] DO-IT AccessEngineering. 2015. Making a Makerspace? Guidelines for Accessibility and Universal Design. "https://www.washington.edu/doit/making-makerspace-guidelines-accessibility-and-universal-design"
[5] Brian Arao and Kristi Clemens. 2013. From safe spaces to brave spaces. *The art of effective facilitation: Reflections from social justice educators* 135 (2013), 150.
[6] Caitlin A Bagley. 2014. *Makerspaces: Top trailblazing projects, A LITA guide.* American Library Association.
[7] Angela Calabrese Barton and Edna Tan. 2018. *STEM-rich maker learning: Designing for equity with youth of color.* Teachers College Press.
[8] Angela Calabrese Barton, Edna Tan, and Day Greenberg. 2017. The makerspace movement: Sites of possibilities for equitable opportunities to engage underrepresented youth in STEM. *Teachers College Record* 119, 6 (2017), 1–44.
[9] Cynthia L. Bennett. 2018. A Toolkit for Facilitating Accessible Design with Blind People. *SIGACCESS Access. Comput.* 120 (jan 2018), 16–19. https://doi.org/10.1145/3178412.3178415
[10] Cynthia L. Bennett, Erin Brady, and Stacy M. Branham. 2018. Interdependence as a Frame for Assistive Technology Research and Design *(ASSETS '18)*. Association for Computing Machinery, New York, NY, USA, 161–173. https://doi.org/10.1145/3234695.3236348
[11] Cynthia L. Bennett, Keting Cen, Katherine M. Steele, and Daniela K. Rosner. 2016. An Intimate Laboratory? Prostheses as a Tool for Experimenting with Identity and Normalcy. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 1745–1756. https://doi.org/10.1145/2858036.2858564
[12] Erin Buehler, Stacy Branham, Abdullah Ali, Jeremy J. Chang, Megan Kelly Hofmann, Amy Hurst, and Shaun K. Kane. 2015. Sharing is Caring: Assistive Technology Designs on Thingiverse. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 525–534. https://doi.org/10.1145/2702123.2702525
[13] Sheri Byrne-Haber. 2022. VMware's First Accessibility Hackathon. https://medium.com/vmwaredesign/vmwares-first-accessibility-hackathon-32fc31d63219
[14] J. Calvert. 2023. Food Focused Nutrition. "https://www.foodfocusednutrition.com"
[15] Debbie Chachra. 2015. Why I am not a Maker. "https://www.theatlantic.com/technology/archive/2015/01/why-i-am-not-a-maker/384767/"
[16] Ruei-Che Chang, Chih-An Tsao, Fang-Ying Liao, Seraphina Yong, Tom Yeh, and Bing-Yu Chen. 2021. Daedalus in the Dark: Designing for Non-Visual Accessible Construction of Laser-Cut Architecture. In *The 34th Annual ACM Symposium on User Interface Software and Technology* (Virtual Event, USA) *(UIST '21)*. Association for Computing Machinery, New York, NY, USA, 344–358. https://doi.org/10.1145/3472749.3474754
[17] Ruei-Che Chang, Seraphina Yong, Fang-Ying Liao, Chih-An Tsao, and Bing-Yu Chen. 2023. Understanding (Non-)Visual Needs for the Design of Laser-Cut Models. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 639, 20 pages. https://doi.org/10.1145/3544548.3580684
[18] Maitraye Das, Katya Borgos-Rodriguez, and Anne Marie Piper. 2020. Weaving by Touch: A Case Analysis of Accessible Making. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3313831.3376477
[19] D. Dougherty, A. Conrad, and T. O'Reilly. 2016. *Free to make: how the maker movement is changing our schools, our jobs, and our minds.* North Atlantic Books.
[20] Morton Ann Gernsbacher. 2017. Editorial Perspective: The use of person-first language in scholarly writing may accentuate stigma. *Journal of Child Psychology and Psychiatry* 58, 7 (2017), 859–861. https://doi.org/10.1111/jcpp.12706
[21] Nanette Goodman, Michael Morris, and Kelvin Boston. 2017. Financial inequality: disability, race and poverty in America. *National Disability Institute* (2017).
[22] Erica Rosenfeld Halverson and Kimberly Sheridan. 2014. The maker movement in education. *Harvard educational review* 84, 4 (2014), 495–504.

[23] Megan Hofmann, Jeffrey Harris, Scott E. Hudson, and Jennifer Mankoff. 2016. Helping Hands: Requirements for a Prototyping Methodology for Upper-Limb Prosthetics Users. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 1769–1780. https://doi.org/10.1145/2858036.2858340

[24] Megan Hofmann, Devva Kasnitz, Jennifer Mankoff, and Cynthia L Bennett. 2020. Living Disability Theory: Reflections on Access, Research, and Design *(ASSETS '20)*. Association for Computing Machinery, New York, NY, USA, Article 4, 13 pages. https://doi.org/10.1145/3373625.3416996

[25] Megan Hofmann, Kristin Williams, Toni Kaplan, Stephanie Valencia, Gabriella Hann, Scott E. Hudson, Jennifer Mankoff, and Patrick Carrington. 2019. "Occupational Therapy is Making": Clinical Rapid Prototyping and Digital Fabrication. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300544

[26] Amy Hurst and Jasmine Tobias. 2011. Empowering Individuals with Do-It-Yourself Assistive Technology. In *The Proceedings of the 13th International ACM SIGACCESS Conference on Computers and Accessibility* (Dundee, Scotland, UK) *(ASSETS '11)*. Association for Computing Machinery, New York, NY, USA, 11–18. https://doi.org/10.1145/2049536.2049541

[27] Jessica Carew Kraft. 2019. Who is a maker? "https://brightthemag.com/who-is-a-maker-603aca72118f"

[28] Hannah Kye. 2020. Who is welcome here? A culturally responsive content analysis of makerspace websites. *Journal of Pre-College Engineering Education Research (J-PEER)* 10, 2 (2020), 1.

[29] Richard E. Ladner. 2015. Design for User Empowerment. *Interactions* 22, 2 (feb 2015), 24–29. https://doi.org/10.1145/2723869

[30] Breanne K Litts, Erica Rosenfeld-Halverson, and Maria Bakker. 2016. *The Role of Online Communication in a Maker Community*. Vol. 1. Routledge, 190–203.

[31] Shannon Mersand. 2021. The state of makerspace research: A review of the literature. *TechTrends* 65, 2 (2021), 174–186.

[32] Zachary A. Morris, Stephen V. McGarity, Nanette Goodman, and Asghar Zaidi. 2022. The Extra Costs Associated With Living With a Disability in the United States. *Journal of Disability Policy Studies* 33, 3 (Dec. 2022), 158–167. https://doi.org/10.1177/10442073211043521 Publisher: SAGE Publications Inc.

[33] Jaya Narain, Ishwarya Ananthabhotla, Samuel Mendez, Cameron Taylor, Hosea Siu, Lora Brugnaro, and Adriana Mallozzi. 2020. ATHack: Co-Design and Education in Assistive Technology Development. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–7.

[34] Alexander Nolte, Irene-Angelica Chounta, and James D Herbsleb. 2020. What happens to all these hackathon projects? Identifying factors to promote hackathon project continuation. *Proceedings of the ACM on Human-Computer Interaction* 4, CSCW2 (2020), 1–26.

[35] National Council on Disability. 2017. Highlighting Disability / Poverty Connection, NCD Urges Congress to Alter Federal Policies that Disadvantage People with Disabilities. http://ncd.gov. Accessed 2023-04-24.

[36] Kylie Peppler and Ted Hall. 2016. The make-to-learn youth contest: Gaining youth perspectives on learning through making. In *Makeology*. Routledge, 141–157.

[37] Kylie Peppler, Erica Halverson, and Yasmin B Kafai. 2016. *Makeology: Makerspaces as learning environments (Volume 1)*. Vol. 1. Routledge.

[38] Mike Petrich, Bronwyn Bevan, and Karen Wilkinson. 2016. *Tinkering with MOOCs and Social Media*. Vol. 1. Routledge, 175–189.

[39] Mónica Pinilla-Roncancio. 2015. Disability and poverty: two related conditions. A review of the literature. *Revista de la Facultad de Medicina* 63 (Sep 2015), 113–123. https://doi.org/10.15446/revfacmed.v63n3sup.50132 Publisher: Universidad Nacional de Colombia.

[40] Halley P. Profita, Abigale Stangl, Laura Matuszewska, Sigrunn Sky, Raja Kushalnagar, and Shaun K. Kane. 2018. "Wear It Loud": How and Why Hearing Aid and Cochlear Implant Users Customize Their Devices. *ACM Trans. Access. Comput.* 11, 3, Article 13 (sep 2018), 32 pages. https://doi.org/10.1145/3214382

[41] Adam Reger. 2018. Creating space for equity in making. "https://remakelearning.org/blog/2018/03/01/space-for-equity-in-making/"

[42] Gina Seymour. 2018. 8 ways to build a more inclusive makerspace. "https://ideas.demco.com/blog/8-ways-build-more-inclusive-makerspace/"

[43] Kristen Shinohara. 2012. A new approach for the design of assistive technologies: design for social acceptance. *ACM SIGACCESS Accessibility and Computing* 102 (Jan. 2012), 45–48. https://doi.org/10.1145/2140446.2140456

[44] Amanda Taboas, Karla Doepke, and Corinne Zimmerman. 2023. Preferences for identity-first versus person-first language in a US sample of autism stakeholders. *Autism* 27, 2 (2023), 565–570. https://doi.org/10.1177/13623613221130845 PMID: 36237135.

[45] Megan Tomko, Melissa W Aleman, Wendy Newstetter, Robert L Nagel, and Julie Linsey. 2021. Participation pathways for women into university makerspaces. *Journal of Engineering Education* 110, 3 (2021), 700–717.

[46] Tara Vinodrai, Brenton Nader, and Christian Zavarella. 2021. Manufacturing space for inclusive innovation? A study of makerspaces in southern Ontario. *Local Economy* 36, 3 (2021), 205–223.

[47] Shirin Vossoughi and Bronwyn Bevan. 2014. Making and tinkering: A review of the literature. *National Research Council Committee on Out of School Time STEM* 67 (2014), 1–55.

[48] Rebekah Willett. 2016. Making, makers, and makerspaces: A discourse analysis of professional journal articles and blog posts about makerspaces in public libraries. *The library quarterly* 86, 3 (2016), 313–329.

A INTERVIEW QUESTIONS

A.1 Questions for Participants

Questions for Makerspace Users:

- Positionality
  - Broadly, can you tell me about yourself and about your background?
  - What are your interests? What do you make and what do you enjoy working on?
- Experience
  - How long have you been working in communities that create things (whether or not you would call them "makerspaces")?
  - What has been your experience as a person with disabilities in creative communities?
- Accessibility and Adaptation
  - What accessibility challenges do you experience in common or open-access maker spaces?
  - What adaptations are the most valuable?

  item Thank you for all this valuable information, is there anything else you'd like to add before we end?

A.2 Questions for Makerspace Operators/Creators:

- Positionality
  - Broadly, can you tell me about yourself and about your background?
  - Can you tell me about the project/space you run/ran/created?
- Design philosophy and history
  - How did your program get started? Did you start it, or did you take over?
  - Was it inspired by other spaces or your prior experiences, and, if so, what did you learn from those experiences to either bring to this space or leave out?
- Accessibility considerations
  - In designing the (program/space), what considerations were made for accessibility?
  - What was the hardest part of making your space and program as accessible as it is?
  - What do you wish you could do or could have done differently to make your space and program more accessible?
- Thank you for all this valuable information, is there anything else you'd like to add before we end?

B CODES/THEMES BY PARTICIPANT

This section contains the data from Figure 2, interview themes by participant type, in a format more accessible to screen readers.

- Count of participants who mentioned the subthemes within the theme "Accessible Space"

  - building infrastructure: 5 MO, 3 DM
  - cleanliness: 1 MO, 2 DM
  - ergonomics: 3 MO, 4 DM
  - pathways: 2 MO, 4 DM
  - safety: 4 MO, 2 DM
  - storage: 4 MO, 2 DM
  - tools:4 MO, 5 DM
  - transportation: 0 MO, 2 DM
- Count of participants who mentioned subthemes within the theme "Barriers"
  - accessible information: 4 MO, 5 DM
  - accessing additional services: 2 MO, 3 DM
  - assumed disinterest in inaccessible tasks/information: 0 MO, 2 DM
  - belonging: 2 MO, 3 DM
  - community labor: 3 MO, 3 DM
  - financial: 6 MO, 4 DM
  - operating hours: 1 MO, 2 DM
  - physical access: 3 MO, 5 DM
  - recruitment/outreach: 5 MO, 0 DM
  - sensory issues: 4 MO, 1 DM
  - support for remedial access/skill building: 3 MO, 1 DM
  - time: 2 MO, 4 DM
- – awareness: 3 MO, 0 DM
  - community: 4 MO, 4 DM
  - identities: 4 MO, 3 DM
  - permission: 2 MO, 2 DM
- Count of participants who mentioned subthemes within the theme "Culture"
  - adaptability: 4 MO, 4 DM
  - atmosphere vs. accessibility: 2 MO, 3 DM
  - beginner-friendly vs. expert-welcoming: 4 MO, 1 DM
  - bespoke design vs. universal design: 3 MO, 2 DM
  - brave space vs safe space: 2 MO, 2 DM
  - invitation-only vs open-to-all: 2 MO, 2 DM
  - inclusion: 5 MO, 4 DM
- Count of participants who mentioned uncategorized subthemes
  - Challenges and advantages of digital media: 3 MO, 4 DM
  - Digital vs physical spaces: 4 MO, 4 DM
  - Getting started/first experience: 1 MO, 3 DM