Melodie: A Design Inquiry into Accessible Crafting through Audio-enhanced Weaving

KATYA BORGOS-RODRIGUEZ and MAITRAYE DAS, Northwestern University, USA
ANNE MARIE PIPER, University of California, Irvine, USA

Despite the promise of the maker movement as empowering individuals and democratizing design, people with disabilities still face many barriers to participation. Recent work has highlighted the inaccessible nature of making and introduced more accessible maker technologies, practices, and workspaces. One less explored area of accessible making involves supporting more traditional forms of craftwork, such as weaving and fiber arts. The present study reports an analysis of existing practices at a weaving studio within a residential community for people with vision impairments and explores the creation of an audio-enhanced loom to support this practice. Our iterative design process began with 60 hours of field observations at the weaving studio, complemented by 15 interviews with residents and instructors at the community. These insights informed the design of Melodie, an interactive floor loom that senses and provides audio feedback during weaving. Our design exploration of Melodie revealed four scenarios of use among this community: promoting learning among novice weavers, raising awareness of system state, enhancing the aesthetics of weaving, and supporting artistic performance. We identify recommendations for designing audio-enhanced technologies that promote accessible crafting and reflect on the role of technology in predominantly manual craftwork.

CCS Concepts: • **Human-centered computing → Empirical studies in accessibility**;

Additional Key Words and Phrases: Accessibility, making, crafting, weaving, audio

ACM Reference format:
Katya Borgos-Rodriguez, Maitraye Das, and Anne Marie Piper. 2021. Melodie: A Design Inquiry into Accessible Crafting through Audio-enhanced Weaving. *ACM Trans. Access. Comput.* 14, 1, Article 5 (March 2021), 30 pages.
https://doi.org/10.1145/3444699

1 INTRODUCTION

Making often refers to a growing set of Do-It-Yourself fabrication techniques (e.g., building circuits, three-dimensional (3D) printing) used to develop various artifacts. Making has been praised for its potential to empower people to take ownership of their own creative initiatives and democratize design [Tanenbaum et al. 2013] regardless of their personal expertise using these tools. Recently, scholars have challenged the notion that making is inclusive of all people by bringing attention to

This work was supported by NSF grant IIS-1901456.
Authors' addresses: K. Borgos-Rodriguez and M. Das, Department of Communication Studies, Northwestern University, 2240 Campus Drive, Evanston, Illinois 60208; emails: {kborgos, maitraye}@u.northwestern.edu; A. M. Piper, University of California, Irvine, 6210 Donald Bren Hall Irvine, CA 92697-3425; email: ampiper@uci.edu.
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1936-7228/2021/03-ART5 $15.00
https://doi.org/10.1145/3444699

accessibility concerns in making [Bennett et al. 2019b; Meissner et al. 2019], such as the difficulties people with disabilities face when navigating these environments [Meissner et al. 2017; Steele et al. 2018]. Consequently, more work has begun to address accessibility in making by studying this practice among people with disabilities [Bennett et al. 2019b; Das et al. 2020; Giles et al. 2018] and designing new tools that support their work [Bennett et al. 2019a; Hurst and Kane 2013; Meissner et al. 2017; Siu et al. 2019].

While these efforts are important steps toward accessible making, much of this work focuses on making high-tech electronics or digital tools accessible. Less research has sought to understand accessibility and the role of technology in more traditional forms of making, such as crafting. Extending this literature, the present study examines weaving as a complex form of crafting and making, focusing specifically on a community of visually impaired weavers. As others have argued [Fernaeus et al. 2012; Rosner et al. 2018], studies of weaving can help understand the early foundations of computing. Weavers engage in a process of decision-making through careful consideration of materials (e.g., type and color of yarn), maintain an awareness of their system state, and constantly assess their work to detect mistakes and ensure high-quality products. Furthermore, the mechanics of the process are algorithmic in nature, involving repetition of steps and variations in numerical sequences to create woven patterns. Given these complexities, weaving can be a rich site for understanding accessible making and reconsidering the role of technology in craftwork.

In this article, we detail our design inquiry into the practices of a group of visually impaired weavers. The study began with eight months of fieldwork in a communal weaving studio for individuals with vision impairments. We conducted 60 hours of participant observations at the weaving studio and held two rounds of semi-structured interviews with community members. This formative work led to insights into how weavers attend to their material workspace, collaborate with their sighted instructors, and the larger societal implications of their labor. Our previous work reports on the material and collaborative practices of weaving in this studio [Das et al. 2020]. The present article extends this earlier work by focusing on the individuals themselves and the design and exploration of an audio-enhanced loom system to support their work practice. Through our analysis, we articulate the ways in which weaving is a learned skill that is honed over time, is both about creating high-quality products and the aesthetic experience of making, and raises tensions around the potential of technology enhancements given the manual nature of this work. To further explore these themes, we introduce Melodie—an interactive audio-enhanced floor loom that was created in collaboration with members of the communal weaving studio for people with vision impairments and their sighted instructors. Melodie was iteratively developed based on insights gained throughout the course of this project. We provide insights from a series of technology exploration sessions that understand how individuals with unique backgrounds and experiences with respect to weaving envision using an audio-enhanced loom as well as the ways in which audio enhancements may support or detract from weavers' craft practice.

Our work makes three primary contributions to the existing literature in accessible making. First, we extend the scope of this literature through an exploration into accessibility in crafting as an instance of making. As part of this, we investigate the role of sound in enabling more inclusive crafting experiences. Second, we describe the process that led to the design of an accessible crafting technology and report on the ways different stakeholders envisioned using this system in their weaving practice. Finally, our analysis offers a broader reflection on what it means to design accessible crafting technologies and the tensions that emerge upon bringing digital enhancements into traditional forms of craft in a communal space.

2 RELATED WORK

Our work builds on prior studies involving various forms of crafting in the human-computer interaction (HCI) literature, existing efforts to improve accessibility in making and crafting, and ongoing theorizing of disability, technology, and design.

2.1 Craftwork and Digital Augmentations in HCI

A large body of literature analyzes various forms of craft practices to both develop design theory and inform new technologies for making and fabrication (e.g., Dew and Rosner [2018]; Rosner and Taylor [2011]; Tanenbaum et al. [2012]). To explore new ways of understanding and experiencing craftwork, researchers have created smart textiles and fabrics that enable electronics to be embedded in them, which crafters may then incorporate into their pieces for increased interactivity [Deepshikha and Yammiyavar 2018; Devendorf and Di Lauro 2019; Kuusk et al. 2015; Nissen and Bowers 2015; Okazaki et al. 2014; Rosner and Ryokai 2010; Takahashi and Kim 2019]. For example, technological enhancements may enable aesthetic changes to woven artifacts in response to touch [Devendorf and Di Lauro 2019; Kuusk et al. 2015]. Other efforts have achieved personalization of finished products based on information about the creator and the process of making. Nissen and Bowers [2015] obtained and translated data from knitters' movements to digitally fabricate a unique artifact using this information. Knitters could keep this artifact as a visual record of their work process or incorporate it into their work. Similarly, Rosner and Ryokai [2010] developed Spyn, a mobile software that associates digital traces (i.e., records of the creative process) with physical locations on handmade fabric. This enhancement prompted recipients' appreciation for the artifacts and the making process.

While much attention has been given to augmentations that directly involve materials and alterations to end-products, less work attends to the crafting *process*. Several studies have explored hybrid crafting, where physical and digital materials co-exist, though few efforts involve an approach that merges digital and traditional into the crafting process itself. In one example, Golsteijn and colleagues [2014] designed "Materialise," a prototyping set that allows users to collaboratively create a physical-digital artifact using tangible building blocks that support displaying digital (i.e., images and audio) files alongside other physical components. Researchers have also created tools that assist crafters in designing complex patterns to guide their work. These tools can facilitate the process of manufacturing textured knitted objects for both machine and hand knitting [Hofmann et al. 2019, 2020b; Kaspar et al. 2019]. Others have built interfaces that support weavers designing pieces that integrate smart textiles [Friske et al. 2019] and even allow the creation of patterns through non-traditional means such as playing music [Zhang et al. 2010]. Although these tools show a promising movement toward supporting crafters in various aspects of their work process through digital augmentations, these are often highly visual, requiring interaction with complex user interfaces that may not be accessible to blind or visually impaired crafters. Furthermore, there remains potential in leveraging technology to support crafters as they engage with the manual aspects of their creative work.

2.2 Accessibility in Making and Crafting

The maker movement, which promotes self-guided design and creation of innovative artifacts and tools, has garnered much attention from the HCI community [Devendorf et al. 2016; Litts 2015; Tanenbaum et al. 2013; Wardrip and Brahms 2015]. Given the increasing popularity of the maker movement and the purported culture that asserts "everyone is a maker," researchers have begun questioning the accessibility of dedicated making spaces and tools [Bennett et al. 2019b; Meissner et al. 2019]. These studies have shown how making environments often lack the resources and organization needed to support disabled makers [Meissner et al. 2017; Steele et al. 2018]. For example, many of the fabrication tools currently available to makers—such as 3D printers, circuit kits, and laser cutter machines—are built with certain assumptions (e.g., interfaces that require visual cues or fine motor control to operate) that make them inaccessible to many people.

Given this, researchers have led efforts to create accessible tools for fabrication [Hurst and Kane 2013; Race et al. 2020; Siu et al. 2019] and identified appropriate configurations of the materials available in makerspaces that can help people feel empowered to make [Bennett et al. 2019b; Brown and Hurst 2012; Giles et al. 2018; Hurst and Kane 2013; Hurst and Tobias 2011; Siu et al. 2019]. For example, Siu et al. [2019] developed a system that assists people with vision impairments in creating and modifying 3D models through touch interactions with a 2.5D shape display. Although these initiatives mark important progress in accessible making, there is still space to understand and support other more traditional forms of making or "crafting." In addition to offering a rich perspective that helps researchers better understand early computing concepts, there are other characteristics of craftwork that set it apart as a form of making and are worth exploring further. First, while maker culture and fabrication is typically associated with engineering and high tech, crafting and associated handwork is more often perceived as low tech and an undervalued form of labor [Fox et al. 2015; Lindtner et al. 2016; Rosner et al. 2018]. As a result, studying crafting can bring forth narratives around making that are not well represented in HCI [Rosner et al. 2018]. Secondly, outcomes from prior work on fabrication and disability have often resulted in unique artifacts that can better support creators in some way (e.g., learning, assistive technologies), whereas crafting may have different goals around aesthetic experience or for the purpose of gifting or selling.

Limited work on accessible making has considered traditional hand work activities such as knitting, crochet, and weaving as instances of making. As a notable exception, Giles et al. [2018] led a series of workshops in which people with vision impairments created interactive art objects that brought together electronic textiles and traditional crafting techniques. Their work echoes insights from previous studies that have revealed how researcher attitudes and thoughtful selection of materials can support accessible making and prototyping [Hofmann et al. 2016]. Beyond narratives of empowerment found in engaging with design, researchers have also identified skill-building and employment opportunities through the act of making, which may support people with disabilities seeking employment [Buehler et al. 2015]. While Buehler and colleagues [2015] focus on promoting employability skills (e.g., computer literacy, receiving and processing orders) that can be practiced through learning 3D printing, as opposed to directly profiting from crafting outcomes, their work highlights another powerful reason to advance research in accessible making and crafting. Building on this collective body of literature, our work considers ways to support people with vision impairments in crafting experiences that do not necessarily involve high-tech electronics or a digital component embedded into the end product. Rather than focusing on enhancing the resulting artifacts, we extend previous efforts by examining the process of weaving as an instance of making and analyzing the potential role of technology in the accessibility of manual craftwork.

2.3 Reworking the Notion of Disability and Technology Design

Since the early 2010s, researchers studying HCI and accessible computing have called for a deeper engagement with disability studies and critical design [Hofmann et al. 2020a; Mankoff et al. 2010]. Yet, much research in this space continues to be framed around a medical or interventional perspective on disability [Spiel et al. 2020]. Scholars have brought attention to ableist[1] ideals in accessible technology design [Alper 2017; Ellcessor 2016; Moser 2006], prompting

[1]Ableism is defined as "a network of beliefs, processes and practices that produce a particular kind of self and body (the corporeal standard) that is projected as the perfect, species-typical and therefore essential and fully human. Disability, then, is cast as a diminished state of being human" [Campbell 2001].

Fig. 1. Table loom inside weaving studio at which our formative work took place.

work that pushes back against the notion that technologies need to solve a problem for people with disabilities. In particular, researchers have pointed out the implicit and explicit deficit narrative—or filling a gap left by disability compared to what an able-bodied individual can do—that is overwhelmingly found in assistive technology [Frauenberger 2015; Ringland et al. 2019; Spiel et al. 2019]. Though well intended, such narratives are a form of violence that can harm disabled people by questioning their credentials and identities [Ymous et al. 2020]. Additionally, accessible technology design often positions independence as the ideal and primary motivation behind designing technologies with disabled people in mind. Instead, scholars have brought forth technologies that give people different ways of expressing their identity and being creative [Giles and van der Linden 2015; Pullin 2009; Ringland et al. 2016]. Technology design through the means of "being with" [Bennett and Rosner 2019] can be a way of understanding experience, exploring one's values, and questioning the normate. For example, Wallace and colleagues [2013] engaged in a design-led inquiry that sought to better understand the experiences of people with dementia and investigate the potential of digital jewelry in supporting their personhood. Prioritizing and taking part in a continuous engagement with individuals' lived experiences throughout the design process can lead to richer design outcomes. The present work builds from these approaches to disability and technology design by investigating accessible crafting among weavers with vision impairments who work in a communal studio.

3 FORMATIVE STUDY: METHOD

Our design process began with eight months of field observations and interviews among a community of weavers with vision impairments.

3.1 Context of Study

Our research took place at the weaving studio located within a supportive living facility for adults with vision impairments in the Midwest region of the United States (see Figure 1). In the studio, residents can learn and work on their own weaving projects alongside three sighted instructors. Weaving sessions in the studio had between one to five residents participating, each typically working on an individual loom prepared exclusively for their project. Volunteers work alongside instructors to keep sessions running smoothly by escorting residents and helping with daily tasks, such as retrieving materials or preparing workspaces. Throughout the study, we held a dual role as volunteers and researchers, which we disclosed to community members. We obtained approval

Table 1. Contextual Interview Participant Table Describing Individuals' Visual Ability, Weaving Experience and Role in the Weaving Studio at the Time Our Formative Work Took Place

Pseudonym	Self-Reported Visual Ability*	Experience	Main Role
Jen	TB—since birth due to RF	3 months	Weaver
Emma	LB—only peripheral vision in one eye, Diabetes	2 years	Weaver
Roy	LB—vision loss due to Optic Nerve Atrophy	6 years	Weaver
Jim	LB—no vision in right eye, partial vision in left eye	15 years	Weaver
Helen	TB—since the age of 40, retina detachments and glaucoma	7 years	Weaver
Paul	TB—since birth	2 years	Weaver
Ruth	LB—with Nystagmus	>1 year	Weaver
Bill	Undisclosed	16 years	Weaver
Lisa	LB—no vision at birth, RF, developed partial vision 4 years ago	6 years	Weaver
Rose	LB—since birth	15 years	Weaver
Adam	LB—vision loss at the age of 7, 20/400 vision, glaucoma	10 years	Weaver
Karen	Sighted	2 years	Instructor
Sara	Sighted	7 months	Instructor
Laura	Sighted	12.5 years	Instructor
Amy**	TB—since birth	23 years	Both

*TB = Totally Blind, LB = Legally Blind, RF = Retrolental Fibroplasia; **Note that Amy is not affiliated with our main field site and instructs a different weaving group.

from the directors of the organization and underwent a background check process prior to our involvement.

3.2 Participant Observations

Two researchers assisted and performed observations at the weaving studio over the span of eight months (from January 2019 to August 2019). Collectively, we conducted 30 observation sessions, each lasting 2 hours on average for a total of 60 hours. To prioritize our role as volunteers, we limited our time taking jottings while on-site and wrote down detailed field notes (each 3–11 pages long) after leaving the studio for the day. In total, we observed 19 weavers, all of whom were legally blind. Their visual abilities ranged from partial vision loss to total blindness from a variety of conditions such as glaucoma and diabetic retinopathy. Residents had varying experience weaving, ranging from beginners to having 15 years of experience. Instructors at the studio had been working there for 7 months to 12 years. To supplement our observations, we video recorded nine of the weavers and instructors in action. These recordings captured weavers' workspaces and dynamics with sighted collaborators. Video length ranged from 40 minutes to almost 2 hours, depending on the time weavers chose to work for the day. These recordings were done with the consent of each participant.

3.3 Contextual Interviews

We conducted two rounds of semi-structured interviews (see Table 1) to understand and contextualize weavers' work practices. First, we invited four visually impaired residents (two female and two male) to join us for an interview before initiating field observations. We also interviewed and observed Amy, a blind weaver and instructor with over 20 years of experience who leads a weaving group at another community. After seven months of field observations at the weaving studio, we invited residents and instructors to participate in a semi-structured interview. At this stage, we had eight visually impaired weavers (five female and three male) and three sighted instructors (all female) from the sessions we attended most frequently join us for an interview. One of our participants, Lisa, joined us for both a pre- and post-observation interview.

Residents were asked to describe their experiences weaving and share about the products they make in the studio. Interviews with instructors narrowed in on their interactions with residents and how they support them. We also used interviews to probe the ways in which technology could become a part of their practice. All interviews were done in person at the participants' workspace or a location where their weaving materials were available. Interviews lasted between 30 minutes to one hour and participants were compensated with $30USD for their time and effort. All interviews were audio recorded and transcribed for analysis.

3.4 Data Analysis

Our data collection and analysis processes followed ethnographic field research methods [Emerson et al. 2011] and borrowed from constructivist grounded theory practices such as iterative coding and constant comparative techniques [Charmaz 2014]. Data include our detailed fieldnotes, video recordings, and transcripts from the contextual interviews described above. In contrast to our prior work, which focuses on the material and collaborative aspects of weaving [Das et al. 2020], here we focused on the individual experiences and goals of weavers. Although both studies share the same data, we revisited all instances and engaged in a secondary round of analysis. In other words, we recoded fieldnotes and interview transcripts, this time narrowing into the learning process, characteristics of weavers' products, and participants' thoughts around technology use in the context of weaving. Similarly, we also rewatched video recordings and took detailed notes that better capture instances related to our new analytic focus. Our iterative process of coding and memoing revealed challenges in the learning process, potential technological additions to understand system state, and how mistakes affect the finished product. Thus, our analysis focused on identifying individual desires and concerns pertaining to weaving, in addition to whether and how technology may fit within weavers' creative work processes.

4 FORMATIVE STUDY: FINDINGS

Below, we detail insights from our observations and interviews with individuals at the weaving studio. Our analysis reveals how weavers overcome initial challenges in the learning process and attend to the aesthetics of their products to ensure high-quality and how weaving becomes an all-around aesthetic experience. We reflect on how these insights can inform the design of new crafting technologies for weavers with vision impairments, yet must be carefully tailored to enhance their work rather than bring further complexities into the process.

4.1 Weaving as a Learned Skill

Through our analysis, we learned that weaving is a complex skill that takes time to master. Weaving involves tightly pressing vertical (warp) and horizontal (weft) threads together using a device known as the loom. The process consists of three primary steps that are performed and repeated in the same order: shedding, picking, and beating. First, shedding causes the warp to split into two separate groups of threads to form a vertical space or *shed*. The weaver will accomplish this by pressing down treadles (i.e., pedals) with feet if working on a floor loom, or manually pulling down levers or turning a peg when using a table loom. The sequence in which these treadles, levers, or pegs are operated will determine the patterns in the resulting cloth. Second, picking involves inserting weft yarn through the shed using a device known as the *shuttle*, which carries yarn in a wound bobbin. Third, beating involves pulling a component called the *beater* to press the weft yarn against the warp to form the woven cloth. For a majority of the residents, their time in the communal studio was their first exposure to weaving. Therefore, the complexities that come with this activity—learning to use unfamiliar equipment and becoming conversant in a new vocabulary—brought forth challenges they had never experienced before. Rose testified to the challenges she encountered as a beginner by sharing, *"First of all, it's hard. Because being a beginner, I thought I never will get it, you know, the pedals and all of that. It takes practice almost to get the hang of it..."*

Some weavers had difficulties identifying treadles, keeping track of the order in which they had to press them, and remembering to beat. If there is a disruption in the sequence (e.g., weaver presses treadles in an incorrect order) or the weaver forgets to beat, then this reflects on the finished product, which many described as less desirable. Although these challenges in the learning process often occur because the weaver loses track of their weaving sequence, through our observations in the studio and conversations with the instructors, we found that this is also often the result of gaps in the contextual information that traditional looms provide users. For example, weavers working on floor looms do not receive any explicit confirmation of which treadle they are currently pressing. To obtain this information, a sighted weaver might briefly halt their work and glance at the treadles to situate themselves visually. Through our video data, we observed blind weavers seeking out this information by using their feet to explore treadles and determine the appropriate one to press. However, this approach can be challenging on looms designed with narrow gaps between each treadle, which makes the bounds of each treadle difficult to assess. Referring to this issue, Paul shared with us about the difficulties he faces situating himself within the workspace, saying *"It's difficult for me to know what the number ... what I was pushing on, sometimes."* This finding indicates the importance of learning to understand and perceive the system state and the potential for technology to support this awareness.

As they obtain more experience, weavers learn to use non-visual environmental cues to understand mistakes and assess system state. These cues may be organic in nature (i.e., produced by the loom as it is traditionally built) or come as a result of modifications that instructors incorporate based on how weavers learn and understand their workspace. For instance, instructors may place textured or colored tape on treadles to make them easier to distinguish. Other cues may come naturally from interactions with materials in the environment. One example of this is awareness of the state of the bobbins (i.e., how much yarn is left), where the weavers *"put their finger on the bobbin to stop it and so, they can feel ... They feel it because all of a sudden you just feel a few threads and you feel plastic underneath .... "* In addition to tactile cues, our informants also identified situations in which auditory cues help them become aware of the project state. In one example, Ruth speaks about how she notices disruptions in the process, when *"something sounds funny on the loom."* Over time, weavers refine their understanding of environmental cues and they develop a sense of "rhythm" that guides their workflow. Upon asking residents how they became more comfortable with weaving and learned to assess their system state, several expressed difficulty in explaining exactly how all of this coordination happens and instead referenced *"a rhythm I have to follow. And sometimes, it's sort of like music."*

During our interviews, we asked weavers whether they had ideas for better supporting the learning process, potentially by modifying the loom with additional technology. Residents expressed wanting *"the whole loom to make a sound."* Thus, they suggested sounds that could be incorporated into not only separate components of the loom, such as the shuttle or beater, but also the entire system. Sara (instructor) builds on this idea, sharing that audio enhancements could support weavers in attuning to their weaving process and environment. She said, *"Having specific tones or*

Fig. 2. Examples of common situations considered mistakes by weavers. On the left, weaver passes shuttle in between warp threads rather than through the shed. Middle image depicts a piece of weft yarn caught in a component of the loom. On the right, weaver detects a disruption in the woven pattern as a result of following an unintended weaving sequence.

sounds that directly relate to each treadle, could be very helpful in the sense that if you know that your pattern is supposed to sound a certain way... I feel like that would only enhance the idea that you're constantly listening to your loom and it's giving you feedback." Distinct tones may not only provide one way to maintain awareness of weaving sequences, but might also help in identifying various components of the loom. By filling gaps in ambient information, weavers could keep track of their process more confidently. Thus, with this additional information, we could think of enhancements that support the sense of "rhythm" our informants described as a way to help both novice and experienced weavers orient themselves while engaging in their work.

4.2 Creating High-Quality Products

Many weavers stressed the importance of creating high-quality products. Residents ensure quality by carefully selecting yarn that can support both durability and uniqueness of each piece. Furthermore, most residents agreed that avoiding "mistakes" is another key aspect to achieve optimal quality. Based on our observations in the studio, a "mistake" (see Figure 2) often involves scenarios such as: (1) passing the shuttle in between warp threads therefore leaving an unwoven piece of yarn; (2) not pulling the weft all the way through while performing a pick that results in pieces of yarn hanging by either side of the cloth; or (3) weaving an unintended sequence that causes a disruption in the pattern of the cloth. Weavers are mindful of these situations and try their best to avoid or mitigate them as soon as they become aware of the mistake.

Upon asking why solving these situations is crucial, residents described pieces with mistakes as *"unfinished"* work. Lisa explained this further adding, *"If you don't learn to solve one, and you get into another jam, you'll never finish it in quality, as I said before. Because, you'll always do mediocre work...."* In addition, both residents and instructors attributed the importance in delivering high-quality products to the fact a significant number of these creations will be available for purchase to the general public. While many residents choose to gift a portion of their work and are generally concerned about their quality, there may be an added pressure toward making profitable products flawless. It is important to consider that for this community, revenue obtained from selling finished work could constitute an important portion of residents' monthly income. As Roy shared, *"I think if I bought a shirt and there's tangles in there, I don't want that shirt... I want one that looks really nice, that will look fitting for me."* Therefore, weavers put great effort into ensuring their finished product is *"as good as I can get it"* to not only feel a sense of accomplishment and pride in their work but also make the pieces more attractive to potential customers.

Residents and instructors agree that mistakes can not only affect the quality of a finished product but also that going back to fix them involves additional work that takes away from the enjoyable aspects of weaving. Along with learning to manage the coordination of various steps and assessing the state of their system, weavers also develop the skills to identify mistakes through the use of ambient information. For example, we noticed some residents taking preventive measures such as running their hand against the cloth throughout their work session to assess their project and determine whether something feels off. Yet, potentially because of the heavy work involved in unweaving (i.e., returning to the state prior to the mistake), they expressed a preference toward consulting instructors for assistance before proceeding. Sharing about her times dealing with these instances, Helen said, *"A mistake? Oh my God. Well, the weaving, you could get the sequence wrong... then you have to start over... You have to go backwards, taking each sequence back. I let them [instructors] do that. I don't have the patience to ... I'll put it in, and you take it out."*

Although instructors are attentive to weavers' requests, they point toward an opportunity to bring technology that can alert weavers of mistakes they might have missed and provide the confirmations they seek from instructors. Both residents and instructors feel technological enhancements could help *"catch the mistakes, and not to make them, or correct them in some way."* Our informants suggested adding buzzing, beeping, or other forms of auditory signals that can alert the weaver of these situations in real time. Sara was particularly vocal in regard to the benefits digital enhancements could have in the crafting process, saying *"I feel like adding technology to the looms can enhance their experience in the sense that they won't have to ask. Perhaps the loom could tell them those sorts of things without them needing to know or before a mistake even happens...."* That is, participants envisioned technological enhancements that can increase awareness of system state and help detect, prevent, and resolve mistakes in the process of weaving.

4.3 Weaving as an Aesthetic and Emotional Experience

In addition to learning to weave and creating high-quality products, our analysis revealed that weavers create an all-around aesthetic experience through careful arrangement of their material workspace to convey their feelings and personal interests. Instructors called attention to how a resident's mood and mindset coming into the weaving studio can have an influence over their performance on a given day. For individuals going through difficult situations, both instructors and residents described weaving as a therapeutic and relaxing experience. To reinforce this peaceful atmosphere, instructors or residents may choose to play music or ambient sounds (e.g., river flow, birds chirping) throughout a session. Residents acknowledged the impact of mood in their work, noting that *"it's not good to weave"* at times when they are not feeling their best, because they are more likely to experience undesirable situations or "mistakes." Recognizing how mood may impact their work, instructors gauge residents' feelings each session and adjust their work strategies accordingly.

The aesthetics of weaving extend beyond how weavers feel at the moment they engage in their work process, to the feelings they convey and evoke through their craftwork. Selecting and coordinating particular fiber colors and textures was a way these weavers expressed their personal style and embedded meaning into designs. To help accomplish this, weavers may build from techniques that change the feel of an artifact. For example, Amy shared her project that uses a weaving technique known as "summer winter," which results in a reversible cloth. She explained how this technique changed the visual and tactile feeling of the piece saying, *"... it's called 'summer winter' and it's sorta like the opposite of each other... See the difference in the texture. And you can see (feel) the diagonals and how they go with your fingertips,"* (see Figure 3, left). One weaver said they consider *"how colors make sounds. I mean, I hear that in my mind all the time when I'm weaving... I've heard colors sing, make funny noises. Just make tones."* Weavers might also choose textures because they make them feel good or trace back to lived experiences. Speaking to this, Jim shared, *"If, let's say for instance you had on a sweater and I've knitted it, I like soft things like real soft fur stuff... I had a*

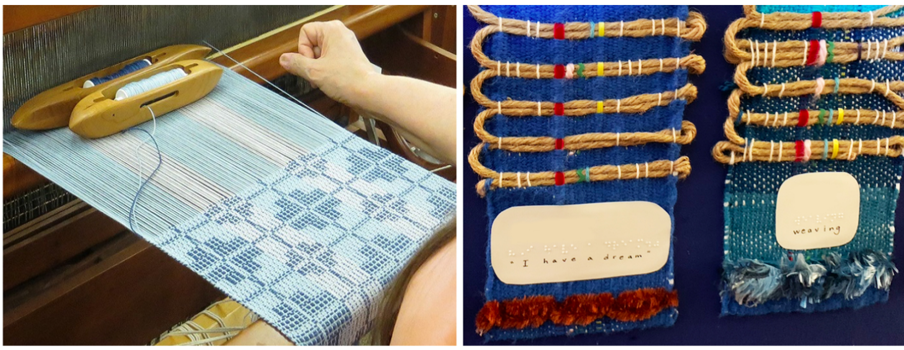

Fig. 3. On the left, Amy shares a project that uses a common weaving technique known as "summer winter," which was created by using two shuttles with contrasting threads. The right image shows two pieces embedded with Braille weaving, one with the phrase "I have a dream" and the other with "weaving."

cat who used to have fur come from her and it was kind of nice and smooth. In my mind, if I make something nice like that... it gives me the idea of, how can I say things I like in the world."

As another way of embedding meaning in designs, some participants use "Braille weaving" techniques, through which they combine distinct pieces of yarn to create Braille characters and send a message through the woven cloth (see Figure 3, right). Paul explains this style of weaving by saying, *"it's like you are pumping Braille in a Braille writer, but you're not. You're pumping it in the yarn... So it's like that, but yes, you can feel the Braille interlinking with the raised print. So it's like a Braille raised print combination."*

Still other weavers use varying equipment and incorporate new types of materials into their projects to embed meaning into their pieces. Lisa shared a compelling example of how she envisions new types of yarn bringing her favorite sceneries to life:

> *I'm thinking about making some textured yarn, because I wanna put some depth into my weaving... Depth, meaning layers. More facets that have never been seen. Say, maybe I wanna make an artwork that feels like the mountains, but I want that rough touch. And then, gradually bring it back out into a smoothness. For me, I love rivers. I love the water. So, I might use a grayish, or green. Something like that kind of yarn. Rough feel. And then, gradually, it'll come back out into a beautiful blue, and it's smooth and flat valleys....*

While weavers expressed pride in their work and the pieces they can produce in the studio, they also recognize the limitations in creating elaborate designs using looms as they are traditionally built. As Helen states, *"sometimes, you want to make designs and you can't always make designs on the loom...."* Taking inspiration from these insights, we can further consider the ways technological enhancements to weaving materials and workspaces might embed additional information into the process and products of weaving [Giles et al. 2018].

4.4 Reflecting on the Role of Technology and Audio

In this study, we used interviews with weavers as an opportunity to question and think through the role of technology in their practice. Although technology was generally perceived positively, both weavers and their instructors expressed a concern that technological enhancements may conflict with manual craft practices such as weaving. Lisa explained:

> *The reason it's [weaving] important to me, is because I wanna see a legacy go back out there ... to me, don't ever lose your roots. Because, when you lose your roots, you've lost you. Yes, computers are wonderful, I couldn't begin to tell you. But, they ain't got no computerized blues now.*

In an effort to preserve the "roots" of hand work and support ownership of their craft, some instructors believe any adaptations to the weaving process for people with vision impairments should be carefully designed to assist rather than "do the work" for the weaver. One strong advocate of this was Laura (instructor), who expressed her concerns by saying, *"That's where I would find technology could be a subtraction, is if it starts to do things that somebody's senses could do but it does it for them. I think that would be a negative instead of a positive..."* Aligned with Laura's comment, prior work has noted the importance of assistive technology not over-helping [Lazar et al. 2016].

In addition to the possibility of technological enhancements conflicting with manual craft practices as we currently understand them, our informants raised a concern that bringing technology—particularly devices with auditory notifications—into their work might take away from the relaxing nature of weaving that many residents have come to value. This concern was articulated by both instructors and weavers. Laura expressed this in her own words, stating:

> *"We have so many things that beep at us, right?... I feel like it makes it a little bit more like maybe I'm in a factory, ... just less in the natural world and more in an automated kind of technological world, where I'm not really in control of everything. There's something else telling me what to do... I think it takes away from the natural sounds of weaving and what gives pleasure, and relaxation, and finding one's own pace, and trusting one's instincts."*

While many informants appeared open to the idea of technology enhancements, the role of audio in the weaving process brought up particular considerations. As we detail above, our informants described how they learned to attend to the organic sounds of the loom (e.g., beater colliding with the woven fabric), which they interpreted as a rhythm and musical. They also spoke of sound cues guiding their creative process and enhancing how they currently experience weaving. In thinking about adding audio feedback to the environment, residents suggested that additional sounds could disturb others in the room or *"misdirect them from their work."* Weavers worried about the appropriateness of additional audio cues in a communal setting. Ruth said, *"I'd probably get distracted..."* Paul shared a similar sentiment by stating, *"You would always have to have headphones nearby so that no one could hear what you were listening to."* Further, weavers explained that any audio enhancements would need to function alongside the organic sounds produced by the loom (e.g., clashing of the beater against the loom, stepping on treadles). The ambient sounds of the loom become *"almost not noticeable, or they're built into this routine"* and serve as cues that guide the weaver in their work.

If audio cues are added to the loom or environment, then they should work in harmony to complement, rather than replace or compete with, existing auditory cues. As Karen (instructor) states, failing to do so *"might make things more confusing..."* Additionally, Sara said:

> *I think if there was an ability to turn it off or enhance it, I think that would make things a lot more helpful because I mean, I get in moods where sometimes I want complete silence and other times I really would like a lot of noise and chatter going on. And I think everybody, they have a personal relationship with their environment ... So I just feel like the ability to adjust whatever enhancement, well, would definitely be super helpful...*

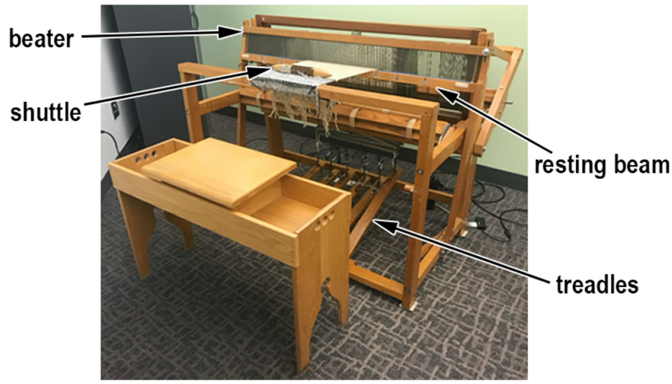

Fig. 4. Overview of Melodie system and bench weavers use to work.

In summary, while informants saw potential in technology to improve their work, they also articulated that technology should augment rather than replace the manual work that is a valuable part of weaving. More specifically, audio enhancements should complement rather than compete with organic sounds produced by looms in a communal weaving space, and allow individual customization of audio feedback depending on each weaver's needs.

5 SYSTEM DESIGN

Based on our formative findings, we designed and built Musically Enhanced Loom Designed for Interactive Weaving Experiences (Melodie) (see Figure 4). Melodie is an exploratory platform for incorporating acoustic traces and audio feedback into the weaving process. Through our design inquiry, we sought to understand whether and how audio cues might support accessible weaving among this community. Our goal in our design inquiry is twofold. First, we aim to understand how various stakeholders envision the use of audio augmentation in this manual and traditional craft practice. Second, we explore the ways in which audio stands to both enhance and detract from the work of weaving.

Melodie is built on a 6-treadle, 4-harness Herald floor loom with 40 inches of weaving width. We chose a floor loom (as opposed to a table loom), because this would allow for greater customization of complex weaving projects and is a familiar loom to residents at our field site. We did not modify the physical structure or mechanics of the loom but instead added components on top of the loom in an effort to have the technological enhancements fade into the background [Lazar et al. 2016]. Melodie senses the three basic steps of the weaving process: (1) pressing treadles to open a shed, (2) passing the shuttle back and forth through the shed, and (3) pulling the beater to push perpendicular threads tightly together. Following each interaction, the system delivers immediate feedback in the form of an auditory cue. Two Teensy 3.2 Arduino boards manage the logic behind the interactions. As our data show, weavers have varying needs and preferences in their work environment and goals. Thus, we created a system that allows user customization of *sound profile*, *volume*, *activation point*, and *velocity threshold* to support different weaving experiences through audio cues. These customizations are achieved via a user interface built with Processing 3, which communicates with the Arduino boards to switch settings. Through this interface, the researchers could make immediate changes to the acoustic environment as weavers interacted with the system.

5.1 Sound Profiles

The first customizable aspect of the system as a whole is the *sound profile*. We created two initial sound profiles for exploration: musical instruments and nature. These soundscapes were

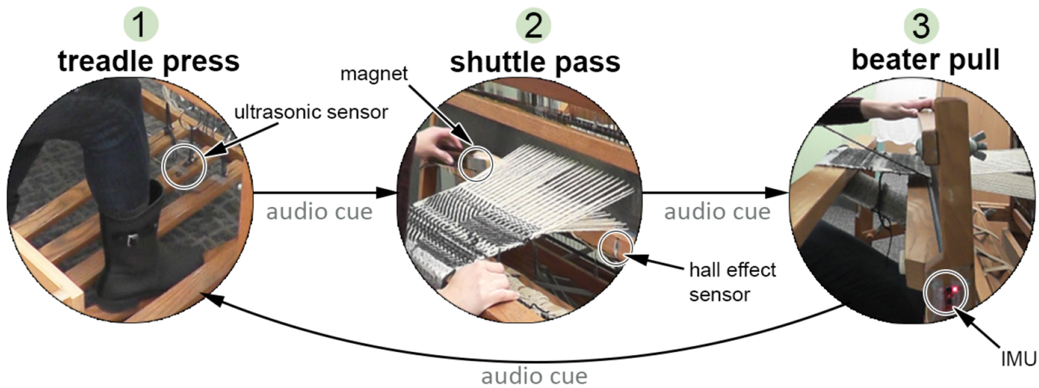

Fig. 5. Melodie system flow diagram showing the three basic steps of the weaving process: pressing treadles, passing the shuttle, and pulling the beater.

implemented based on participants' expressed interest in nature and how weaving was described as a rhythm. Each sound profile contains predetermined audio cues that are automatically assigned to the system components. For example, choosing the musical instruments sound profile will assign piano key tones to the treadles and varying tones of guitar strings to the movement of the shuttle and the beater. The nature profile assigns footsteps to the treadles, bird chirps to shuttle passes, and the sound of a cricket to the beater. Although we wanted to offer as much customization as possible, we learned from technology testers that we should be cautious about overwhelming weavers. Therefore, we thought that having the flexibility to change overall sound experience through sound profiles, but pre-assigning the specific cues associated with each component would allow customizability without overwhelming users. The *volume* of each independent component may also be modified, which can be useful to adjust the prevalence of sound feedback from a particular component (e.g., treadles, shuttle, beater), or muting a component altogether.

5.2 Treadles

To detect a treadle press, we installed ultrasonic distance sensors (HC-SR04) underneath the four centermost treadles (see Figure 5, left). Although the sound associated with all four treadles is preassigned depending on the selected sound profile, each treadle plays a distinct tone or frequency of that sound. For example, under the musical instruments sound profile, pressing the leftmost treadle will emit the sound of a piano key at a particular frequency, while pressing the second leftmost treadle produces the sound of a piano key at a different frequency. In the same way, the sound of footsteps in the nature sound profile will be played at a different frequency on each treadle. The *activation point* variable denotes the moment in time in which the user will experience the sound associated with a particular treadle. This setting can be changed such that the sound will play immediately after detecting a treadle is being pressed or only after the treadle is pressed all the way to the ground. These settings were designed for two potential use cases. The immediate feedback may quickly bring awareness of which treadle is being pressed based on tones. However, playing the audio cue only after pressing the treadle all the way to the ground might encourage weavers to produce the largest shed possible (created by pressing the treadle down to the floor), which is preferable to make the shuttle slide through without damaging the warp.

5.3 Shuttle

Our approach to detect the shuttle involves an array of eight hall effect sensors distributed across the resting beam (see Figure 5, center). We chose this configuration because instructors encourage weavers to pass the shuttle by placing it on the resting beam and pushing it into the shed. Because hall effect sensors operate as switches that toggle with a strong magnetic presence, the resting beam was the most effective location to place sensors given its proximity to the shuttle. We attached a two-inch magnet outside the shuttle that activates the sensors as it glides across the resting beam. Similarly to the treadles, the sound varies as the shuttle travels through each hall effect sensor. For instance, under the nature sound profile, the weaver introduces the shuttle into the shed and hears a bird chirp sound. By the time the shuttle travels to the other side of the shed, the weaver will have experienced different frequencies of the bird chirps sound. This change was intended to act as a guide that allows the weaver to understand both the location and direction of the shuttle within the space.

5.4 Beater

Interactions with the beater are sensed by a SparkFun Virtual Reality Inertial Measurement Unit (IMU) Breakout, which provides the velocity at which the beater is traveling (see Figure 5, right). Auditory cues are activated after the weaver has pulled on the beater past a customizable (low, medium, high) *velocity threshold*. For example, when high velocity is selected, the user will be required to pull the beater with stronger force to experience any sound feedback. This was designed to guide weavers toward the most appropriate beating force with respect to their current project, given that different artifacts may require a softer or harder beat to form the appropriate density of cloth.

6 DESIGN EXPLORATION: METHOD

We invited four individuals with varying weaving expertise to participate in a series of use explorations in our lab space to solicit feedback and understand how different stakeholders could imagine using an audio-enhanced loom. Three participants were weavers at the communal studio where we conducted our formative study. One participant, Anthony, is not a resident but has worked with members of the weaving studio on other related projects. For each session, there were at least two researchers present to observe, take notes, and answer questions. We followed a semi-structured procedure during each session and allowed the weavers' feedback to inform the direction of our questions about their experience. Sara and Anthony had individual sessions, while Paul and Jen had a joint session. Given the communal aspect of the weaving studio, we invited them to try out Melodie together to spark discussion among residents. However, they each used Melodie individually before being brought into the room together. Although researchers prompted for collaborative use, responses from our joint session were highly individual. This spoke to the importance of creating meaningful individual experiences with Melodie, and reinforced our decision to introduce all sessions with our participants as case studies.

After going through the consent form with participants, the leading researcher provided a shuttle with a full bobbin and requested the participant to explore the sound feedback provided by the system by pressing treadles, passing the shuttle, and pulling the beater. This was meant to be a warm-up exercise such that weavers began getting familiarized with the various sounds associated with components and actions when weaving. Subsequently, we introduced different audio sounds or customizations (e.g., musical instruments sound profile with audio feedback from the treadles only when they are pressed down to the floor, nature profile with immediate audio feedback from the treadles) and asked participants to weave one or two sets to explore each configuration available. The research team asked participants to share any thoughts or feedback they might have at any point during the interaction with the system. Upon completing the weaving tasks, the researchers present during the session asked questions about the individuals' experience with the system. These included their thoughts on the auditory feedback implemented in the loom and any

Fig. 6. Sara, a sighted instructor, prepares to pass the shuttle.

changes they would like made to the current implementation. All sessions were video recorded such that we could transcribe and revisit interactions in greater detail. Each session lasted no more than one hour and participants were compensated with $30 USD for their time and effort.

As part of our analytic process, we reviewed our notes, video footage, and interview transcripts from each session. Given the exploratory nature of our evaluation and small sample size, our design inquiry examined these cases individually instead of analyzing across them. Below, we present each weaver's reflections as a case study of initial use. We compared these new findings to insights from our formative work with the goal of better understanding how people conceived of the role of audio within the process of weaving and imagine using an audio-enhanced loom in the context of their creative practice.

7 DESIGN EXPLORATION: FINDINGS

Our analysis of four individuals with different backgrounds and experiences with weaving revealed unique intentions and ways in which participants related to an audio-enhanced loom. Specifically, we find that sound enhancements could scaffold learning and instruction, raise awareness of the system state among users, enhance the aesthetic experience, and support weaving as an artistic performance. Below, we offer a detailed account of our takeaways from each case.

7.1 Scaffolding Learning and Instruction

Sara has worked as a sighted instructor at our field site for almost 2 years (see Figure 6). She is an advanced weaver with more than 10 years of experience. Her involvement with the community began with volunteer work that transitioned into a full-time role as a fiber arts instructor. Coming from a background in weaving instruction, much of Sara's feedback revolved around the potential for Melodie to support novice weavers and provide instructor support.

After using Melodie, Sara indicated a key function would be to help weavers remember steps of their process and situate themselves in their workspace based on the sound feedback associated with each component of the loom and corresponding action. Aligned with her feedback, this was one of the key challenges learners experienced upon their initial exposure to weaving. Sara believes the added audio cues could be particularly beneficial in a teaching environment to provide direction and affirmation of steps as they are completed. In addition to these benefits, she can imagine residents being interested in following the audio feedback to achieve the high-quality products they described throughout our formative work.

> "I liked it, especially from an initial orienting experience... in a teaching environment... the added experience of having sounds going on at the same time is awesome... there are weavers out there who would always, if it was available, turn on the sound and only do that while they were weaving just so that they knew that

> they were getting a perfect product or as near as possible, just by using the cues."
> —Sara (sighted instructor)

Sara also identified opportunities for leveraging the audio feedback provided by the system to encourage best practices among novice weavers. For example, Sara felt that providing an audio cue only when the weaver presses treadles all the way to the floor is an intuitive choice for learners, because *"you kind of are forced to open the shed to its maximum opening, which is what you want to do when weaving."* Similarly, triggering a sound when the weaver has pulled the beater, as opposed to providing a reminder, could encourage learners to develop this habit. In other words, the absence of the sound itself would serve as a reminder to beat. Sara explained, *"if you're constantly just relying on a sound to remind you to beat, you're then reliant completely on a sound as opposed to knowing that you're beating and then getting the confirmation that 'yes, you've done it, that's good'...."* Through this suggestion, she also brings out a design tension in determining whether and how we should implement enhancements that can assist the weaver without hindering expectations of skills that weavers typically develop with time. That is, as we learned in the first stage of our study, weavers believe technology should assist in the learning process rather than do the work for the user. Building on the idea of using audio cues to guide weavers toward best practices, Sara suggested having customizable activation points (i.e., velocity activator) that trigger the sound for the beater in accordance with the selected intensity. Since different projects will prompt varying levels of intensity in the beat, sound alerts could encourage weavers to seek out sounds and an appropriate beating force for each project. In the longer term, this could also substitute the need to install physical alterations to the loom (e.g., rubber bands) that instructors employ to "mechanically disallow" weavers from pulling the beater forcefully. In addition, these insights informed the current version of the treadles' feedback, which originally provided continuous sound cues. Instead, we opted for discrete cues that guide the weaver toward the ideal opening of the shed.

Importantly, Sara dismissed one of our main concerns in designing Melodie, which was whether sound enhancements would disturb a weaver's workflow. Sara stated, *"I see a version of this where it isn't a distraction, it isn't over and above what's going on. It kind of merges and relates really well ... once I knew what to expect, I really was able to listen for those sounds and they didn't feel overwhelming, they felt more reassuring, more 'okay, yeah, I'm doing that—that's fine, that's happening'...."* With this, she touches on another design consideration in that integrating sound enhancements into accessible crafting needs to balance existing organic sounds with additional sound cues. Sara further advised against providing too much freedom for customization of sounds, suggesting that *"it could start also sounding a little chaotic if all the sounds were different, which you don't necessarily want to feel when you're weaving."*

Finally, Sara suggested improvements for our design to better support learning and instruction. She stated that a verbal sound profile (i.e., providing verbal guidance rather than tones) would be particularly helpful for novice weavers who are just starting to find their rhythm and build their vocabulary. She elaborated by stating,

> *Purely from an educator's stand point, to have the verbal cues would be extremely nice. And that's how we teach people anyway. It's not the loom telling them, but it's me standing there, saying those things... One thing that is very important about weaving is that you develop the correct vocabulary within it, so I could see that being a benefit in two ways. One, in that they're learning... If this says 'treadle two'—they're hearing over and over 'treadle two' but then also, um... again, it's a reminder.*

Fig. 7. Paul, an experienced blind weaver, marks the shed by pulling the warp with his left hand.

As such, Sara suggests that a verbal sound profile could ultimately benefit novice weavers and instructors alike by serving as an additional resource that teaches learners weaving vocabulary and procedures in a similar way to what instructors currently do at the studio. This could be helpful to weavers in that they receive real-time feedback as needed while also potentially allowing instructors more time to assist other weavers that are encountering issues in their work. At the same time, in sharing this idea, she encourages us to reflect on the role of Melodie in the studio and how it could impact existing dynamics between residents and instructors.

7.2 Raising Awareness of System State

Paul is a totally blind weaver at our field site (see Figure 7). At the time of this testing session, Paul has worked on a variety of projects at the studio, including both personal and communal initiatives, for approximately three years. He also participated in the first stage of our study and his insights helped us design the early versions of Melodie. Something that stood out to the research team during his exploration was his strong interest in computers and technology. After the session was over, Paul navigated our lab space through touch and quickly identified the technologies we had in the room (e.g., pointing out that we had our system powered through a desktop and were taking notes on a MacBook device). This could be an important consideration while analyzing the suggestions he made upon interacting with our prototype, which revolved around leveraging existing sounds and behaviors from devices he operates in his everyday life to enable more accessible crafting engagements. Paul wanted to bring in these elements to receive sequential instructions that could help him prevent mistakes.

Paul described a version of Melodie in which guidance integrated into the system could assist the weaver throughout their work process and make them aware of any mistakes that may occur. Through our previous sessions, we ideated with participants about the benefits of adding either sound or verbal cues into the system to support various goals and experience levels. However, Paul wanted both modalities coming together to provide the information he needed to better assess system state.

> "Just in case that you didn't know what the sequence was... Like it'll tell you, 'the sequence is... four, two, three, six' ... and then, and it'll say, 'start your project!' ... and if you get the sequence wrong, I think there should be like a buzzer noise. Like... I don't know, like a little buzzer noise that'll tell you if it's correct or not...."
> —Paul (experienced weaver)

Paul expressed liking the additional audio provided and suggested other cues that can make the weaver aware of system states (e.g., the sound of a cash register could represent when the loom needs advancement). However, he also wanted verbal guidance added into the system, much

Fig. 8. Jen, a novice blind weaver, holds shuttle with right hand and prepares to pull beater with left hand.

like what he experiences when navigating with a screen reader. While pressing treadles, he said, *"I think we need to have a screen reader, like... 'two', 'three', 'four' ...."* In regards to how these two forms of feedback could come together, he explained: *"when you go, like, through the shuttle and then it tangles, you could just have a buzzer like that and then it'll tell you like, 'you have got a tangle' or 'you have got a loop'."* Thus, the system may not necessarily have to focus on either verbal or audio feedback but could actually achieve its purpose in providing ambient information and guidance to the weavers through a combination of both. Paul's preference for joining sound and verbal cues might be due to this configuration strongly resembling existing dynamics in the weaving studio. As our formative findings highlight, in addition to remarks by Sara during her testing session, weavers often attend to both ambient cues and verbal assistance from the instructors to understand the state of their project (e.g., whether they need advancement, made mistakes, and so on). Thus, by having both forms of feedback implemented, this could help support weavers in a way that is already familiar to them.

Our discussion also led to a conversation around agency and how accessible crafting technologies should respond to error detection. Describing how he would envision the system alerting him of a mistake, Paul said *"... it'll just be like a 'diiing!' or 'no, you got this wrong, unweave!' ... 'are you sure you want to unweave?' ... And then you could just, like, unweave if you want to and then, like, say no you don't want to unweave. Yes or no... 'Are you sure you want to unweave?"'* Thus, Paul raises an important point in that assistance around the procedural aspects of weaving should be offered and optional for the weaver. This is in line with what we learned as volunteers at the weaving studio, in that we should always offer assistance rather than assume assistance is needed, as the weaver might be content with their work despite mistakes in their product. With this in mind, a system like Melodie should help make the weaver aware of their environment, but provide them agency in choosing whether they would like to remedy any mistakes that occur.

7.3 Enhancing the Aesthetic Experience

Jen is also a totally blind weaver at our field site (see Figure 8). She is newer to weaving, with almost one year of experience from regularly attending sessions at the studio. As in the cases of Sara and Paul, Jen participated in our formative study through the contextual interviews that guided our design process. Jen has a strong connection to music and her identity as a piano player was evident throughout our study. Our discussion of Melodie highlighted how the aesthetics of weaving could be re-imagined by bringing together music and craftwork.

Jen envisioned engaging with Melodie as a system that supports accessible crafting while also re-inventing the aesthetic experience of weaving. When asked about her thoughts on the additional audio feedback being provided, she indicated that *"the music comes together"* while weaving and noted several times that she never thought about these two art forms coming together. Jen shared with the research team that interactions with our system reminded her of the times when she plays the instrument. Having interacted with both sound profiles offered by Melodie, Jen reflected on how different soundscapes may bring forth unique crafting engagements. Jen described the nature profile as *"pretty peaceful and quiet,"* a sentiment Sara also shared during her session. Jen stated that, if given the option to change those sounds while weaving, she would likely make her selection according to *"what kind of mood you're in."*

Jen also went beyond our current implementation and brought up the idea of having different colored yarn associated with unique sounds. In particular, she built on the idea of Braille weaving techniques to embed instructions and messages and *"get it [the woven product] to give speech"* [Giles and van der Linden 2015]. This discussion evidenced the various ways in which the aesthetics of weaving could be enhanced, both in terms of the process (i.e., by having weaving and music coming together while the weaver is performing their work) and through the finished artifact, with the possibility of sound cues being fixed into cloth to experience finished products in new ways.

> "I think it's kind of interesting... I'd say it's [Melodie] about the size of a full-size keyboard or piano. And that way it kind of reminds me of one. 'Cause... the pedals, they're on the floor. You press them and they make, it makes different sounds. So in fact... weaving can be like music and music can be like weaving."
> —Jen (novice weaver)

While providing suggestions on how Melodie could be improved to support work in the weaving studio, Jen also raised several tensions in designing a system for accessible crafting in this context. First, Jen agreed with prior remarks in that verbal guidance integrated into the system could assist the weaver throughout their work process. She noted that this could be particularly helpful *"if you made a mistake or you had a knot or tangle, and no one was there to help you, you could fix it."* This brings out a tension in thinking about the boundaries around what the system should or should not do in place of the instructors. Although system design should consider ways to maintain the dynamics and interdependence between weavers and instructors in the studio [Das et al. 2020], as Jen points out, there might be certain scenarios where it would be helpful to have this verbal guidance assist the weaver instead of an instructor. Last, although excited about the new weaving experiences our system could support, Jen agreed with previous concerns that a system like Melodie could bother other residents in the weaving studio. Given that weavers in our field site work in a shared space, Jen worried about the potential to interrupt others who are wanting to concentrate on their work. In regards to the inclusion of a headphone Jen commented, *"Headphones are a good idea so you don't disturb other people. If there's a lot of people doing it at the same time... then you wouldn't disturb them. You can have your headphones and just... be able to concentrate on whatever we're weaving... and not disturb anybody else."* In summary, our session with Jen led to insights on how an audio-enhanced loom could allow weavers to re-imagine the aesthetics of weaving with respect to music, the crafting process, and finished artifacts. Additionally, her exploration revealed the importance of supporting accessible crafting without disrupting the work of other residents or instructors working in the studio.

7.4 Supporting Artistic Performance

Anthony does not have prior experience weaving but is a sound artist who is blind (see Figure 9). Before testing our prototype, he had several opportunities to engage with weavers at our field site for his own work but had never tried weaving prior to his participation in this study. While Anthony also offered much helpful feedback from the perspective of a novice weaver, what stood out from his time interacting with Melodie was the opportunities for unique artistic performances

Fig. 9. Anthony, a blind sound artist, passing the shuttle through the shed.

that he felt the system could support. Given his expertise, much of his insights involved ways in which sound art and weaving could come together.

> "I love considering this as a performance as well, you know? Not just the art of creating this kind of work (touching the warp) but also... making this thing is a performative thing so it's adding that kind of musical and like sonic level to—it is kind of cool." —Anthony (blind sound artist)

Based on his experience as a sound artist, Anthony could imagine positioning the floor loom as a musical instrument and *"making a music score out of a piece and performing it"* [Devendorf and Rosner 2015; Giles and van der Linden 2015]. This idea of enhancing woven products with music parallels insights from our formative findings that revealed how weavers at our field site will occasionally weave Braille messages into their products to add more depth and meaning to their work. In joining musical performance and weaving together, we could build on this idea to envision collaborative efforts between weavers and sound artists. Anthony suggests a scenario with multiple looms modeled after Melodie coming together in harmony. He elaborates, *"... blows my mind just watching them [weavers] and listening to the machines themselves ... I can see it being really cool to have multiple looms like this in the studio, people performing on them...."* Likewise, while weavers are engaging in their work and receiving audio feedback in real time, a sound artist could manipulate these traces alongside and perform for an audience. In another scenario, he suggested having a selection of yarn in varying colors and textures, each associated with a particular sound. Weavers could have the freedom of choosing their materials in accordance to the mood they want to portray through their work. For example, perhaps blue-toned silk yarn could be chosen to recreate a serene atmosphere. As they weave, every move could be recorded into a digital file that compiles these traces together, associating actions with sounds. The end result is an audio file that plays through all sounds associated with the traces that led to the completion of a piece, merging sound and craft in new ways.

As both a sound artist and blind individual, Anthony had many thought-provoking comments in regards to designing an audio-enhanced loom for accessible crafting. First, Anthony reiterated the importance of bringing all sounds within the ecosystem together coherently, particularly because traditional looms are noisy devices by themselves, with wood and metal elements repeatedly clashing against each other. Building on this, he expressed, *"these machines make a lot of cool sounds on their own that I think a lot of people that aren't just – that just do that probably just overlook, you know. It's like when you do something – it's like, when do you notice the sounds that your keyboard is making when you're typing? ... that stuff gets lost because you just tune it out."* To illustrate an example of sound enhancements blending in with organic traces, he noted that the metal sound when the shuttle clashes against the reed and the guitar string sounds associated to the shuttle complemented each other. By doing so, Anthony confirmed what we had learned through the formative study: that audio enhancements should be distinct enough to be noticeable amongst organic sounds but should also mesh well with these sounds. In expanding our sound library, he recommended developing techniques that adapt sounds to make them appropriate for weavers across a variety of working speeds and ensure their repetition throughout the weaving session does not ultimately fatigue or overwhelm the weaver. Anthony also brought up another crucial point when he advised we take into account the positioning of the speakers that output all sound associated to Melodie. At the time he tested our prototype, the speakers were resting on the floor at either side of the device. Thus, Anthony encouraged us to bring the speakers closer to the weaver, because *"sound can be very distracting when you use your hearing for everything."*

Overall, Anthony's experience with Melodie reveals how an audio-enhanced loom could support artistic performance by integrating new interactive and collaborative crafting experiences that go beyond traditional weaving. However, his insights highlighted design tensions around balancing audio enhancements with existing organic sounds that are an important part of the experience of weaving.

8 DISCUSSION

Our design inquiry prompts critical reflection on how technology might support—and potentially detract from—accessible crafting experiences. Here, we synthesize insights from across our fieldwork and design inquiry to inform future work on accessible crafting and the role of technology in a communal studio.

8.1 Reflecting on the Role of Technology in Accessible Craftwork

Despite positive reactions to Melodie, it is necessary to reflect on how technological additions could take away from the crafting experiences that weavers turn to for relaxation, as a form of work, and to achieve a sense of accomplishment [Das et al. 2020]. While our study suggests that digital tools and materials can benefit the process and outcomes of craftwork, we encountered several tensions throughout our design inquiry. One major tension lies in the presence of technological additions hindering the valued characteristics of hand work [Cheatle and Jackson 2015; Meissner and Fitzpatrick 2017], rather than extending and supporting crafters' existing creative processes [Goodman and Rosner 2011]. Across the various stages of our project, we encountered various ways in which participants attributed the act of *doing* or *"using my hands"* as a source of satisfaction and what contributes to an artifact being *their* work [Ullrich 2004]. Instructors and residents alike expressed their concerns about technologies doing the work for them. These observations echo sentiments from other communities of crafters, for whom interfering with the embodied material aspects of their work through direct integration of technology might be considered disruptive [Cheatle and Jackson 2015; Meissner and Fitzpatrick 2017]. Mistakes, for example, are considered part of the learning process [Marchand 2016] and imperfections are celebrated as valuable characteristics that set aside craft outcomes from massively produced objects [Goodman and Rosner 2011].

The goal of ensuring crafters are actively involved in the act of making and have ownership over the process shapes how instructors attune to residents and constantly negotiate assistance. Similarly, as volunteers, we were encouraged to never assume help is needed and give weavers the space to decide whether and how they wanted assistance. These interactions in the weaving studio align with recent work on the interdependent nature of access [Bennett et al. 2018] and collaboration among ability-diverse groups across different contexts, such as the home [Branham and Kane 2015a; Storer et al. 2020], shopping [Yuan et al. 2017], work environments [Das et al. 2019; Wang and Piper 2018], making [Das et al. 2020; Wallace et al. 2013] and athletics [Thieme et al. 2018]. These studies push back against independence as the end-goal for design, noting the rich social interactions that shape access [Bennett et al. 2020; Soro et al. 2019]. A key part of this interdependence framework is making sure people with disabilities are agents in securing access [Bennett et al. 2018]. As we consider new ways to bring technology into the crafting process, we must remain attentive to the interdependent nature of access—which may suggest shared use of technology between crafters and instructors or technology that performs difficult or tedious tasks—while balancing individual desires around active "doing" and ownership over one's work.

Given some informants' initial concerns, one surprising finding across our work involves how the introduction of technology can open up *new* ways for individuals to relate to their work practice, such as through the aesthetic experience or as performance art. Some weavers might be more interested in the emotional experience of their craft, while others are determined to create high quality products from which they may receive profit. Having these divergent goals in mind, there is great opportunity in designing customizable crafting tools that can better support individuals in achieving the products they seek to sell, yet also appeal to weavers who want to experience and explore new forms of creative making. Through our session with Jen, we observed how some weavers might prefer leveraging audio feedback to achieve an aesthetically pleasing weaving experience. Both the end product and the process of crafting itself offer opportunities for crafters to express their identities and relationships in the social world [Costin 1998]. This encourages technologies that extend their role as functional tools to support deeper connections between users and artifacts [Tanenbaum et al. 2013; Wright et al. 2008]. In this sense, accessible crafting systems have the potential for enabling creative performances that go beyond the work of craft and open up new avenues for design, collaboration, and performance art [Devendorf and Rosner 2015; Giles and van der Linden 2015]. With a system like Melodie, people who otherwise might not have the opportunity to engage in an activity such as music production, perhaps because of unfamiliarity with musical instruments, could engage in mixed media exploration of fiber arts and music. Based on the feedback Anthony provided, we could imagine several weavers in multiple audio-enhanced looms that come together to perform before a crowd. A weaver may also work alongside a sound artist to create musical pieces while simultaneously developing a physical, woven artifact.

8.2 Accessible Craft Technologies for Learning Skilled Practices

The insights generated from our design inquiry into weaving extend previous literature on making by narrowing into craftwork as a less explored area, and understanding what it means to design accessible crafting systems. Beyond this, our design inquiry reveals new ways in which accessible craft systems may support learning to perform manual craftwork and to operate complex crafting systems or tools, such as a large floor loom. Much prior research on crafting focuses on developing enhancements that change how crafters and recipients of their work can experience end-products (e.g., embedding messages in cloth as in Rosner and Ryokai [2010] and Giles et al. [2018]). In the studio environment we studied, informants were interested in technology to support learning the complex skilled practice of weaving, from the repetition of basic steps to figuring out how to unweave and fix mistakes.

Across our work, participants described weaving as an embodied practice that was difficult to master, but became easier once they attended to environmental cues and developed a "rhythm." Still, weavers shared about the potential in accessible craft technologies supporting both novice and advanced weavers alike. Sara and Paul, for example, suggest that a system like Melodie could be designed to support accessible weaving instruction and guide newcomers toward developing skills required for weaving. Strategically choosing *when* and *how* sound cues should be triggered could encourage the weaver to learn the movements and sequences, and then fade out the instructional support over time. Drawing from prior work on how people learn other embodied practices (e.g., glassblowing) [Atkinson 2013; O'Connor 2005], we could take weaving as another case of embodied learning to develop scaffolding systems that support novice learners as they make sense of this process and learn new skills. This can be approached by offering crafters the ability to easily choose from a variety of system features (e.g., turning mechanism to detect disruptions on and off, having the option to turn sound on and off for certain system components like the beater). Connecting with our earlier findings on how weavers value the manual labor and skill building that come with experience, this further supports the importance of designing augmentative crafting technologies that do not hinder the weavers' existing processes. Further, as Paul pointed out, crafters should still have the agency to establish the areas in which they want help. In this sense, technologies that support learning and encourage crafters to develop their expertise over time are more likely to be widely accepted by their respective communities as opposed to, for example, a system that acts as a shortcut and helps users complete their work at twice the speed. This understanding could inform the design of new scaffolding systems meant to support skill-building and then fade away (e.g., Wedoff et al. [2019]).

8.3 Designing Accessible Technologies for Communal Studio Spaces

Another tension that our design inquiry highlights is the nature of designing accessible craft technology for use in a shared, communal studio space. Here, we reflect on whether and how Melodie may complicate existing dynamics between community members and affect the overall shared studio environment. Although residents at our field site are not typically involved in each others' work processes, the weaving studio is a place where residents often gather and discuss community affairs. In addition, as we learned through our prior work [Das et al. 2020], instructors and residents work together to co-create accessibility in making from the moment a project idea is conceived and throughout project completion. And, without careful reflection, the introduction of new technology may disrupt, instead of augment, those practices of working together to create accessibility. Participants from our technology testing sessions imagined a version of Melodie performing tasks typically done by weaving instructors (e.g., identifying mistakes and teaching weaving terminology). While such features could reduce instructors' work load and involvement, this may have a negative affect on the relationships between community members, as these interactions are an integral part of making individual capacities possible [Bennett et al. 2020]. To avoid this from happening, Melodie could simply alert the weaver when a mistake occurs, but ultimately give weavers the agency to decide whether to keep working, try fixing it themselves, or notify the instructor and decide what to do together. We can think of Melodie and other accessible crafting technologies as extensions of, rather than substitutes for, the assistance that collaborators already provide. With this framing, crafters, collaborators, and technological systems together sustain accessibility through an interdependent relationship [Bennett et al. 2018; Middleton and Byles 2019].

Shared studio spaces also bring forth considerations for the use of audio notifications, such as those integrated into Melodie. Although participants shared positive feedback on the soundscapes included in our early version of Melodie, the question of whether audio enhancements could be more disruptive than supportive remains. Participants in our study provided diverging comments with respect to audio feedback preferences (i.e., wanting to have more or less), suggesting this aspect of the experience is highly individualized. Their feedback also points to the complexities in designing audio-enhanced experiences in a communal space, as successful integration of sound cues might involve not only making sure these cues work well together, but also ensuring they are only received by the intended user rather than available to everyone in the surrounding environment. Future versions would greatly benefit from further participant input to identify a library of soundscapes that better complement weavers' varying work preferences. Some weavers might have a preference for serene atmospheres, verbal instruction or a combination of both. It is also unclear whether sound enhancements might be appropriate in the communal work environment and how they would be received over a prolonged period of use. Branham and Kane [2015b] detail the complexities of audio feedback from screen readers in shared workspaces, where a screen reader user's notifications can interfere with other communication happening in the environment. Given this, participants in our work suggested adding a headphone jack to Melodie to avoid distracting other weavers or interrupting the relaxing atmosphere many residents value in the studio. This may have the added benefit of privacy for the individual weaver but could also change the social dynamics in the space if weavers become less aware of what others in the studio are doing. Previous work navigating similar tensions [Rector et al. 2015, 2017] has suggested exploring devices like bone conduction headphones, which may not entirely isolate the weaver from the action around them, as a potential workaround. Involving community members throughout this ongoing process of negotiating and identifying boundaries around crafting technologies is crucial in further evolving Melodie and addressing remaining concerns pertaining audio cues.

8.4 Limitations and Future Work

The present article focuses on a design inquiry that is purposefully exploratory and meant to understand practices and values through the iterative design of new technologies. This approach, however, has several limitations. First, our inquiry engaged a limited number of individuals in the use of Melodie, and different weavers will hold varying perspectives on whether and how they imagine interacting with an augmentative crafting technology. Though we aim to involve more weavers in future iterations, participants' early feedback identified areas to improve our design and further enhance weaving experiences. Second, interaction with Melodie was limited to a brief experience in a lab setting, and the novelty of this system undoubtedly affected informant responses and ways of imagining system use in the studio. Our future work aims to deploy Melodie in the weaving studio for extended, naturalistic use. Third, although our goal was to re-think accessible craft technologies more broadly, we identified many specific improvements that should be made to a future version of Melodie. This includes migrating to a hardware configuration with a single controlling unit to enable the headphone support that participants requested, revising the architecture so that the system better understands the coordination of different elements (i.e., treadles, shuttle, beater), and improving screen reader access to the audio customization interface so that weavers can adapt interactions with Melodie to better support their unique goals and approaches to craftwork [Meissner and Fitzpatrick 2017]. Beyond this, we can think about how to make the system accessible to a broader range of people through a multimodal approach that integrates audio and haptic feedback [Abu Doush et al. 2010] or cross-modal mapping that translates existing sound into tactile cues [Tanaka and Parkinson 2016].

9 CONCLUSION

Through our design inquiry into accessible crafting, grounded in extensive fieldwork and iterative system design, we explore the potential for acoustic feedback to support visually impaired weavers within a communal studio. To understand how different stakeholders imagine using Melodie, we invited four individuals with varying experiences with respect to weaving to test our prototype. By studying their diverse use cases, we identified a potential for sound cues to support early learning and instruction, raising awareness of system state, re-thinking the aesthetics of weaving, and promoting artistic performance. Our analysis motivates reflection on designing audio-enhanced weaving experiences, while navigating the tensions inherent in bringing together technological enhancements and traditional forms of craftwork in a communal environment. Careful integration of sound cues and ensuring user customization are important considerations to achieve a system that supports weavers' work processes, but also preserves the nature of crafting and existing community dynamics that weavers value. These insights present new opportunities for designing technologies that center collaboration, performance art, and accessible crafting. Furthermore, Melodie helps us rethink the kinds of systems we are creating for learning and expertise, by focusing not on the end product, but rather supporting skill-building throughout the process.

ACKNOWLEDGMENTS

We thank anonymous reviewers for their feedback on an earlier draft and Evan Li for his contributions to the technical component of this project. We also thank Andy Slater, Blake Epperson, Don Anderson, Elizabeth Bolanos, Anita Phifer, Kim Sands, Joseph Lamperis, Maria Franco, Margarita Marrero, Antonella Russo, Morgan Cole, Ashley Block, Carlos Hranicka, Wally Tomasiewicz, Julia Blake, Carolyn Marcantonio, Judith Querciagrossa, and our community partners for their contributions to this study.

REFERENCES

Iyad Abu Doush, Enrico Pontelli, Tran Cao Son, Dominic Simon, and Ou Ma. 2010. Multimodal presentation of two-dimensional charts: An investigation using open office XML and microsoft excel. *ACM Trans. Access. Comput.* 3, 2, Article 8 (Nov. 2010), 50 pages. DOI: https://doi.org/10.1145/1857920.1857925

Meryl Alper. 2017. *Giving Voice: Mobile Communication, Disability, and Inequality*. MIT Press.

Paul Atkinson. 2013. Blowing hot: The ethnography of craft and the craft of ethnography. *Qual. Inquiry* 19, 5 (2013), 397–404.

Cynthia L. Bennett, Erin Brady, and Stacy M. Branham. 2018. Interdependence as a frame for assistive technology research and design. In *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility*. 161–173.

Cynthia L. Bennett, Burren Peil, and Daniela K. Rosner. 2019a. Biographical prototypes: Reimagining recognition and disability in design. In *Proceedings of the 2019 on Designing Interactive Systems Conference (DIS'19)*. ACM, New York, NY, 35–47. DOI: https://doi.org/10.1145/3322276.3322376

Cynthia L. Bennett and Daniela K. Rosner. 2019. The promise of empathy: Design, disability, and knowing the "other." In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI'19)*. Association for Computing Machinery, New York, NY, 1–13. DOI: https://doi.org/10.1145/3290605.3300528

Cynthia L. Bennett, Daniela K. Rosner, and Alex S. Taylor. 2020. The care work of access. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI'20)*. Association for Computing Machinery, New York, NY, 1–15. DOI: https://doi.org/10.1145/3313831.3376568

Cynthia L. Bennett, Abigale Stangl, Alexa F. Siu, and Joshua A. Miele. 2019b. Making nonvisually: Lessons from the field. In *Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'19)*. ACM, New York, NY, 279–285. DOI: https://doi.org/10.1145/3308561.3355619

Stacy M. Branham and Shaun K. Kane. 2015a. Collaborative accessibility: How blind and sighted companions co-create accessible home spaces. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI'15)*. Association for Computing Machinery, New York, NY, 2373–2382. DOI: https://doi.org/10.1145/2702123.2702511

Stacy M. Branham and Shaun K. Kane. 2015b. The invisible work of accessibility: How blind employees manage accessibility in mixed-ability workplaces. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS'15)*. Association for Computing Machinery, New York, NY, 163–171. DOI: https://doi.org/10.1145/2700648.2809864

Craig Brown and Amy Hurst. 2012. VizTouch: Automatically generated tactile visualizations of coordinate spaces. In *Proceedings of the 6th International Conference on Tangible, Embedded and Embodied Interaction (TEI'12)*. Association for Computing Machinery, Kingston, Ontario, Canada, 131–138. DOI: https://doi.org/10.1145/2148131.2148160

Erin Buehler, William Easley, Samantha McDonald, Niara Comrie, and Amy Hurst. 2015. Inclusion and education: 3D printing for integrated classrooms. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility*. 281–290.

Fiona A. K. Campbell. 2001. Inciting legal fictions-disability's date with ontology and the abieist body of the law. *Griffith L. Rev.* 10 (2001), 42.

Kathy Charmaz. 2014. *Constructing Grounded Theory*. SAGE.

Amy Cheatle and Steven Jackson. 2015. Digital entanglements: Craft, computation and collaboration in fine art furniture production. In *Proceedings of the ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW'15)*. 958–968. DOI: https://doi.org/10.1145/2675133.2675291

Cathy Lynne Costin. 1998. Introduction: Craft and social identity. *Archeol. Pap. Am. Anthropol. Assoc.* 8, 1 (1998), 3–16.

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 (CHI '20)*. Honolulu, Hawaii, USA.

Maitraye Das, Darren Gergle, and Anne Marie Piper. 2019. "It Doesn't win you friends": Understanding accessibility in collaborative writing for people with vision impairments. *Proc. ACM Hum.-Comput. Interact.* 3, Article 191 (Nov. 2019), 26 pages. DOI: https://doi.org/10.1145/3359293

Deepshikha and Pradeep Yammiyavar. 2018. Traditionally crafted digital interfaces. In *Proceedings of the 2018 ACM International Conference on Interactive Surfaces and Spaces (ISS'18)*. Association for Computing Machinery, 387–392. DOI: https://doi.org/10.1145/3279778.3281462

Laura Devendorf, Abigail De Kosnik, Kate Mattingly, and Kimiko Ryokai. 2016. Probing the potential of post-anthropocentric 3D printing. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS'16)*. Association for Computing Machinery, New York, NY, 170–181. DOI: https://doi.org/10.1145/2901790.2901879

Laura Devendorf and Chad Di Lauro. 2019. Adapting double weaving and yarn plying techniques for smart textiles applications. In *Proceedings of the 13th International Conference on Tangible, Embedded, and Embodied Interaction (TEI'19)*. ACM, New York, NY, 77–85. DOI: https://doi.org/10.1145/3294109.3295625 event-place: Tempe, Arizona, USA.

Laura Devendorf and Daniela K. Rosner. 2015. Reimagining digital fabrication as performance art. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA'15)*. Association for Computing Machinery, New York, NY, 555–566. DOI: https://doi.org/10.1145/2702613.2732507

Kristin N. Dew and Daniela K. Rosner. 2018. Lessons from the woodshop: Cultivating design with living materials. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI'18)*. Association for Computing Machinery, New York, NY, 1–12. DOI: https://doi.org/10.1145/3173574.3174159

Elizabeth Ellcessor. 2016. *Restricted Access: Media, Disability, and the Politics of Participation.* Vol. 6. NYU Press.

Robert M. Emerson, Rachel I. Fretz, and Linda L. Shaw. 2011. *Writing Ethnographic Fieldnotes, Second Edition.* University of Chicago Press.

Ylva Fernaeus, Martin Jonsson, and Jakob Tholander. 2012. Revisiting the jacquard loom: Threads of history and current patterns in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. Association for Computing Machinery, 1593–1602. DOI: https://doi.org/10.1145/2207676.2208280

Sarah Fox, Rachel Rose Ulgado, and Daniela Rosner. 2015. Hacking culture, not devices: Access and recognition in feminist hackerspaces. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing.* 56–68.

Christopher Frauenberger. 2015. Disability and technology: A critical realist perspective. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS'15)*. Association for Computing Machinery, New York, NY, 89–96. DOI: https://doi.org/10.1145/2700648.2809851

Mikhaila Friske, Shanel Wu, and Laura Devendorf. 2019. AdaCAD: Crafting software for smart textiles design. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI'19)*. ACM, New York, NY, 345:1–345:13. DOI: https://doi.org/10.1145/3290605.3300575 event-place: Glasgow, Scotland Uk.

Emilie Giles and Janet van der Linden. 2015. Imagining future technologies: ETextile weaving workshops with blind and visually impaired people. In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition (C&C'15)*. Association for Computing Machinery, New York, NY, 3–12. DOI: https://doi.org/10.1145/2757226.2757247

Emilie Giles, Janet van der Linden, and Marian Petre. 2018. Weaving lighthouses and stitching stories: Blind and visually impaired people designing e-textiles. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI'18)*. ACM, New York, NY, 470:1–470:12. DOI: https://doi.org/10.1145/3173574.3174044 event-place: Montreal QC, Canada.

Connie Golsteijn, Elise Hoven, David Frohlich, and Abigail Sellen. 2014. Hybrid crafting: Towards an integrated practice of crafting with physical and digital components. *Pers. Ubiq. Comput.* 18, 3 (Mar. 2014), 593–611. DOI: https://doi.org/10.1007/s00779-013-0684-9

Elizabeth Goodman and Daniela Rosner. 2011. Agency of autistic children in technology research–A critical literature review. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*. 2257–2266. DOI: https://doi.org/10.1145/1978942.1979273

Megan Hofmann, Lea Albaugh, Ticha Sethapakadi, Jessica Hodgins, Scott E. Hudson, James McCann, and Jennifer Mankoff. 2019. KnitPicking textures: Programming and modifying complex knitted textures for machine and hand knitting. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST'19)*. Association for Computing Machinery, 5–16. DOI: https://doi.org/10.1145/3332165.3347886

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.* 1769–1780.

Megan Hofmann, Devva Kasnitz, Jennifer Mankoff, and Cynthia L Bennett. 2020a. Living disability theory: Reflections on access, research, and design. In *Proceedings of the 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. 1–13.

Megan Hofmann, Jennifer Mankoff, and Scott E. Hudson. 2020b. KnitGIST: A programming synthesis toolkit for generating functional machine-knitting textures. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*. 1234–1247.

Amy Hurst and Shaun Kane. 2013. Making "making" accessible. In *Proceedings of the 12th International Conference on Interaction Design and Children (IDC'13)*. ACM, New York, NY, 635–638. DOI: https://doi.org/10.1145/2485760.2485883

Amy Hurst and Jasmine Tobias. 2011. Empowering individuals with do-it-yourself assistive technology. In *Proceedings of the 13th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'11)*. Association for Computing Machinery, 11–18. DOI: https://doi.org/10.1145/2049536.2049541

Alexandre Kaspar, Liane Makatura, and Wojciech Matusik. 2019. Knitting skeletons: A computer-aided design tool for shaping and patterning of knitted garments. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST'19)*. Association for Computing Machinery, 53–65. DOI: https://doi.org/10.1145/3332165.3347879

Kristi Kuusk, Marjan Kooroshnia, and Jussi Mikkonen. 2015. Crafting butterfly lace: Conductive multi-color sensor-actuator structure. In *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers (UbiComp/ISWC'15 Adjunct)*. Association for Computing Machinery, 595–600. DOI: https://doi.org/10.1145/2800835.2801669

Amanda Lazar, Raymundo Cornejo, Caroline Edasis, and Anne Marie Piper. 2016. Designing for the third hand: Empowering older adults with cognitive impairment through creating and sharing. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS'16)*. Association for Computing Machinery, New York, NY, 1047–1058. DOI: https://doi.org/10.1145/2901790.2901854

Silvia Lindtner, Shaowen Bardzell, and Jeffrey Bardzell. 2016. Reconstituting the utopian vision of making: HCI after technosolutionism. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 1390–1402.

Breanne K. Litts. 2015. Resources, facilitation, and partnerships: Three design considerations for youth makerspaces. In *Proceedings of the 14th International Conference on Interaction Design and Children (IDC'15)*. Association for Computing Machinery, New York, NY, 347–350. DOI: https://doi.org/10.1145/2771839.2771913

Jennifer Mankoff, Gillian R. Hayes, and Devva Kasnitz. 2010. Disability studies as a source of critical inquiry for the field of assistive technology. In *Proceedings of the 12th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'10)*. Association for Computing Machinery, New York, NY, 3–10. DOI: https://doi.org/10.1145/1878803.1878807

Trevor H. J. Marchand. 2016. *Craftwork as Problem Solving: Ethnographic Studies of Design and Making*. Ashgate Publishing, Ltd.

Janis Lena Meissner and Geraldine Fitzpatrick. 2017. Urban knitters on interweaving craft, technologies and urban participation. In *Proceedings of the 8th International Conference on Communities and Technologies (CT'17)*. Association for Computing Machinery, 12–21. DOI: https://doi.org/10.1145/3083671.3083674

Janis Lena Meissner, Pradthana Jarusriboonchai, Janice McLaughlin, and Peter Wright. 2019. More than the sum of makers: The complex dynamics of diverse practices at maker faire. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI'19)*. Association for Computing Machinery, 1–13. DOI: https://doi.org/10.1145/3290605.3300348

Janis Lena Meissner, John Vines, Janice McLaughlin, Thomas Nappey, Jekaterina Maksimova, and Peter Wright. 2017. Do-It-yourself empowerment as experienced by novice makers with disabilities. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS'17)*. ACM, New York, NY, 1053–1065. DOI: https://doi.org/10.1145/3064663.3064674

Jennie Middleton and Hari Byles. 2019. Interdependent temporalities and the everyday mobilities of visually impaired young people. *Geoforum* 102 (2019), 76–85.

Ingunn Moser. 2006. Disability and the promises of technology: Technology, subjectivity and embodiment within an order of the normal. *Inf. Commun. Soc.* 9, 3 (2006), 373–395.

Bettina Nissen and John Bowers. 2015. Data-things: Digital fabrication situated within participatory data translation activities. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI'15)*. ACM Press, 2467–2476. DOI: https://doi.org/10.1145/2702123.2702245

Momoko Okazaki, Ken Nakagaki, and Yasuaki Kakehi. 2014. metamoCrochet: Augmenting crocheting with bi-stable color changing inks. In *ACM SIGGRAPH 2014 Posters (SIGGRAPH'14)*. Association for Computing Machinery, 1. DOI: https://doi.org/10.1145/2614217.2633391

Erin O'Connor. 2005. Embodied knowledge: The experience of meaning and the struggle towards proficiency in glassblowing. *Ethnography* 6, 2 (2005), 183–204.

Graham Pullin. 2009. *Design Meets Disability*. MIT Press.

Lauren Race, Claire Kearney-Volpe, Chancey Fleet, Joshua A. Miele, Tom Igoe, and Amy Hurst. 2020. Designing educational materials for a blind arduino workshop. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing*

Systems (CHI EA'20). Association for Computing Machinery, New York, NY, 1–7. DOI: https://doi.org/10.1145/3334480.3383055

Kyle Rector, Lauren Milne, Richard E. Ladner, Batya Friedman, and Julie A. Kientz. 2015. Exploring the opportunities and challenges with exercise technologies for people who are blind or low-vision. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS'15)*. Association for Computing Machinery, New York, NY, 203–214. DOI: https://doi.org/10.1145/2700648.2809846

Kyle Rector, Keith Salmon, Dan Thornton, Neel Joshi, and Meredith Ringel Morris. 2017. Eyes-free art: Exploring proxemic audio interfaces for blind and low vision art engagement. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 3, Article 93 (Sep. 2017), 21 pages. DOI: https://doi.org/10.1145/3130958

Kathryn E. Ringland, Jennifer Nicholas, Rachel Kornfield, Emily G. Lattie, David C. Mohr, and Madhu Reddy. 2019. Understanding mental ill-health as psychosocial disability: Implications for assistive technology. In *Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'19)*. Association for Computing Machinery, New York, NY, 156–170. DOI: https://doi.org/10.1145/3308561.3353785

Kathryn E. Ringland, Christine T. Wolf, LouAnne E. Boyd, Mark S. Baldwin, and Gillian R. Hayes. 2016. Would You be mine: Appropriating minecraft as an assistive technology for youth with autism. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'16)*. Association for Computing Machinery, New York, NY, 33–41. DOI: https://doi.org/10.1145/2982142.2982172

Daniela K. Rosner and Kimiko Ryokai. 2010. Spyn: Augmenting the creative and communicative potential of craft. In *Proceedings of the 28th International Conference on Human Factors in Computing Systems (CHI'10)*. ACM Press, New York, NY, 2407. DOI: https://doi.org/10.1145/1753326.1753691

Daniela K. Rosner, Samantha Shorey, Brock R. Craft, and Helen Remick. 2018. Making core memory: Design inquiry into gendered legacies of engineering and craftwork. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI'18)*. Association for Computing Machinery, 1–13. DOI: https://doi.org/10.1145/3173574.3174105

Daniela K. Rosner and Alex S. Taylor. 2011. Antiquarian answers: Book restoration as a resource for design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*. Association for Computing Machinery, New York, NY, 2665–2668. DOI: https://doi.org/10.1145/1978942.1979332

Alexa F. Siu, Son Kim, Joshua A. Miele, and Sean Follmer. 2019. shapeCAD: An accessible 3D modelling workflow for the blind and visually-impaired via 2.5D shape displays. In *Proceedings of the 21st International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'19)*. Association for Computing Machinery, New York, NY, 342–354. DOI: https://doi.org/10.1145/3308561.3353782

Alessandro Soro, Margot Brereton, Laurianne Sitbon, Aloha Hufana Ambe, Jennyfer Lawrence Taylor, and Cara Wilson. 2019. Beyond independence: Enabling richer participation through relational technologies. In *Proceedings of the 31st Australian Conference on Human-Computer-Interaction (OZCHI'19)*. Association for Computing Machinery, New York, NY, 149–160. DOI: https://doi.org/10.1145/3369457.3369470

Katta Spiel, Christopher Frauenberger, Os Keyes, and Geraldine Fitzpatrick. 2019. Agency of autistic children in technology research—Critical literature review. *ACM Trans. Comput.-Hum. Interact.* 26, 6, Article 38 (Nov. 2019), 40 pages. DOI: https://doi.org/10.1145/3344919

Katta Spiel, Kathrin Gerling, Cynthia L. Bennett, Emeline Brulé, Rua M. Williams, Jennifer Rode, and Jennifer Mankoff. 2020. Nothing about us without us: Investigating the role of critical disability studies in HCI. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (CHI EA'20)*. Association for Computing Machinery, New York, NY, 1–8. DOI: https://doi.org/10.1145/3334480.3375150

Katherine Steele, Brianna Blaser, and Maya Cakmak. 2018. Accessible making: Designing makerspaces for accessibility. *Int. J. Des. Learn.* 9, 1 (Jun. 2018), 114–121.

Kevin M. Storer, Tejinder K. Judge, and Stacy M. Branham. 2020. âAll in the same boatâ: Tradeoffs of voice assistant ownership for mixed-visual-ability families. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI'20)*. Association for Computing Machinery, New York, NY, 1–14. DOI: https://doi.org/10.1145/3313831.3376225

Haruki Takahashi and Jeeeun Kim. 2019. 3D printed fabric: Techniques for design and 3D Weaving programmable textiles. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST'19)*. Association for Computing Machinery, New York, NY, 43–51. DOI: https://doi.org/10.1145/3332165.3347896

Atau Tanaka and Adam Parkinson. 2016. Haptic wave: A cross-modal interface for visually impaired audio producers. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI'16)*. Association for Computing Machinery, New York, NY, 2150–2161. DOI: https://doi.org/10.1145/2858036.2858304

Theresa J. Tanenbaum, Karen Tanenbaum, and Ron Wakkary. 2012. Steampunk as design fiction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12)*. Association for Computing Machinery, New York, NY, 1583–1592. DOI: https://doi.org/10.1145/2207676.2208279

Theresa J. Tanenbaum, Amanda M. Williams, Audrey Desjardins, and Karen Tanenbaum. 2013. Democratizing technology: Pleasure, utility and expressiveness in DIY and maker practice. In *Proceedings of the SIGCHI Conference on Human*

Factors in Computing Systems (CHI'13). Association for Computing Machinery, 2603–2612. DOI: https://doi.org/10.1145/2470654.2481360

Anja Thieme, Cynthia L. Bennett, Cecily Morrison, Edward Cutrell, and Alex S. Taylor. 2018. "I can do everything but see!" – How people with vision impairments negotiate their abilities in social contexts. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI'18)*. Association for Computing Machinery, New York, NY, 1–14. DOI: https://doi.org/10.1145/3173574.3173777

Polly Ullrich. 2004. Workmanship: the hand and body as perceptual tools. *Objects and Meaning: New Perspectives on Art and Craft* (2004), 198–214.

Jayne Wallace, Peter C. Wright, John McCarthy, David Philip Green, James Thomas, and Patrick Olivier. 2013. A design-led inquiry into personhood in dementia. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'13)*. Association for Computing Machinery, New York, NY, 2617–2626. DOI: https://doi.org/10.1145/2470654.2481363

Emily Q. Wang and Anne Marie Piper. 2018. Accessibility in action: Co-located collaboration among deaf and hearing professionals. *Proc. ACM Hum.-Comput. Interact.* 2, Article 180 (Nov. 2018), 25 pages. DOI: https://doi.org/10.1145/3274449

Peter S. Wardrip and Lisa Brahms. 2015. Learning practices of making: Developing a framework for design. In *Proceedings of the 14th International Conference on Interaction Design and Children (IDC'15)*. Association for Computing Machinery, New York, NY, 375–378. DOI: https://doi.org/10.1145/2771839.2771920

Ryan Wedoff, Lindsay Ball, Amelia Wang, Yi Xuan Khoo, Lauren Lieberman, and Kyle Rector. 2019. Virtual showdown: An accessible virtual reality game with scaffolds for youth with visual impairments. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI'19)*. Association for Computing Machinery, New York, NY, 1–15. DOI: https://doi.org/10.1145/3290605.3300371

Peter Wright, Jayne Wallace, and John McCarthy. 2008. Aesthetics and experience-centered design. *ACM Trans. Comput.-Hum. Interact.* 15, 4, Article 18 (Dec. 2008), 21 pages. DOI: https://doi.org/10.1145/1460355.1460360

Anon Ymous, Katta Spiel, Os Keyes, Rua M. Williams, Judith Good, Eva Hornecker, and Cynthia L. Bennett. 2020. "I Am just terrified of my future"–epistemic violence in disability related technology research. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (CHI EA'20)*. Association for Computing Machinery, New York, NY, 1–16. DOI: https://doi.org/10.1145/3334480.3381828

Chien Wen Yuan, Benjamin V. Hanrahan, Sooyeon Lee, Mary Beth Rosson, and John M. Carroll. 2017. I Didn't know that you knew i knew: Collaborative shopping practices between people with visual impairment and people with vision. *Proc. ACM Hum.-Comput. Interact.* 1, Article 118 (Dec. 2017), 18 pages. DOI: https://doi.org/10.1145/3134753

Jiahua Zhang, George Baciu, Shuang Liang, and Cheng Liang. 2010. A creative try: Composing weaving patterns by playing on a multi-input device. In *Proceedings of the 17th ACM Symposium on Virtual Reality Software and Technology (VRST'10)*. ACM, New York, NY, 127–130. DOI: https://doi.org/10.1145/1889863.1889890

Received August 2020; revised December 2020; accepted December 2020