# Weaving by Touch: A Case Analysis of Accessible Making

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## ABSTRACT

The rise of maker communities and fabrication tools creates new opportunities for participation in design work. With this has come an interest in increasing the accessibility of making for people with disabilities, which has mainly emphasized independence and empowerment through the creation of more accessible fabrication tools. To understand and rethink the notion of accessible making, we analyze the context and practices of a particular site of making: the communal weaving studio within an assisted living facility for people with vision impairments. Our analysis helps reconsider the material and social processes that constitute accessible making, including the ways makers attend to interactive material properties, negotiate co-creative embodied work, and value the labor of making. We discuss future directions for design and research on accessible making while highlighting tensions around assistance, collaboration, and how disabled labor is valued.

## Author Keywords

Disability; design; making; vision impairments; materiality

## CCS Concepts

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

## INTRODUCTION

Maker and fabrication technologies have garnered much interest given their potential to accelerate innovation [2] and democratize design [78]. Yet, a growing body of work questions whether contemporary maker culture is truly inclusive and democratic [1, 32, 50] and which forms of making are valued [26, 50]. Among these critiques is the exclusive nature of making to those who are not younger, able-bodied, well-educated, and affluent [1, 53, 78]. As part of this discourse, scholars of accessibility and assistive technology have been concerned with *accessible making*, or what it means to make making accessible to people with disabilities [41]. Prior work shows that people with disabilities still face numerous accessibility barriers to making, ranging from the physical environment to the lack of appropriate and approachable software for design [14, 42, 53]. Others have understood accessible making by engaging people with disabilities in co-design sessions [15, 28, 53] and design retrospectives of making and hacking [5, 6, 35]. Collectively, this work argues that participating in making can foster autonomy, creative expression, and empowerment among people with disabilities [15, 28, 42, 49, 53].

Despite significant scholarly and public attention [17, 60, 70], certain assumptions around accessible making remain relatively unquestioned. For example, increasing the accessibility of maker technologies is typically conceptualized as supporting the individual themselves through improved digital tools [14, 41, 42], neglecting the ways other people and one's material workspace can shape interaction. Similarly, questions remain regarding how accessible maker communities are created and sustained through social structures and institutions (i.e., through "care work" [82]) rather than simply the availability of technology. Finally, certain narratives of making, such as empowerment [53], may neglect the political and structural disadvantage that led to the circumstances of one being a maker in the first place [6].

To help understand these issues and rethink the notion of accessible making, we turn to a traditional and manual form of making among an understudied demographic: a community of blind and visually impaired weavers. Our work is grounded in eight months of participant observations in a community weaving studio for people with vision impairments coupled with contextual interviews with these weavers and their sighted instructors. This weaving studio is a particularly compelling site for inquiry, as weaving is a complex practice of making that can take years to master. The process of weaving involves deciding upon an arrangement of yarns and patterns for a project, tracking placement of threads as they are woven together, detecting possible mistakes in the woven fabric, and maintaining awareness of the state of the entire loom system. Weavers also engage in a form of algorithmic thinking as they systematically interlace threads and repeat and vary numerical sequences of patterns. Further, studies of weaving help understand the foundations of early computing [25, 80] and expose non-dominant narratives of making and engineering [66].

The present paper makes three primary contributions. First, our analysis brings together work on accessibility and materiality as a way of relocating the 'interface' in accessible making, shifting attention from digital and physical tools to their material constituents (e.g., feeling and sounds of fibers and wood). Through this, we probe the ways in which material properties, such as texture, tension, and collisions, constitute an accessible language for making. Second, we revisit the

goal of promoting independence and autonomy in making by detailing the co-creative and interdependent nature of work, in which accessibility is collaboratively created and negotiated. Our analysis extends a growing literature on ability diverse group interaction (e.g., [10, 11, 79, 86]) to include a rich site of creative making and skilled learning among blind and sighted individuals. Third, our inquiry contributes to ongoing discussions of making and design among disabled communities, broadening who is considered a designer or maker [6, 7, 66] and revealing tensions in why and how this labor is valued.

## RELATED WORK
We situate the present study among literature on making for people with disabilities, material practices in design, and collaboration among ability-diverse groups.

### People with Disabilities and Making
A growing literature investigates the ways people with disabilities design, repair, and repurpose their own assistive tools and devices [6, 13, 42, 53, 61]. Researchers have highlighted that the ability to directly control the design and making of assistive devices can foster empowerment, ownership and self-efficacy among individuals with disabilities [35, 42, 53]. Studying the online e-NABLE maker community for 3-D printed prostheses, others have found that making and fabrication is a way of developing one's identity and challenging notions of normalcy [5, 35]. Researchers have also conducted co-design workshops with people with vision impairments, where participants assembled electronic devices with Arduino [8], created personalized and interactive products with e-textiles [27, 28], and engaged in sculpting, carving, collage making, raised line drawing and other lapidary arts using clay, wire, stone, foam and wiki-sticks [73]. These analyses highlight key challenges and provide future recommendations for inclusion of people with vision impairments into participatory design and making. Other work details the empowering and expressive nature of embodied visual expression through art making for people with complex communication needs [49] and cognitive impairment from dementia [48]. In summary, this work focuses on retrospective accounts of design by people with disabilities [5, 6, 7, 13, 35, 61] and co-design sessions with people with disabilities [8, 15, 28, 37, 53, 73] and their caregivers or therapists [38, 40, 48, 49]. We extend this body of work by detailing the situated, community-led practices of making among weavers with vision impairments.

### Material Practices in Design
Scholars have long turned to situated cases of craft, handwork, and DIY practice as a way of advancing theories and concepts of design in HCI. Prior work has attended to how the interactive nature of materials shape the way we see and do design work. Schön's seminal works put forth the idea of materials "talking back" to the designer in a "reflective conversation" [67, 68]. Similarly, Barad emphasized the performative role of design materials by reframing interactions as "intra-actions" between components [3]. That is, materials have properties that emerge "with and through a vast array of human-machine relationships," [22] and moderate the ease or difficulty of creating a "material utterance" (i.e., suggesting or modifying a material artifact) [20]. Closely related to the present study, Fernaeus et al. highlighted how a 140-year-old

Jacquard loom's material construction using graspable and recyclable components can inform the concepts of tangible interactions and sustainability [25]. With studies on knitting [29, 65], bookbinding [63], and woodworking [22], Rosner and collaborators have contributed to understanding the ways seemingly individual craft practices are constituently part of larger collaborations between materials, other people, and the workspace. As an example, Rosner stressed how materials such as cords, pages and saw grooves in the book bindery workshop 'collaborate' with the binder, providing hints as to how it should be sawed, sewed, or pressed [63]. Similarly, Desjardins and Wakkary [21] investigated the practice of hobbyist jewelers and steampunk enthusiasts where the designers "let materials speak" and act according to the fluid exchange with the materials. Tsaknaki and Fernaeus studied how craft materials such as leather, textile, metal and wood afford particular sensory experience, physical manipulations and interactive behavior with the artefacts [85]. Despite this extensive literature, studies of material practice in design rarely feature people with disabilities, whose work may reveal interactive properties of materials that are taken for granted or under-explored.

### Collaboration among Ability-Diverse Groups
While the ways people with disabilities collaborate with materials during making is relatively under-explored, there is a large and growing body of literature within HCI and CSCW that examines ability-diverse collaboration (e.g., deaf and hearing dyads [86], neurodiverse student groups [90]). Most related to the present study, Branham and colleagues investigated co-reading [74] and shared living practices [10] of people with vision impairments and their sighted companions. This work helped establish the notion of accessibility as a collaborative phenomenon within HCI, in which all group members play an active role in co-creating accessible experiences. Others have studied collaborative writing practices of blind and sighted professionals, where collaborators established shared norms and strategies for writing while negotiating power and ableism in the workplace [19]. Metatla and colleagues analyzed how children with and without vision impairments can practice shared learning, storytelling and co-design using multisensory elements [18, 54] and voice user interfaces [55]. Still other work examines how people with vision impairments and sighted persons form a shared understanding while shopping together [89], performing navigation tasks [88], and learning programming concepts [47, 79]. This body of work highlights how practices in ability-diverse teams are shaped by collaborators' interpersonal relations, power dynamics, and sociomaterial configurations, particularly in academic, professional, and personal spaces. The present paper deepens our understanding of the dynamics of interaction between blind and sighted collaborators as well as with the material workspace in the context of creative making and design.

## METHOD
Our analysis is grounded in eight months of participant observation at a communal weaving studio for people with vision impairments and is supplemented by contextual interviews with weavers and sighted instructors. We obtained approval to conduct this research from our university's Institutional Review Board and our community field site.

**Context of Study: The Weaving Studio**
Our research takes place within the weaving studio of an assisted living facility for people with vision impairments located in a large U.S. city. While all community residents are visually impaired, the vast majority also have chronic health conditions (e.g., hearing, cognitive, or motor impairments, cancer, diabetes) and are low income. Three sighted instructors and several volunteers work in the weaving studio to support the residents who come to the studio to weave[1]. The weaving studio is open four or five days a week, typically with two, two-hour working sessions per day. Given the popularity of the weaving program and limited resources in the studio, each resident is assigned a maximum of two hours weaving time per week. Each session usually includes 1-4 visually impaired residents and 1-2 sighted instructors. Introductory sessions are available for residents who are new to weaving, where they learn the components of a loom, the process of weaving and necessary tactics by working one-on-one with an instructor. Sighted instructors and volunteers perform a number of roles that include guiding the residents from the main building to the studio when needed, adding finishing touches to completed products (e.g., repairing mistakes, sewing, cleaning and tagging items), taking measurements, and maintaining a log file with all information pertinent to the projects including the name of the weaver and number of completed items.

The residents work on different weaving projects such as rugs, mug rugs, dish towels, tote bags, bookmarks, baby blankets, belts, and cane holders. They also participate in communal projects in which they work together to create tapestries or artistic rugs, which have previously been exhibited in local art centers. In accordance to an agreement between the organization and residents, residents may keep half of the products they make. They can choose to sell their products or keep them for their personal use or other purposes. The rest of the products go to the organization and are sold to the general public, which helps support studio maintenance and buying tools and supplies (e.g., yarns, warping boards, bobbin winders, etc.).

**Participant Observation**
With approval from the community, two researchers conducted participant observation at this community weaving studio by serving as volunteers. From January 2019 to August 2019, we conducted a total of 30 observation sessions at the weaving studio, each lasting for two hours on average (60 hours in total). Over the course of our field work, we observed 19 weavers, all of whom were legally blind, ranging from partial vision loss to total blindness due to a variety of conditions (e.g., glaucoma, optic nerve atrophy, diabetic retinopathy, nystagmus, retina detachment). These residents had varying levels of experience weaving at the studio, ranging from 3 months to 15 years. We also observed three sighted instructors who had been working with residents in the studio for 7 months to 12 years. We discussed our dual roles as volunteers and researchers and the purpose of the study while introducing ourselves to the residents and instructors. During our time as volunteers, we followed volunteering guidelines maintained by the community (e.g., sighted guiding techniques, asking if the resident would like assistance instead of jumping to help). We prioritized our duties as volunteers and took jottings sparingly during our time at the studio. However, we prepared detailed fieldnotes (each 3-11 pages long) after leaving the site. Also, to better understand the routines of individuals in the weaving studio, we video-recorded eight observation sessions with consent from the weavers and the instructors involved. Video recordings focused on the workspace of each individual weaver as well as their interactions with sighted instructors. Video recordings lasted between 40 minutes and 2 hours.

**Contextual Interviews**
We conducted semi-structured interviews with 4 visually impaired residents (2 identified as female and 2 as male) before starting our field observations. Additionally, we conducted an interview with Amy[2], a blind weaver and instructor who has 23 years of weaving experience and leads her own weaving group at another community. We were also able to observe Amy weaving during the interview session. After 7 months of field observation at the weaving studio, we conducted semi-structured interviews with 3 sighted instructors (all identified as female) and 8 visually impaired residents (5 identified as female and 3 as male) who attended the sessions in which we volunteered and observed most frequently. One resident, Lisa, was interviewed both at the beginning and after observations.

Before the start of each interview, we collected consent from the participant. We encouraged weavers to talk freely about their experiences, probing about their motivations for weaving, the products they make, and the tools they use. We also asked them to describe how they learned to weave and show us how they understand different states of their workspace and the products they work on. Interviews with instructors focused on their interactions with residents and the kind of support they provide. All interviews including the one with Amy were performed face-to-face in their weaving workspace or with their weaving materials in hand. The interviews lasted for 30-60 minutes, and participants were compensated with $30USD. Interviews were audio-recorded and transcribed for analysis.

**Data Analysis and Positionality**
Our approach to data collection and analysis follows ethnographic field research methods [24] as well as the iterative coding, constant comparative techniques, and theorizing described by Charmaz [16]. Data include our jottings, full fieldnotes, photographs, video recordings and interview transcripts. We began with open coding of our interviews and fieldnotes, which included codes that captured hand and foot coordination, organization of the workspace, interaction between residents and instructors, etc. Two researchers also reviewed the video recordings to examine these phenomena in detail, using video data to enrich our understanding. The research team met regularly to discuss emerging ideas and used those understandings to refine our interview questions and probe these areas further. Throughout our analysis, we wrote analytic memos and engaged in constant comparison of data to data and data to emerging themes and established theories in the literature.

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[1]Throughout the paper, we use 'residents' and 'weavers' interchangeably to refer to the weavers with vision impairments who work at the weaving studio.

[2]All names are pseudonyms.

Throughout the process of data collection and analysis, we adopt a view of interaction as multimodal, embodied, and situated [30, 31, 36, 39, 43, 75, 76] and attend to how participants combine different modalities to establish shared meaning. Our own analytic views also align with the philosophy of our field site, which aims to foster individual potentials, autonomy, and engagement. Informed by Kafer's political/relational model of disability [46], as well as work from other feminist disability scholars [4, 23, 51, 87], our analysis views disability as enacted through particular sociomaterial relations and configurations rather than located solely in the individual (i.e., medical model) or society (i.e., social model). Although we aim to understand disability, making, and design, we are mindful of whether our participants want to be called designers at all and how analyzing people with disabilities as inspiration for design can reify power differentials [7]. Our ethnographic approach is an attempt to come alongside these individuals and *be with* this community [6, 7], although we bring with us inherent power differentials as researchers, engineers, designers, and sighted people. These sensitivities shape our analysis and results, and we return to them in the discussion.

## FINDINGS

Our analysis focuses on a community-based weaving studio as a rich site of learning, making, and skilled practice. As such, we first provide brief background on the process, components, and mechanics of weaving. In weaving, two sets of yarns or threads are interlaced at right angles to form a cloth. The longitudinal threads are called the *warp* and the lateral threads are the *weft*. The warp threads are held stationary in tension on the loom, while the transverse weft thread is drawn through and inserted over and under the warp. Weaving consists of three primary steps. First, *shedding* involves dividing the warp into two separate groups or planes of threads, forming a shed or a vertical space between two warp groups. This is done by pressing down certain *treadles* (i.e., pedals) with foot in a floor loom and pulling down *levers* or turning a *peg* forward or backward with hand in a table loom. Following particular sequences (e.g., 2-3-5-2), where each number denotes the treadle or lever that should be operated, creates different weave patterns. Second, *picking* involves inserting the weft yarn through the shed using a *shuttle*, which carries the weft in a bobbin. As the shuttle moves back and forth across the shed, it weaves an edge on each side of the fabric to prevent the fabric from unraveling. Third, *beating* involves pulling the beater to press the weft yarn against the woven cloth. The above operations are repeated in this particular order for the insertion and interlacing of the threads.

By studying weavers within this community, we draw out three key practices that help rethink the notion of accessible making. Specifically, we find that accessible making involves attending to interactive material properties, negotiating co-creation, and valuing one's labor of making.

### Attending to Interactive Properties of Materials

Studies of materiality have long shaped our understanding of design by examining how designers engage in conversation with materials [67, 68] during situated practices of making (e.g., [22, 63]); yet, this work centers the experiences of able-bodied designers. Through our analysis, we identify interactive material properties, such as *texture*, *tension*, and *collisions*, that are central to the practices of visually impaired weavers at our field site. As one resident with low vision commented, *"I'm not even trying to see, although it looks like I'm looking at the shuttle. I'm just using my touch."* While these material properties are important to all weavers, they take on a particularly salient role in the way visually impaired weavers understand system state, potential mistakes, and how the design will take shape through their actions.

For weavers with vision impairments, the texture of various yarns—or their feel based on thickness, composition, elasticity, and other attributes—is a particularly important interactive property. For example, Sara (instructor) and Lisa described the shiny portion of a yarn by its "rough" texture. In the same way, Amy traced her fingertips along the texture of woven cloth and explained, *"... 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 1, left). Residents also incorporate Braille into their work to create artistic pieces by weaving words using six threads of different thicknesses and textures that represent the six dots in a Braille character.

The contrasting feel of the fibers can give a piece its meaning (e.g., symbolically through texture or literally through Braille weaving) as well as signify ownership and individual labor associated with a project. Touching the cloth on a loom she was about to use, one resident sensed that she was assigned to a different project than the one she had been working on and said, *"I didn't weave this, did I?"* Thus, the tactile feel of textured fibers coming together into a pattern gives off cues about which work is one's own. *"As it (yarn) comes together... they have the ability to make a very unique article,"* said Lisa, appreciating the uniqueness of the hand-woven products that bear testimony to her individual labor and skill [84].

Further, the 'feel' of fibers woven together reveals possible disruptions in the pattern caused by mistakes (e.g., pressing a wrong treadle in the weaving sequence). As an example, another resident from our observations sensed a disruption in her pattern by feeling the contrast of texture between the location of the weft where she had pressed a wrong treadle and the rest of the cloth. Relatedly, Bill described using thicker yarn in his work, since thicker yarn makes the imperfections in the pattern easily discernible from the rest of the cloth. He said, *"It's easier for a blind person to feel the heavier yarn than the thinner yarn. You can feel what you're doing better, and you can easily feel out mistakes, if any at all."*

One of the most important and unique interactive properties of weaving is the practice of iteratively sensing and creating tension on the threads. Throughout a project, maintaining adequate tension on the warps is critical. Warps under appropriate tension work *"like a surface"* or an interface [63], making it easier to pass the shuttle through the shed smoothly. In contrast, if the warps are not taut enough, the shuttle is more likely to come out through the middle of the warps (instead of through the other side of the shed) and thus disrupt the weaving pattern. Too much tension also leaves traces of past activity on the end product [64], making the edges of the
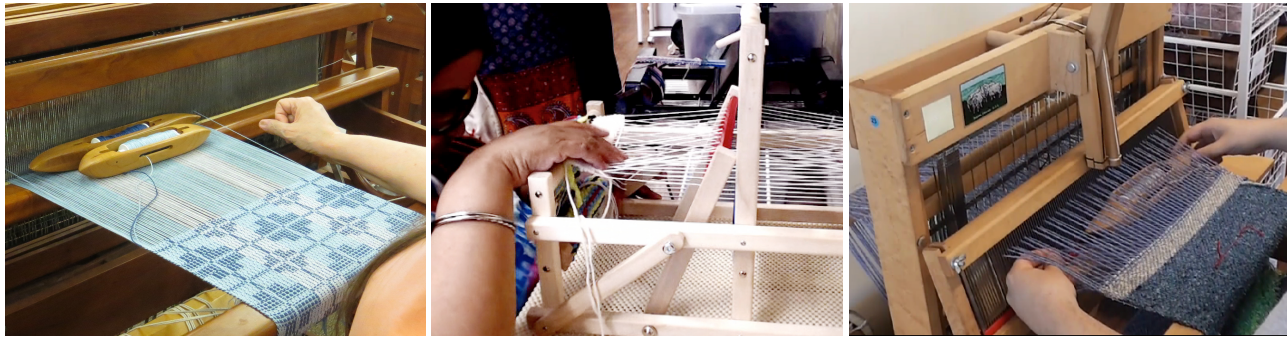
Figure 1. *Left:* **Amy works on her "summer winter" pattern using two shuttles with contrasting threads;** *Center:* **Lisa feels tension on the warps while learning to advance the loom;** *Right:* **Paul waits for shuttle to collide with left hand during picking.**

woven cloth curve inwards and more rigid than the middle portion of the cloth or even causing threads to break. Lisa explained, *"as long as it (threads) cooperates, I'm fine... It's held by tension, but if you're not careful in how you work with some threads, they'll break before you know it. And so, weaving is sometimes very fragile."* Thus, weavers must carefully negotiate the tension and fragility of fibers and convince these materials to cooperate [63].

One scenario in which weavers attend to the tension in the warp threads is when they search for the shed with the tip of their shuttle to initiate picking but cannot locate it. Subsequently, they assess the tension in the loom by placing their hands over the warps and pressing lightly (see Figure 1, center) and then request a readjustment of their loom accordingly. As Laura (instructor) explained to Jen while adjusting her loom, *"See how the warps are loose. Now I'm going to make it tighter... feel that?"* Tension is not just in the warps; the weaver pulls the weft in the shuttle until they *"feel the tug"* (i.e., a mild tension) to prevent any unwanted loops and maintain a smooth edge in the woven cloth. Occasionally the weaver feels a strong tension while pulling the weft, which tells them the weft is getting stuck in the loom's gears in the corner:

> *"It's the tension... let's say I put this (shuttle) through over here (shed) and I've tangled it (weft). When I get ready to do the other weave, this (weft) will pull tight and that means something up here has been done wrong... You may have two or three of those little catches (gears catching the weft) and this thing will let you know."* - Jim

That is, the shuttle will "talk back" to the weaver, alerting him of a possible mistake. Tightness of the shed is another indicator of the loom's state. As Paul explained, he knows the loom needs to be advanced (i.e., the completed sections rolled out of the way to allow free space for weaving) when *"this box (shed) gets tight, to the point where it goes zoop...like a little box."* As these examples illustrate, tension in the threads conveys information about the loom system as a whole – whether the loom is advanced, a loop occurred near the edge, or the weft is stuck with other loom components.

Beyond texture and tension as interactive material properties, the manual process of weaving prompts weavers to attend to the ways in which materials collide with each other and one's body. For example, in the first step of shedding, the weaver carefully attends to possible collisions between the shuttle and

the shed. If the shed is not large enough for the shuttle to pass through, the weaver needs to *"pull the peg all the way down"* or *"put [their] feet fully on the treadle."* Thus, the material response and natural collisions between the shuttle and shed provide valuable information about the system state and guide the weaver's next steps.

The step of picking—or sending the shuttle through the shed— is a bimanual process of coordinated movement from one hand to the other. The weaver shoves the shuttle between the shed from one side applying a certain amount of force, which ideally makes the shuttle travel the complete distance. Expecting the shuttle to appear at the opposite side, they keep their free hand ready at that side to catch the shuttle immediately (see Figure 1, right). Occasionally, the shuttle never reaches the hand and instead collides with the warp, creating a 'floating pick' or mistake in the woven cloth; sensing this collision is key to identifying and correcting mistakes. Jim explained:

> *"I would slap it (shuttle) through [the shed] and it would stop somewhere over here. It's easy for this (shuttle) to come up and over [the warps]... I could tell the mistake right away, because this thing (shuttle) will sure let you know, you've done something wrong."*

After picking, the weaver beats-up, which makes the beater collide against the cloth, resulting in a distinct beating sound and also marking the end of a weaving cycle. Also echoed by Jen, Jim, and Helen, Paul described this flow of interactions as *"a rhythm I have to follow. And sometimes, it's sort of like music."* Weavers learn to distinguish a correct beat from a "soft beat" (i.e., not exerting enough force on the beater), in which the beater does not collide with the cloth. By attending to the sound of this collision, the weaver knows that they need to beat multiple times to make sure that the beater is pulled *"all the way down to the cloth"* so that the cloth has a uniform density. Furthermore, residents can perceive the state of the loom and their project from the response they receive from the beater: the beater travels a shorter path to reach the cloth (or collides earlier) when the loom needs advancement.

Instead of visually following the beater, shuttle, and loom position to inspect the progress of one's work, these weavers engage in a "reflective conversation" [67, 68] with their design materials using *"their other [non-visual] senses."* Here, we see that accessible making involves the situated practice of learning to attend to the ways in which physical sensations and

sounds of material against material and material against bodies communicate with the designer, thus creating a uniquely accessible material language between designer and workspace.

**Negotiating Co-Creation**

Rather than conceiving of accessible making as a state or feature of a system (i.e., whether a particular physical or digital tool is accessible), our analysis reveals that weavers and instructors collaboratively create and negotiate accessibility [10, 19, 86]. That is, accessible making is created through coordinated embodied learning between residents and instructors, the negotiation of physical space and adaptations, and dynamic support that fades into the background.

*Coordinated Embodied Interaction*

Especially in early learning, residents engage in coordinated embodied interaction with the instructors to gain an understanding of the key steps in weaving. This often involves the instructor helping place a weaver's hands on the loom in certain positions or hand-over-hand guidance as they work through a task (see Figure 2) all the while narrating the interactive experience. Consider the following example of Jen and Laura (instructor) working together to secure the tail of a weft yarn that is about to be used for the first time:

> Laura asked Jen to feel the tail of the thread that was coming out of the shuttle. She gently brushed the tail over the back of Jen's hand to give her a hint about where she should look for the tail. After Jen found the tail, Laura placed her finger in the middle of the warp and instructed, "Feel my finger right here." Jen searched for Laura's finger by moving her hand and found the point of interest. Next, Laura asked Jen to "pass the tail [through the shed] using your hand as if your hand was like a shuttle." While Jen was following this instruction, Laura asked, "Do you feel how you're going underneath the warp?" ... When Jen's hand that was holding the thread reached the point of interest from underneath the warp, Laura instructed, "Make a pinch with your other hand [the one that was over the warp], with your thumb and the index like this." She touched Jen's hand and helped her rearrange the fingers to form a pinch. After that, Laura asked Jen to "hold the thread with your pinch. Pull [it] all the way towards yourself." - Fieldnotes, July 11, 2019

In this example, embodied cues along with simultaneous verbal instructions helped Jen understand which elements to look for and where. We observed similar hand-over-hand guidance where the instructors used *"a combination of verbal, physical, and more of a sound sort of explanation"* to teach weaving concepts to a new weaver. Laura explained that at times her words alone are insufficient for demonstrating actions. Instead, she says, *"'Place your hand on my hand,' and then, 'This is how it is.' (Makes a beat.) They get the reverb effect, they get the feel, they get the rate, the speed, the emphasis."* That is, learning the step of beating requires coordinating the instructor's verbal guidance along with experiencing the sounds and embodied 'feel' of exerting force on the wooden beater.

*Co-Creating Workspaces*

Another aspect of accessible making is observed through how the instructors and residents collaboratively create and collec-



**Figure 2. Top: Karen (instructor) holds out the end of the weft for Paul to find. Bottom: Laura (instructor) provides hand-over-hand support to a resident while passing the shuttle.**

tively uphold particular strategies and spatial organization of different tools in their workspace. This helps residents get situated in their workspace and perceive different states of their projects on their own. For example, as Roy explained, residents learn to manage interruptions to their work by *"try[ing] to get [a] set (a weaving sequence) done before I leave, so when I come back, I go back to the beginning [of the next set] again."* By doing so, residents do not need to memorize where they left off in the sequence to resume their work at a later time. Karen (instructor) also explained, *"I try not to stop people in the middle [of a sequence], just because it's a disruption. They get confused and then it can be this weird transition back into the project."* Thus, instructors must uphold and abide by these strategies and spatial organizations as a way of working cooperatively alongside residents. Sara (instructor) said:

> *"If we're (instructors) moving things around, we have to put it back that way... so when they come back, they don't have to mentally readjust to something completely different... They're able to sit down with a sense of confidence and not have to worry about, 'Oh, now I have to figure out all of this before I even start.'"*

Rather than doing *for* a resident, instructors look for ways to augment the workspace so that residents can actively participate in the weaving process. In particular, when the residents face difficulties in navigating their workspace, instructors work together with them to pinpoint the source of their problems and come up with ideas for adapting the workspace to best suit their individual needs and abilities. For example, new learners often struggle with detecting appropriate treadles on a floor loom according to the weaving sequence. To make the treadles easily distinguishable and help residents memorize the sequence, often instructors provide additional tactile and

embodied adaptations. These adaptations may involve setting up the treadles in a "walking treadling sequence" that allows the residents to develop a muscle memory for operating the treadles with alternating feet every time (e.g., right, left, right, left), increasing the space between adjacent treadles to easily detect appropriate treadles without needing to count them, attaching textured tapes to the treadles, and, for weavers with some remaining vision, putting down the weaving sequence in large print or color-coded format on the loom corresponding to the numbers (or colored tapes) of the treadles.

Designing adaptations happens collaboratively, with instructors and residents working together to figure out which kinds of adaptations will be most useful to them. Sara (instructor) explained, *"Sometimes, well, many times, I will ask the resident themselves, 'what would be helpful? This or this?' and they will then make their decision... A lot of it is collaboration in doing, most of it is, in fact."* That is, instructors aim to ensure that residents have agency in securing assistance and customizing their workspace rather than being passive recipients of support [4].

Over time as residents become familiar with the weaving process, instructors move from embodied guidance (e.g., hand-over-hand support) and workspace adaptations to offering mainly verbal instructions. As part of this, they develop a common vocabulary [8] to refer to different states of the loom and the weaving process (e.g., "set" denotes a complete weaving sequence), which allows them to better communicate and coordinate about their work. Interestingly, building up the shared vocabulary occurs through a two-way interaction where the resident and the instructor both learn from each other, particularly when an instructor is new at the studio. Sara (instructor) reflected on how she learned the shared vocabulary: *"It's sort of organic in the way that we learn what each other are talking about, in which if they're confused and I'm confused, then I just start asking questions to figure out what's going on."*

### Collaborative Design and Co-Weaving

Much like the way a shared workspace and vocabulary are co-created, the planning, design and iteration of a project are also shaped by a mutual exchange between weavers and sighted instructors through "material utterances" [20]. In the early stage, residents ideate with the instructors regarding the product they want to create and its physical properties (e.g., color, texture). While choosing the colors, the instructors often explain the compositions and shade of a color (e.g., *"It's [magenta] a combination of red and pink... It can be of lighter shade, but the one you are using is bright."*) and which color of the weft might "look good" with those in the warps. They also work with residents to determine the visual pattern of the projects (e.g., *"Would you like stripes just on the side? Would you like little stripes or big stripes?"*). Relatedly, to visualize a new pattern, Amy (an experienced blind weaver) and her sighted teacher will draw on each other's hands or, *"She'll (teacher) take my (Amy's) fingertip like a pen, and walk me through what's on the [pattern]."* They do this *"'cause it's the quickest"* way for her to understand how the final pattern may look on the cloth. Further, to support other blind and low vision weavers' participation in designing phase, Amy generates accessible versions of her design patterns using large print, Braille or raised line drawings and builds a shared repository by collecting patterns from other weavers in her group. Thus, weavers develop shared strategies with other blind and sighted collaborators to co-create access [10, 19, 86] in the process of visual design and color selection.

While many residents participate in selecting the yarn colors and visual patterns, instructors typically set up the loom (i.e., "dress the loom") and help prepare the pattern. Even Amy (an experienced blind weaver and instructor) who actively participates in the setup steps, consults with her sighted collaborators for specific tasks that are visually demanding and require using (inaccessible) technology. She explained:

> *"For sighted folks, there's a computer program that you can plug it into and it shows the [draft] pattern... but it's all graphics, so we can't use it. So, I will, after I figure something out, just say, 'Could you just make sure I haven't hit a wrong number or something?' And, she does... you have to have somebody who's willing to do that sort of thing. Or you don't get anywhere."*

Still there are instances in which certain tasks become "tedious" or a "distraction" for a resident, such as fixing mistakes by unweaving. Helen said that she does not *"have the patience to [unweave]... I let them (instructors) do that. I'll put it (thread) in, and you take it out."* In such cases, instructors and residents often engage in a "co-weaving" approach, where they synchronously perform different portions of the task to *"get through that process as quickly as possible so that he (resident) can get back to the thing that he actually wants to do."* Further, experienced weavers, like Adam, also helps others in detecting and fixing mistakes. Since he has partial vision, he *"watch[es] if they're going the right way, and if they're not, I say you gotta go back."* Thus, instructors and weavers continually negotiate the boundaries of assistance [8], collaboration, and ownership among each other to create an accessible space for weaving. In doing so, instructors aim to achieve a balance between teaching the residents to develop their skills and providing dynamic support as a "tool" in the background.

> *"I like to be viewed as more of a tool than maybe an instructor or even a helper... What my goal I think is...for the people that aren't already there, bring them to the point of more individuality and more sort of taking the reins and then for me to be there to just assist in the things that either they're more interested in or need help with."* - Sara (instructor)

> *"There are some people who are more independent and they want to do everything on their own and they don't want your assistance. In those situations I pull back a little so that they can do what they want to do, and I can be there to...just help out."* - Karen (instructor)

These excerpts further highlight the ways sighted instructors play the role of a "Third Hand" [48], as they listen and attune to the desires of the residents and thus, confirm the residents' abilities and contributions in the weaving process. Together *with* the residents, they create and uphold this relationship that leads to mutual understanding and interdependence [4].

## Valuing the Labor of Weaving

Our analysis reveals that accessible making is also about how the labor of making is valued, in which one's personal satisfaction and enjoyment derived through making cannot be separated from the politics of what it means to produce goods and be recognized for one's labor. That is, accessible making simultaneously confronts issues of empowerment and representation alongside systemic disadvantage and necessity.

Aligned with common rhetoric of making [62], weavers in our community explained that they derived pleasure from their work, calling it a "fun" and "relaxing" experience. These weavers, however, also turn to their work as a way to *"keep the mind occupied"* and distracted from stressful events in their personal lives. Lisa said, *"I've gotten addicted to weaving, actually. What I'm weaving, it's my relaxation."* Opening up about how weaving has helped him through difficult situations, Roy explained, *"you've got something on your mind that's really heavy, then you come to weaving, weaving has helped to release it and move forward."* Another weaver said of the studio, *"This is the only place where I feel I belong."* Others described how weaving motivated them to step out of their homes in spite of their circumstances and "heal." Emma said:

> *"It's like a workshop. For me, it's something...just to do and not stay in the room all day... It's hard, getting back into things after loss. For me, it's a good way to get back to where I was, but at the same time, in a new direction."*

Although the therapeutic value was positioned as a benefit of weaving, we cannot forget the broader context of their lives that seems to contribute to this view. Many are dealing with sudden changes in their visual abilities and other chronic health conditions that affect their day-to-day life. Similarly, many are unable to hold traditional jobs due to their disability and health status, which is reconciled by turning to weaving as a way to find focus for one's time. One instructor (Laura) equated work in the weaving studio to a job:

> *"...weaving of these products and coming regularly, it really replicates having a job and discipline. It replicates making something that's useful to society that gives them pride in what they do. It gives them self-confidence and that's why I believe...this is the by and far most popular program at [this community]."*

Nevertheless, the act of *doing* or making itself is a source of satisfaction and has value. Jim shared, *"I get a kick out of using my hands, so this is something new and I like it because I can do it."* Jen indicated that she enjoys *"seeing how the product comes into being. And then that [she] can make something that [she] can use or somebody else could use."* As these weavers indicate, the value of making derives from both the *process* and *products* of their labor.

Beyond seeing how products come into being, participants describe value in being able to gift or sell their products from the studio. Gifting work to family and friends was identified as a common practice among the weavers in our study. Jim said that it *"makes me (Jim) feel good"* to see family members using the products they make. Residents described personalizing aspects of their products (e.g., choosing yarn in accordance with the recipients' favorite colors). Lisa explained, *"When I give something, I want that person to not only appreciate what's in my hand, but I think a piece of my soul..."* By gifting their work to meaningful individuals or someone in need, residents show caring towards others. Bill said:

> *"I sometimes just give it away to people. Like I made a bunch of baby hats... and I just gave them to the hospital to free as a donation, and it just gives me a good feeling inside knowing that hopefully I helped someone, like I've brightened someone's day, and that's all it takes for me."*

Here, we see that the value of their goods helps confront social disadvantage and being positioned in a continual state of needing care. Gifting the products they create allows participation in a reciprocal relationship with others, which can be denied to some people with disabilities [4, 72], and helps shift power dynamics from receiving to giving support.

In addition to gifting, the commodification of their products is particularly meaningful to these individuals. Many of the weavers who work in the studio live on limited income and have multiple chronic conditions that prevent them from participating in other forms of employment. Receiving profits from a sold product can be a significant source of income for these residents. Adam explained that the best part of weaving is *"making the money. We get like half of what we sell. And the other half, they get, to pay for the loom and the fabric."* Some residents even advertise their products to other people within their networks (e.g., through social media). Bill described selling his work on Facebook: *"I try to sell all my work... I've made well over $200 selling my scarves and hats."* Despite the appeal of financial gain through their products, some weavers described wanting their products to be priced lower so that they would be more affordable to all. *"I wish they would be a little bit less... I couldn't even afford it myself. Some things are $40, at the most, without the tax,"* said Helen, highlighting the tension between selling products to outsiders as a way of sustaining community efforts (i.e., paying for weaving materials) and the fact that even she, as the maker, could not afford to purchase some of the products she creates.

Importantly, weavers described how their work can lead to broader societal recognition of their abilities and existence as a community. Helen explained that their work shows that people with vision impairments *"are still able to do things... Old, young, or middle-aged, that we're still able to learn new things to do, and to sell."* Emma stated that public recognition of their work *"will help communicate to people that we're not throwaways, we're not just helpless, we have something to offer."* Helen was particularly vocal about the importance of recognition of their work by those outside of their community:

> *"I wish I could tell them on the radio, even talk to somebody on [a local radio station] to come and see the weavers here, and then other people would buy and know more about the weaving, also, from the blind... People should know more about the visually impaired life."*

Their desire for recognition is about exposing narratives of ability and contribution [6], both as individual validation and collective advocacy. To this end, the staff at the assisted living

**Figure 3. Display case of products created by weavers with vision impairments within the community of study, including a rug, baby bibs, bookmarks, mug rugs and cane holders.**

facility display products made by these weavers in the common spaces (see Figure 3) and organize projects in collaboration with local artists. These communal projects, in which many weavers contribute to the final product, have been displayed in areas of wide exposure (e.g., the downtown area of a large U.S. city) – all while publicly recognizing their disabled identity. Many weavers expressed enthusiasm towards these community efforts and were excited about having their work displayed to the general public. Emma said:

> *"For me, as a designer, it's a great way to collaborate and also to do something that is beyond just placemats... I think it (public exhibition) definitely would bring a lot of publicity for this type of facility... our names will be up there, and I've asked them if I could take a picture of the one section I've done... I would like to create a website and show that off, like a visual portfolio."*

In having their work recognized by a broader audience, these weavers aim to show their worth as people with disabilities and inspire other individuals with disabilities. Lisa said:

> *"My weaving is my life, and legacy, and art. I want it to get out there so other people can know that they're free as well, despite their disabilities. They might not be able to talk, but they can talk through this... Some people have blind children, kids with down syndrome. They can come here and learn (weaving) from us. I want to pass it on."*

Lisa emphasizes the expressive nature of weaving (i.e., being able to "talk" through it [49]) as well as a desire to pass on her skills, which is part of the community ethos. The instructors also encourage residents to share their skills and help each other, since *"they get great pride out of being able to teach what they know to somebody less experienced and it gives them the realization, 'Oh, I know more than I thought I knew.'"* Thus, weaving is a valuable skill that can be passed on to foster personal satisfaction, financial gain, and recognition for people with disabilities. As an instance of accessible making, weaving also reveals how these individuals reconcile the value of their labor against a backdrop of ableist views of what it means to be a productive, contributing member of society and desire for upward financial and social mobility.

## DISCUSSION

Accessible making has been a topic of much interest, with prior work emphasizing the lack of suitable fabrication technologies for people with disabilities [14, 42, 53] and the empowering nature of engaging in making and design [35, 42, 49, 53]. Set against this literature, our inquiry prompts future directions for design and research while also revealing new tensions, informing a broader agenda around disability and making.

### Rethinking Accessible Making through Materiality

Our analysis calls attention to the surprising lack of discussion between the accessibility and material studies literature, which may be due to, in part, the lack of in situ analyses of disabled makers – prior work instead relies on workshops [8, 15, 28, 53, 73] and design retrospectives [6, 35]. Through our field work, we observe the ways in which certain interactive properties of materials "speak" to disabled makers and become salient and central to their design work. Through this, we relocate the 'interface' in accessible making from digital and physical tools to their material constituents. Although retrofitting existing tools to be accessible (e.g., ensuring graphical software is compatible with a blind person's screen reader) is one way forward, attending to the material constituents of tools used in making provides another avenue. Consider how one can exert and sense force simultaneously on a loom, perceive the texture and tension of arrays of fibers, and attend to the presence or absence of collisions as a sign of possible mistakes. This rich vocabulary of tactile and acoustic sensations serves as both feedback and feedforward information for the designer. The shuttle, for example, has its own communicative properties and "talks back" to weavers through the mechanics of its movement through the shed. The response from the beater simultaneously cues the weaver into the current system state and hints as to how the final product will look and feel. As we show here, materials help set the terms of interaction and "have a say" [63] in how accessible making happens.

With materiality as a theoretical orientation for inquiry and design, we can begin to envision new types of tangible and hybrid systems for accessible fabrication and making. Similar to pin matrix displays [9, 56, 59], what might an array of fibers held in particular orderings and tensions convey about a computer-based design while allowing new degrees of freedom with input? How might multiple devices work as the shuttle and shed to "let the designer know" of possible mistakes and next steps? We can also bring digital bits closer to existing practices of making (e.g., Lilypad [12], Phem [52], Spyn [65], Loominary [77]). With respect to enhancing accessible making in the weaving studio, looms could be augmented with haptic or acoustic signals that participate in the embodied rhythm and music of weaving. Textures, colors, and patterns, or perhaps even mistakes, could take on new multimodal forms (e.g., through sonification [71] or data translation [57]) that support meaning making. As these examples illustrate, attending to the ways materials "talk back" to disabled bodies, both as designers themselves and as points of departure for future systems, is a productive step towards accessible making.

### From Independence to Empowered Co-Creation

To date, much of accessible making concerns facilitating conditions under which people can be autonomous and independent [13, 14, 41, 42], and positions assistance from others as dependency [53]. Although independence has been an important frame given the tendency for others to do *for* an individual with disabilities and their limited say in self-design of assistive

technology [13, 53], our analysis provides another way of viewing activity. Specifically, we view the co-creative, coordinated practices of weavers and sighted instructors as helping constitute accessible making. Drawing from disability studies, we understand accessibility as not a system feature or state but an emergent sociotechnical phenomenon that is sustained through social and material relations [4, 23, 46].

From engaging in hand-over-hand support to upholding particular spatial organizations, sighted instructors actively help *create* accessibility within this maker space [10, 19, 86]. Although the role of instructor and their designation as sighted introduces power differentials, the instructors in our study continuously attune to residents' desires to do for oneself, perform the labor of weaving, and learn the requisite skills. Ensuring that the resident plays an active role in the weaving process, whichever parts of the process they choose, is essential to empowerment in this context [53]. Even for experienced weavers, collaboration with sighted others was a key aspect of their process of making. This collaboration, however, was not positioned as an assistance-based relationship; rather, assistance flowed in multiple directions and people with disabilities were agents in securing their own support [4]. Moreover, these weavers acted as knowledgeable contributors within this community, passing on their skills to others.

The cooperative negotiation of accessibility calls attention to the ways able-bodied others hone the skill of empowered co-creation, in which they foreground the individual's labor and attempt to make their labor fade into the background (see also [48]). We can consider how technologies might move from providing assistance-based support (e.g., assuming help is always needed or wanted) to those that facilitate empowered co-creation by fading into the background while foregrounding the individual's contributions and labor. Further, rather than considering independence from able-bodied collaborators as the ideal design goal, we can reconceptualize accessible maker technologies as needing to support interdependent, co-creative practices [81, 82], embodied skill sharing [69], and the coordination of labor between ability-diverse collaborators [19].

### Disability and the Value of Making
Our analysis joins that of many others who call attention to issues of power and the under-valued labor of certain communities [44], particularly those who do manual, non-technical handwork [26, 50, 66]. In addition, people with disabilities are often not recognized for their design labor given that much of design scholarship and practice tends to position able-bodied people as designers and people with disabilities as non-designers [6, 7]. Indeed, the weaving community we examine—comprised of people with disabilities and chronic health conditions and situated in a low-income assisted living facility—are largely invisible in the broader maker movement [1, 50, 53, 78]. Narrating under-valued stories of making, as we do here, may be one way of broadening who is considered a maker and dismantling the elite status of design [33, 34, 44, 83]. Bennett, Peil, and Rosner [6] caution, however, that "Celebrating design stories, then, may obscure the oppression underpinning their necessity..." That is, framing weaving as meaningful and empowering may miss the fact that this labor emerges *because* of one's social position, limited options for

employment, and financial constraints. Tellings of weaving as therapy, a job, giving focus for one's time, enabling gift giving, and a source of financial gain all speak to the necessity of this work. Instead, weaving may be told as a practice of resistance that surfaces imposed expectations and competencies [45]. Stories of accessible making more broadly must be told through, not apart from, the social, political, and structural forces that work to construct disability [46, 51, 87].

Studying this community also brings awareness to social and organizational practices (i.e., "care work" [82]) that enable and sustain accessible making. This ranges from providing a physical space and training to creating a culture of ability and contribution through one's labor. Selling weavers' work is a key part of community sustainability (i.e., weaving materials are expensive), but this is politically complex. With the rise of online communities like Etsy and Facebook Marketplace, selling one's products enables a form of societal participation that may otherwise be denied to some people with disabilities. Yet, these same practices that are meant to be empowering may also disempower: selling one's work is rooted in capitalist ideals of what constitutes productivity and success, reaffirming a particular social ordering. Further, we question whether the resulting products are valued on their own merits or because of their association with disability, framed by ableist views that such work is exceptional for people with vision impairments. Sensationalism of disability and making is a ready trap, foreshadowed by the exploitative history of Outsider Art in which artwork created by those considered "other" is valued because the creators are so different from the viewers [49, 58]. As conversations on accessible making continue, we must be mindful of how this valuation of disabled labor and resulting products has the potential to reify stigma and ableist views.

### CONCLUSION
Through our inquiry into of a community of weavers with vision impairments, we question and rework the notion of accessible making. The situated practice of *weaving by touch* encourages thinking differently about accessible design by attending to the interactive properties of materials in assistive technology and making for disabled individuals. Our analysis also prompts new considerations for what the goals of accessible making should be by attending to how blind and sighted individuals continually negotiate assistance and ownership through their co-creative work. We argue that accessible making is inherently political in that it confronts tensions between wanting to participate in important social practices—whether being recognized as contributing to society, showing caring through gifts, or profiting from one's work—and how one's labor is valued by the self and others.

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