Making Nonvisually: Lessons from the Field

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ABSTRACT
The Maker movement promises access to activities from crafting to digital fabrication for anyone to invent and customize technology. But people with disabilities, who could benefit from Making, still encounter significant barriers to do so. In response, we share our personal experiences Making nonvisually and supporting its instruction. Specifically, we draw on examples from a series of workshops where we introduced Arduino to blind hobbyists and guided assembly of an accessible voltmeter prototype [24]. In so doing, we offer future directions for accessible Making research and application.

Author Keywords
Accessibility; Arduino; Blind; Making.

ACM Classification Keywords
Human-centered computing~Empirical studies in accessibility • Human-centered computing~Interface design prototyping • Social and professional topics~People with disabilities • Hardware~Tactile and hand-based interfaces.

INTRODUCTION
The Maker movement describes a popular set of activities meant to open mysteries and challenges of creativity, engineering, and entrepreneurship to everyone, without requiring professionalized expertise. Making activities promoted in this movement span a spectrum, from needlework to soldering and coding, with the aim of instructing and empowering hobbyists to build and adapt their own worlds. To this end, Making is believed even more promising for people, including those with disabilities, whose needs are underserved by existing technologies [11]. However, the Maker movement is critiqued for being less inclusive in practice [3], [16]. Despite claims that barriers to entry are low, instructions, spaces, supplies, and cultures are often inaccessible and unwelcoming to people with disabilities [1], [4], [10], [23], [30]. As such, a subset of people with disabilities, blind makers including [5] and [25], have begun to instruct nonvisual making and publish tutorials.

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In this report, we contribute our experiences as researchers, activists, and blind people among the afore-mentioned nonvisual makers and the ASSETS community. Our experiences may assist others to design and implement more accessible and participatory studies, direct future accessible Making research, and increase access to computing fields. To elucidate these contributions, we share examples from the co-design of an accessible voltmeter prototype and two workshops with blind hobbyists focused on teaching Arduino basics, through the assembly of their own voltmeter. Our aims aligned with Design for User Empowerment which promotes technical skills and self-determination as tools for people with disabilities to leverage to work around access barriers [19]. We offer broader suggestions, which may be applicable across multiple research and Making settings, rather than prescribing specific techniques like those found here [5], [24].

In what follows, we briefly background the intersection of Making and accessibility, where we situate our contributions. We then introduce ourselves to contextualize the insights we offer and summarize our co-design and workshop procedures. Following this description, we discuss key successes and challenges synthesized from our workshop observations and attendee reflections.

BACKGROUND
Making has been taken up to guide design and assembly of customizable, affordable assistive technology (AT). First, scholars have shown that Making has enabled people with disabilities to invent and adapt AT themselves [17], [18]. But several barriers to Making accessibly have been identified. First, many people with disabilities enter spaces with little experience Making or creative expression [12], [29]. Second, many online instructions or in-person trainings assume vision and expertise to comprehend technical diagrams and terms, [6], [7]. Third, many Makerspaces remain crowded and disorganized, supplies are labeled visually, and test equipment is not accessible [10]. Even when spaces and supplies are accessible, assembly may not be [4]. Finally, few Makerspace staff or other organizers in the Maker movement invite or have experience working with people with disabilities [1], [9], [12], [30].

In response, researchers and hobbyists have explored sharing AT designs publicly [6], creating accessible spaces and activities [5], [9], [10], [17], [18], [21], [22], [25], [29], accessible tools [29] and teaching relevant skills to people with disabilities [5], [7], [12], [25], [30]. Researchers also demonstrate how to involve people with disabilities in instruction development [7], [12], [29] and DIY AT co-design [8], [14]. Finally, researchers have identified stakeholders, like volunteers and clinicians, whose expertise complement disabled and engineering making perspectives [13], [15], [26], [27].

Despite the importance of this work, in our experience the barriers to accessible Making and more generalized social stigma about disability perpetuate cultures and practices of inaccessibility [30]. These can leave nondisabled and disabled Makers, alike, defaulting to dominant ways of Making--even if they can or prefer to Make accessibly. Our experience report offers insights into nonvisual Making, as a way to disrupt this culture of inaccessibility. In addition, while prior interventions have focused on accessible making for people with other disabilities, nonvisual Making is an under-explored facet of accessibility research.

OUR TEAM

We briefly introduce ourselves to demonstrate the multiple and overlapping ways we each connect with nonvisual Making. Bennett is an HCI researcher and blind activist interested in increasing the accessibility of research and design methods. She organized workshop logistics, and facilitated data collection and analysis. In preparation for the workshops, Bennett formalized a collaboration between the other authors. She initiated this effort while attending Blind Arduino events hosted by Miele. Miele is a longtime accessibility researcher and electronics hobbyist. A founder of the Blind Arduino Project [5], he is one of the blind experts publishing and instructing nonvisual tutorials for coding and building electronics for years. Miele co-designed the voltmeter with Siu, prepared supplemental materials, and taught concepts while leading the workshops. Siu is a sighted HCI researcher and Blind Arduino event attendee who develops multimodal design tools aimed at increasing nonvisual access to Maker technologies [29]. Siu co-designed the voltmeter with Miele, helped produce its parts, and assisted participants with their projects during the workshops. Finally, Stangl, an HCI researcher and sighted friend and activist in the blind community, collected and analyzed visual data from the workshops. Stangl researches how to design accessible, inclusive learning experiences, media, and technology [30].

In addition, the volunteers listed in the acknowledgements helped implement the workshops. Most had prior connections with blind people and all were trained in offering consensual assistance and nonvisual describing.

DESIGN, IMPLEMENTATION, AND EVALUATION

In this section, we report on the co-design of the voltmeter prototype and two workshops with blind hobbyists, implemented by the Blind Arduino Project [5]. During all activities, we collected notes from meetings, design sessions, the workshops themselves, video and photos of the

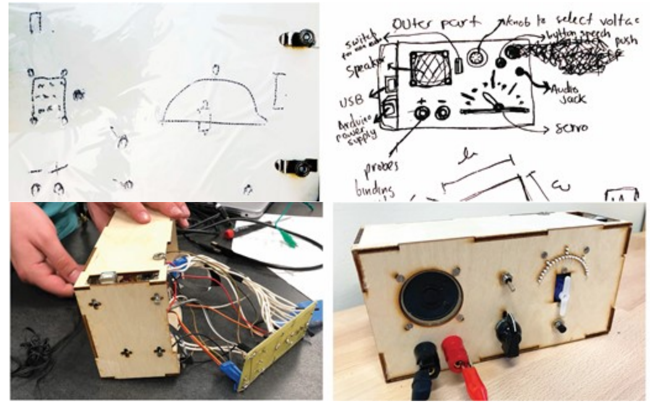

Figure 1. a) raised line sketch of the voltmeter layout drawn by Miele on a mylar sheet; b) an equivalent sketch drawn by Siu on paper; c) a voltmeter in progress; d) front view of a completed voltmeter.

workshops and post workshop surveys and interviews with attendees. We took an autoethnographic approach to our thematic analysis, allowing our lived experiences as blind people, Makers, and researchers to guide the development of these lessons and implications [28].

Workshop Design and Implementation

We assembled six adult blind and low vision hobbyists for two workshops a month apart at the San Francisco Lighthouse for the Blind and Visually Impaired [20], a community center widely respected among blind people in the US. Hobbyists were recruited through our personal networks and Lighthouse newsletters. Prior Making experience was not required but all worked in technology fields as assistive technology trainers, IT professionals, or software developers; five were men and one was a woman (elaborated in our limitations).

We designed the workshops based on our prior experiences practicing, learning, and teaching nonvisual Making. For example, to make workshop instruction accessible (and avoid barriers introduced by visual instruction and tools) we provided audio and tactile supplements and verbal and screen reader accessible instructions with nonvisual metaphors. During the first workshop, we began with a tour of an Arduino Uno board [2], common hardware components and the IDE. We passed around tactile and large-print maps of Arduino Uno boards and guided participants to orient each board in a common manner and to touch each pin. After they were familiar with the tactile diagram, we taught participants to use wires to explore the headers of an Arduino Uno board, using the tip of a wire like a white cane to locate and count the Arduino connection sockets. We then passed around components, made sure everyone's IDE was up and working with their assistive technology, and went through some sketches together. Hobbyists concluded the workshop by individually making experimental modifications to example sketches. The second workshop comprised of voltmeter assembly. Prior to the workshop, we asked hobbyists to listen to audio tutorials, created by Miele, that explained the components and design process. During the workshops, Miele overviewed basic electronics concepts, and then led an orientation of voltmeter components, voltmeter calibration and testing, and hardware assembly.

Voltmeter Design and Rationale

Prior to joining this collaboration, Miele had iterated on initial specifications for an accessible voltmeter. With the prospect of implementing workshops organized by Bennett, he shared his plans with Siu to begin a second round of iteration. Miele took the lead on designing the user interface, hardware, and software for the meter, but wanted the benefit of Siu's mechanical engineering expertise, as well as her assistance in fabricating a custom project box using a laser cutter. This collaboration required Miele and Siu to make use of a variety of visual and tactile media, as well as modes of design and communication. When working together they leveraged multimodal representations (tactile lines for Miele, visual lines for Siu) to enhance their design communication and balance practicality and convenience (Figure 1a-b). For example, they created tactile sketches using mylar polyester sheets and an ink pen; which allows for simultaneous rendering of visual and tactile lines. Siu took photos of intermediate and final tactile sketches for her own reference, while Miele retained the tactile graphics. They also made extensive use of text descriptions via e-mail to discuss both the circuit design and the layout of the project box. The vocabulary developed in these exchanges grew into the descriptive language used in the workshop to discuss the project with the hobbyists.

The result of this collaboration was a prototype Arduino-based meter [24] capable of measuring voltages from -1000V to +1000V, with 4 ranges of sensitivity. It included 3 modes of nonvisual output (tactile, speech, and sonification) to provide feedback about the input voltage (Figure 1d). this design is particularly meaningful. Though multimeters with Bluetooth capability can be accessed with a screen reader on a smartphone or computer, to our knowledge, no nonvisually-accessible, stand-alone voltmeter (a basic electronics measuring tool) is currently available.

The three modes of output were: 1) text to speech, providing a spoken voltage value triggered with the press of a button; 2) sonification, providing a pitch-based qualitative representation of changes in the input voltage, activated or deactivated with a switch, and which, when on, only sounds when the voltage varies; 3) a tactile gauge whose pointer is driven by a servo motor with tactile markings indicating voltage values.

The three different modes of non-visual display provide flexibility depending on the user's sensory abilities and what kind of information the user is trying to obtain. For example, text-to-speech allowed a quick and accurate voltage reading, but provided no information about the possible fluctuation of the input voltage. On the other hand, sonification provided the user with excellent qualitative information about variation in the input voltage. The tactile gauge provided both quantitative voltage readings as well as information about temporal variations of the input voltage, and did so without speech or sound, enabling deafblind hobbyists to use the voltmeter. In addition, a headphone jack allowed the auditory interface components to be amplified in loud environments. All controls were physical buttons, switches, and knobs, which provided tactile indicators for voltmeter orientation and nonvisual operation. All of the hardware was housed inside a laser cut wooden box with holes cut to fit the various input/output components. Inside the box was an Arduino Uno board, and the main voltage reading circuit soldered on a protoboard.

During the design, Miele and Siu opted to pre-solder the circuit boards. Though Miele has taught soldering, it requires targeted instruction, and a lot of practice—scoped beyond the workshops. In assembling the circuit, participants focused on connecting the protoboard to the Arduino and peripheral components, attaching the components to the box, and testing and calibrating the circuit. More details about the voltmeter are here [24].

LESSONS AND IMPLICATIONS

Next, we describe each finding with a short reflection of what went well and what we would do differently. We first report on the co-design of the voltmeter and continue with findings from the workshops themselves.

Shifting Representational Styles During Co-design

As described above, Miele and Siu engaged in a multimodal design practice that resulted in an accessible voltmeter. This practice was important for them to maintain a continuous dialogue and move the design process forward. For example, Siu photographed and annotated the co-designed tactile/visual sketches for her own archives, beginning her process of designing a case around the sketched hardware configuration. While Miele focused on the circuit design, fabrication and code, Siu returned to her Makerspace and converted sketches into 3D-models ready for fabrication. When working remotely, Siu and Miele corresponded via email to share progress and further iterate the voltmeter case design. Siu then converted these text-specified modifications into hand-drawn, annotated schematics and then into 3D-modeling software. Siu brought a laser cut case to a second meeting with Miele where further modifications were suggested through conversation and tactile exploration. Siu then produced a casing for each hobbyist, leaving the bottom unattached so hobbyists could affix the hardware inside.

Miele and Siu's collaboration revealed several insights that may be helpful for future designs of instructional guides and examples. First, we advocate for the allocation of time to develop a shared multimodal vocabulary that enables co-designers to find agreement about representations and to communicate non-textual information that would work for both. Next, to aid in tactile/visual design collaborations, we also recommend that co-Makers have a variety of tools available that allow for the rapid creation of multimodal representations. Multimodal representations were so key to the success of Miele and Siu's co-design that we strongly recommend they become default, rather than only created when explicitly requested.

Instructional and Material Successes

While conducting the workshops, we observed several successful instructional strategies, exemplified next.

Nonvisual Descriptions

First, as noted above, during both workshops we presented participants with instructional materials in accessible formats (audio tutorials, accessible electronic documents, tactile diagrams, and verbal instructions). In addition, we provided nonvisually-friendly descriptions and time for tactile exploration. For example, before describing the purpose of each wire connected to the circuit board, Miele directed hobbyists to turn their circuit board so the solder faced away from them and the wires faced toward them, with the prominently tactile sharp pins on the right side. Finally, he clarified that he would explain wires in clockwise order. This instruction enabled participants to create a mental map of their circuit board and have a starting point for following along with Miele's verbal tour.

Orientation

Second, we believe the hour we spent orienting to materials at each workshop's outset was essential. By having all of the information about what was available upfront, the participants were positioned to decide how and when they would access and maintain the information they needed for any given task (through listening, accessing notes, and writing new notes). Furthermore, they were prepared to ask questions and focus on what they needed to learn to accomplish the task at hand.

Providing Assistance Thoughtfully

Third, we offered but did not enforce assistance and gained consent before assisting. For example, while circulating, Bennett asked a hobbyist what they were working on. They mentioned having difficulty keeping track of the test voltage values they measured while calibrating. Bennett also noticed that the hobbyist had been reading braille. In turn, she offered to write the test values in braille and to read out the instructions out loud. After he agreed, they calibrated his voltmeter together. This instructional strategy encouraged hobbyists to fully utilize their preferred techniques, while accepting assistance.

Instructional and Material Challenges

In addition to these successes, we noted several instances when instruction and the designed materials led to confusion, which we describe here.

Distracting Instruction

During the second workshop we began guiding hobbyists through the assembly process as a whole group. While the instructional materials offered everyone a step by step process for building the voltmeter, all of the hobbyists started working at their own pace. In response, volunteers attempted to work one-on-one with hobbyists as they lost their place. However, as dialogue erupted the room became loud and participants became confused by competing or non-sequential explanations for assembly; hobbyists had difficulty simultaneously listening to a primary instructor and communicating with volunteers. We observed volunteers offering alternative explanations for connecting all of the components to address confusion. At a certain point, the explanations were so unwieldy, Bennett re-gathered the group and offered a complementary explanation of the circuit board. Miele inferred from this that it was time to go into more detail and move forward with the large group instruction. However, at this moment, most hobbyists still needed time and significant guidance to get to that stage in the process.

Though we wanted to jump in as soon as we noticed confusion, this often produced more distraction. In instances like these, where hobbyists have different paces and practices through which they approach the task, we recommend building in more breaks and auditory cues or phrases that someone can give if they need clarification or to concentrate on one-on-one assistance. we observed that these auditory cues are especially helpful for blind attendees in instructional roles.

Confusing Hardware

The design of the circuit boards and wires may have also impacted the instruction's effectiveness. As noted above, we presented hobbyists with a circuit board with wires of different colors and corresponding braille labels. Though we anticipated that the labels would help participants differentiate the wires and learn where to connect them on the Arduino Uno board, we quickly learned that 12 moving wires was too many to keep track of, even when guided with nonvisual-friendly verbal instruction. We observed several hobbyists create their own keys to orient themselves to the wires using Perkins Braillers or taking notes on their computers. One hobbyist made a list of each wire label and its purpose. He referenced this list repeatedly when discerning wires became frustrating, to remind him of the greater purpose for each wire which then structured which task he would pursue next. Offering supplies were important for hobbyists to create their own notes about the project but we would add more structure to facilitate the making of these individualized guides in future.

In addition, we observed that in some instances, hobbyists would have benefited from raised line tactile representations of everything, even if the object they were handling was tactile. That being said, after the second workshop the hobbyists reported having little familiarity with reading tactile graphics in their daily life which emphasizes that grounding explanations with orientation instructions and tips for how to interpret the information are still important components of nonvisual instruction.

Fragile Hardware

During the implementation of the workshops, another issue that emerged was the fragility of the soldered connections. Since blind attendees largely relied on touch to locate, identify, move, and verify hardware, connections wore easily. These broken connections inhibited the hobbyists from testing their assembly processes. As such, a sighted volunteer spent the final hours of the workshop re-soldering circuit boards. We observed that the task of placing the circuit boards accurately inside the casing became stressful as hobbyists grew weary of touching their voltmeter too much. While this fostered interdependencies, it also limited our hobbyists who spent much of the workshop eagerly touching their projects.

While we chose to use flexible hardware, so we were not constrained by the limitations of more robust and easily connectable components, we found that modularizing the connections via plugs and sockets would have served us better. In future, we recommend using multi-conductor modular plugs where possible, and, if at all possible, the creation of a pre-stuffed printed circuit board for any custom hardware. This would reduce the number of individual wires to deal with, while simultaneously providing more time for explanation and instruction. Still, nonvisual Making offers an excellent case for experimenting with and improving the quality of flexible, customizable hardware components.

Effects of Audio Output

Miele often uses audible rather than visual output for teaching introductory Arduino concepts (i.e., speakers and tones instead of LEDs and light). Throughout the workshop, we noted both positive and negative related phenomena. Namely, we noted that the audio output facilitated sharing of the status of one's work with the cohort, while also creating distractions. We noticed attendees become excited and engaged as they listened to each other experiment with Arduino code. For example, one hobbyist who is a musician found a chart converting musical notes to parameters online and incorporated it into their code. As their tunes played, other hobbyists shared praise and interest to experiment on their own. All the while, some hobbyists produced unintended audio which alerted others to ask if they needed any help or to speculate what might be changed in the code or hardware connections to produce more desirable output.

Attendees agreed that this engagement was rare and welcome. Post-workshop feedback indicated hobbyists appreciated hearing their output to debug code or hardware. Some cited this being a prior barrier to working with electronics; when writing software, they had a screen reader to explore their code, but they had not encountered a screen reader of sorts to provide information about the state of their hardware since many introductory tutorials to electronics rely on ability to perceive light. Adapting the code and using speakers provided a relatively easy fix to insure these hobbyists could experience running and debugging basic programs.

Additionally, the audio output sparked conversation among everyone. Attendees gave praise when a hobbyist successfully ran their code and offers to assist upon hearing undesirable sounds came from blind and sighted attendees alike. This marked a unique and welcome shift in power from many of our experiences attempting to make nonvisually where visual modes of information acquisition and sharing remain privileged. As such, we recommend that not only supplies, but progress sharing and outputs privilege nonvisual senses.

At the same time, the audio was sometimes cacophonous. As such, during the second workshop, we offered that attendees visit a quiet room nearby when they needed to pay attention to their screen reader.

LIMITATIONS

Sharing our personal experiences, we provide unique rather than generalized insights to Making nonvisually. As such, our suggestions should be taken cautiously, iterated, and evaluated rigorously. Additionally, the hobbyists were mostly men with technical expertise, further limiting our validity. While our recruitment efforts sought gender balance, unforeseen challenges arose leading to several women cancelling, and a male showed up unannounced. In future, we and other researchers should better anticipate and respond to challenges that raise when attendees encounter barriers to showing up and feeling welcome, as much as our careful attention to providing nonvisual access.

CONCLUSION

Making holds potential to allow people with disabilities opportunities to learn valuable skills while customizing and personalizing technology. Yet barriers to entry remain high as many purportedly friendly Maker instructions, supplies, and spaces assume vision. In response, we shared our engagements with the Maker movement as researchers, activists, and blind people. By explicating a series of workshops where we introduced blind hobbyists to Arduino and assembly of an accessible voltmeter prototype, we offer lessons and recommendations for future Making and participatory design to be more nonvisually accessible. As blind and sighted people worked equally and interdependently to plan and execute these workshops, we demonstrated not only significant barriers that remain to accessible Making, but the potential for immense creativity and careful attention to access when disabled people are taken seriously as accessible maker movement leaders.

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