Designing Accessible Adaptations for an Electronic Toolkit with Blind and Low Vision Users

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Figure 1: We adapted an existing electronics toolkit with a) a set of 3D printed physically identifiable covers for modular electronic boards, b) a Near Field Communication (NFC) device to provide participants with component-specific audio descriptions and use instructions, and c) self-describing 3D printed circuit templates with tactually distinguishable circuit connectors.

Abstract

There is a growing availability of computational and electronic toolkits designed for learning and enrichment activities, however, these toolkits are often inaccessible for blind and low vision (BLV) users. We co-designed with BLV participants, several types of adaption and augmentations that can increase the accessibility of a previously developed electronic toolkit. We explored NFC-enabled 3D-printed circuit templates, braided connectors, and other tactile adaptions developed from co-design sessions with BLV users. We evaluated the resulting toolkit with nine blind and low-vision participants and found that they experimentally and tactually learned to compose circuits of increasing complexity. A key design aspect was incorporating redundant methods that enabled participants to exercise their personal modality preferences when identifying components and making connections. Through our work, we highlight how digital fabrication can be applied to adapt modular electronic toolkits to increase the availability of existing electronics learning platforms for the BLV population.

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CCS Concepts

• **Human-centered computing** → **Accessibility technologies**.

Keywords

Blind; Low Vision; Accessibility; Electronics Toolkit; Co-design

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1 Introduction

A number of electronic and computational toolkits have been developed in recent years to engage users in hands-on circuit building activities [5, 37, 54]. Rather than focusing on individual components (e.g., resistors, potentiometers, LEDs), these toolkits consist of small modular circuit boards with individual functions, such as light, sound, sensors, or buttons that can be connected without soldering or programming. However, many of these toolkits can be challenging for blind and low vision (BLV) users since they rely on visual affordances for module discoverability and making connections. Access to these toolkits is valuable because they facilitate learning and the creation of digital artifacts that could be personally meaningful. This has been shown to improve self-confidence and mental health by promoting satisfaction and a personal sense of agency [50, 58]. Moreover, these toolkits are beneficial for encouraging engagement in STEM, which may lead to the pursuit of engineering and science disciplines in higher education. Indeed, the BLV community has made key contributions to engineering through inventions such as the Optacon (a tactile reader) [26] and cruise control [36].

To address some of these accessibility barriers in electronics and circuits, researchers have focused on braille labeled parts and instructions [23], improving learning materials through 3D printing [18], and adaptations to fundamental circuit components for breadboarding [15]. However, research in this area is limited and there is not much work that explores and evaluates modular electronic toolkits from a BLV viewpoint. Rather than create a new custom electronics toolkit, we examined the infrastructure around an existing toolkit called TronicBoards [54] and co-designed accessible adaptations to support BLV users with limited or no experience with building electronic circuits. Our aim is to reduce barriers for novice BLV users to independently explore and enter the field of electronics.

Our adaptations to the toolkit consist of 3D-printed covers for modular circuit boards that provide power, sensing and actuating functionality (Figure 1). Much like puzzle pieces, these unique physically identifiable covers can be inserted into different 3D-printed circuit templates that have tactile polarity and connection guides to create various circuits. Electrical connections are facilitated through braided wires that users can touch and follow with their hands. Furthermore, to aid discoverability, the modular circuit boards and templates are NFC-enabled with audio descriptions, high-contrast symbols, and braille labels.

We evaluated the adapted toolkit with 9 BLV participants during one-on-one sessions using a guided exploration approach. They found the accessible adaptations allowed for independent learning and supported their circuit making goals with several participants expressing a positive perception shift towards electronics. The importance of tactile exploration and recognizing "patterns" with the board covers and templates were crucial to constructing circuits. Although the templates made circuit construction easy through "slotting", participants also expressed their need to explore circuit building beyond the confines of the templates. The NFC reader supported autonomous problem solving; however, some participants also requested additional instructional information.

This work makes the following contributions: (i) a co-design focused account of toolkit adaptations that support the use of an existing electronics toolkit for BLV users; (ii) empirical evidence from one-on-one evaluation sessions of how BLV users engage with the adapted system to construct circuits and the challenges therein; and (iii) insights regarding how digital fabrication can facilitate the accessibility of existing electronics toolkits.

2 Related Work

We begin by reviewing STEM toolkits in the research and commercial space for the BLV community to understand potentially suitable adaptations for making an existing modular electronic toolkit accessible for BLV users. As the literature on circuit-making toolkits for BLV users is sparse, this section also broadly examines programming and STEM-related activities. Next, we explore how researchers have made existing toolkits accessible for other user groups, such as children, people with other disabilities and older adults. Finally, we examine how instructions and descriptions have been conveyed to the BLV community to foster independence and agency.

2.1 STEM Toolkits for BLV Community

Several research initiatives have examined STEM education from a programming context for BLV users. Prior work has explored teaching basic programming concepts to the blind community through audio narratives [41, 43]. ACCembly, an accessible block-based environment with audio feed-forward features (verbally announces its actions) [49] has enabled visually impaired children to construct tangible block-based programs for a multimodal robot.

The opportunity for 3D-printed models and tactile/accessible graphics to support programming education and circuit creation for BLV users has gained significant momentum, with touch being a promising modality for those with vision impairments [14]. An open-source coding toolkit known as TIP-Toy [4] employs a series of physical blocks to provide children with diverse visual abilities with a platform to explore computational concepts through music. Furthermore, research by Goolsby et al. [28] introduces puzzle-piece-style component fittings and snap-to connections representing syntax, along with expandable parameter slots. In a related study, a blind student was provided with modular 3D-printed circuit components [19], enabling them to explore and comprehend fundamental electric circuits. Three research studies have concentrated specifically on the domain of circuit-making for BLV users. The first study involved the augmentation of traditional circuit elements with 3D printable add-on components [15]. Breadboards, microcontrollers, electronic components, and wire strippers were coded with supplementary tactile information, including pins and hole landmarks, to enhance the accessibility of circuit development. The second study focused on the creation of a 3D-printed tangible model of a circuit [18], and this provided audio tutorial instructions whenever circuit components were touched. The third study developed a tangible toolkit [31] comprised of Sensing modules to detect both environmental information and user commands, Feedback modules to send multi-modal feedback, and Base modules to power and connect the sensing and feedback modules. Utilising tactile textures and symbols to support the recognition of modules and a plug-and-play mechanism to connect sensing/feedback modules to the base.

In the commercial domain, several toolkits have been developed to support the programming and circuit-making ambitions of BLV users. Prominent examples include CodeJumper [17], Snapino [53], the RC Snap Rover Access Kit [22], Snap Circuits [23] and the Accessible Code and Go Mouse [21]. These toolkits prioritize tactile graphics as a means to facilitate the learning of programming and circuitry. For instance, CodeJumper provides a tactile approach to teaching students basic computer coding and programming skills. Meanwhile, the Accessible Code and Go Mouse offers tactile and interactive learning, allowing students to program a physical mouse character to navigate mazes. Snapino, Snap Circuits and the RC Snap Rover Access Kit provide tangible representations of electronic concepts. Apart from Snap Circuits [23], which provides braille labels and written instructions in braille and large print for an existing electronic toolkit, the majority of these implementations focus primarily on programming through tangible approaches.

The aforementioned studies and commercial products highlight the valuable inclusion of audio descriptions and the usefulness of tactile graphics and 3D-printed models to assist with circuit-making for the BLV community. This work motivated us to incorporate these tools in the construction of toolkit adaptations.

2.2 Accessible Toolkit Adaptations

Accessible toolkits have evolved rapidly in recent years, aiming to enhance circuit-making skills for both children and adults. Toolkits such as BBC micro:bit [2] and LittleBits [5] have made significant advancements towards making electronics more user-friendly. In an extended study, 3D-printed bases were added to LittleBits to improve ease of handling and pickup, supporting people with learning disabilities to independently experiment with technology [32]. Another example is Squishy Circuits, whereby Johnson et al. [38] simplified circuit design for children by replacing traditional wires with malleable conductive and non-conductive dough, not only presenting children with a unique circuit-making medium but also providing insights into the polarity of circuit components [45]. Our work builds on this area for the BLV community and similarly focuses on tactually distinctive shapes and connectors that aid comprehensibility and handling.

Enhancements in circuit making for individuals with intellectual disabilities have been achieved through projects like TapeBlocks [20], TronicBoards [54], and the design of e-textiles [29]. TapeBlocks scaffold circuit making through the placement of electronic components on manipulable foam blocks using conductive tape, and TronicBoards utilizes 3D-printed knobs and stands for graspability and stability during the circuit construction process. Gotfrid et al. developed a simplified method for individuals to create their own e-textiles by integrating differently shaped circuit components, effectively transforming the circuit making process into a puzzle-solving activity [29]. Both TronicBoards and Gotfrid et al.'s work hint at the importance of creating supportive adaptations in addition to toolkits. Our work with circuit templates is guided by Gotfrid et al.'s work to aid users in distinguishing circuit components.

Research has also focused on providing older adults with circuit-making opportunities [37, 51]. One example is Craftec, a research project that promotes easy electronics crafting [37]. Based on Lilypad Arduino [11], Craftec provides older adults with laser-cut enclosures and conductive fabric strips to existing toolkit components to improve circuit comprehension and connections. Our work is similar in idea; it takes an existing toolkit and examines how it can be adapted by designing enclosures, connectors and templates to support the BLV community.

2.3 Accessible Instructions

Braille labels are a common method for providing BLV individuals with accessible instructions. These are extensively employed across multiple fields, including education, public signage, and map accessibility, greatly enhancing the independence of individuals with visual impairments [34]. More recent research has examined how electronic components like resistors, potentiometers [15] and circuit diagrams [46] can be augmented with braille. In the commercial space, Snapino [53], Snap Circuits [23] and the RC Snap Rover Access Kit [22], have all employed braille in instruction manuals or part descriptions. Although new technologies, such as interactive audio, have examined the possibility of extending information communication beyond braille [9], it continues to remain an essential form of conveying information.

Tactile graphics and 3D models provide users with supplementary information through the capacity to convey height and depth. Race et al. [46] used microcapsule fusers (e.g., raised areas on paper) to develop tactile graphics for schematics. This work was extended with tactile circuit descriptions, component diagrams, and schematics provided in the form of tactile graphics during an Arduino workshop for blind users to learn about circuit assembly [47]. Several commercial toolkits also use tactile graphics to convey information about circuit components [19, 23].

Screen readers are widely used by individuals with visual impairments across various domains, including education, productivity applications, and data visualizations [44]. They have also been used to access and interpret inaccessible information related to circuit diagrams [18]. However, screen readers continue to encounter challenges in fully comprehending non-textual content, such as images and 3D components, particularly for BLV users. More recently, voice assistants have been employed to support programming for students with visual impairments [41, 43, 56]. In this regard, contextual audio descriptions have proven to be useful in providing timely instructions or feedback on tasks.

The studies presented above highlight the importance of conveying information through braille as well as audio or voice. Consequently, we have integrated both features into our designs, ensuring that relevant, context-sensitive audio instructions and braille labels are provided to users for the boards as well as templates.

3 Co-Designed Adaptions for TronicBoards

Although there is a growing availability of electronic toolkits for education and enrichment activities, many of them have limited accessibility features to support BLV users. One approach to address this problem is to design a new toolkit that caters to the specific needs of BLV individuals. While this is a valid pathway, we focused on methods to increase the accessibility of existing toolkits, potentially growing the range of what is available for this target group. For our work, we chose TronicBoards [54], among other commercial options of Lilypad (an e-textiles modular toolkit) [11], LittleBits (a modular magnetic toolkit for children) [5] and Snap Circuits [23]. We chose this toolkit mainly because its design files are public and freely available for manufacturing and research purposes. Furthermore, given this toolkit consists of single-sided PCBs that are sufficiently large, TronicBoards naturally supports easy augmentation. Moreover, the functionality of its modules is split by 3 types of functions providing; power (e.g., battery), sensing (e.g., push buttons, tilt sensors), and action (e.g., generation of vibrations or music) functionality (see Figure 2).

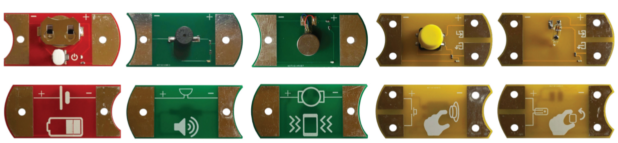

Figure 2: Subset of TronicBoards. Including power (red), action (green), and sensing (yellow) modules.

Program logic such as IF, AND, and OR are built into the boards thereby limiting the need for programming. This facilitates the designing of activities, which progressively increase in complexity, making the toolkit well-suited as a circuit-making introduction for novices.

3.1 Co-design Sessions and Participants

We conducted 8 co-design sessions (S1-S8) with 4 participants (P1-P4) in a one-on-one manner, using a guided exploration approach [40]. The aim of the initial sessions (S1-S4) was to identify the common challenges and needs associated with building TronicBoard circuits by BLV. We encouraged participants to share their perspectives and suggest improvements, thus grounding the research in the lived experience of BLV individuals. The final four co-design sessions were conducted with P1 (a blind participant) and P4 (a low-vision participant), who volunteered to participate in additional iterative sessions (P1: S6 & S8; P4: S5 & S7), which aimed to resolve the toolkit's pain points by modifying the toolkit, based on feedback from previous sessions. Table 1 provides participant demographics and session information.

3.2 Co-Design Findings

Table 2 provides an overview of when, and with whom, the toolkit accessories were developed and evaluated during the co-design sessions.

3.2.1 Easy to Follow & Tactually Distinct Circuit Connections. The original kit's modules are designed to support 4 connector types; banana plug wires, alligator clip wires, conductive tape and conductive threads. While all connector types were provided to all the participants in the initial co-design sessions (S1-S4), we discontinued the use of conductive thread from S5 onwards because it required hands-on assistance and more time (P1 - P4).

The most used connectors were wire connectors. Initially, we used off-the-shelf color-coded and double-ended alligator clip and banana plug wires (see Figure 3, 1). From the first session (S1), it became evident that while participants could establish successful connections using these wires, a significant amount of time was spent tracing and distinguishing one wire's end from several others due to excessive wire lengths and their lack of tactile differentiation. Considering feedback from P1 during S1, as an improvised solution, we custom-made shorter alligator clip and banana plug wires. We also used diverse textures for each wire by creating wires with a single wire, flat ribbon wires with different numbers of wires, three braided wires, and two twisted wires (as in Figure 3, 2A-E). After verifying the success of these custom-made wires with P2 during S2, we continued to use this new set of wires.

After session S4, the banana plug wires were further modified with a set of stackable (daisy-chain) plugs to facilitate the making of more complex circuits (see Figure 3, 2E). We also replaced the original rubber-covers on the alligator clips, which aided in identifying the appropriate leverage point. However, alligator clip wires were not included in the final toolkit due to the intermittent issue of clips slipping from the circuit board pads, leading to inadvertent disconnections, which frequently went unnoticed by the participants.

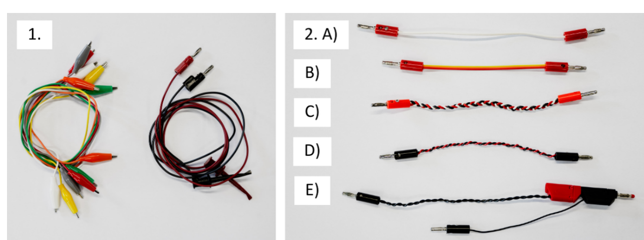

Figure 3: (1) Tactually-similar and hard to follow off-the-shelf color-coded and double-ended alligator clip wires and banana plug wires, (2) final set of shorter and tactually distinguishable banana plug wires (A) single wire, (B) flat ribbon wires with different number of wires, (C) three braided wires, (D) two twisted wires and (E) textured stackable (daisy-chain) wires.

Table 1: Participant information of co-design sessions

Participant ID	Age	Gender	Level of Vision	Braille Literacy	Circuit Making Experience	Participated Sessions
P1	60+	Female	Blind	Yes	Moderate	S1, S6, S8
P2	42	Female	Low-vision	Yes	Minimal	S2
P3	23	Male	Blind	Yes	None	S3
P4	54	Female	Low-vision	No	Minimal	S4, S5, S7

When we provided participants with a roll of conductive tape to form connections between circuit boards, they initially relied on the researchers' external assistance to appropriately measure and cut tape pieces. To enhance participant autonomy in this task, we introduced a commercially available automatic tape dispenser into the toolkit (see Figure 6), delivering predefined tape lengths at the touch of a button.

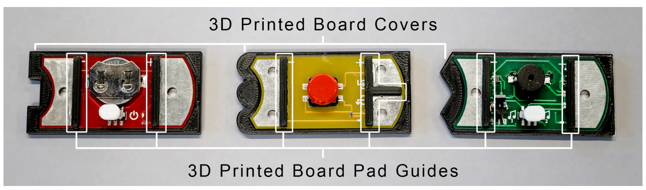

Figure 4: Distinctly shaped board covers to support the recognition of power, sensor, and action board types, and tactile guides to minimize short circuiting errors and highlight the individual conductive pads when making circuits with conductive tape.

3.2.2 Form-Based Identifiers & Inclusive Labelling. TronicBoard modules feature variations of their left edges, corresponding to their respective functions (power, sensor, or action). During S1-S4 sessions, following the completion of 2-3 circuits, participants (P1-P4) were prompted to assess whether the edge shapes facilitated the tactile identification of modules. However, all four participants only identified the nuanced edge shape differences after the researchers provided explicit guidance. Therefore, we 3D-printed board covers providing new, distinguishable shapes to differentiate the module types (see Figure 4).

Additionally, across the first four sessions (S1-S4), a higher rate of connection errors was observed when participants (P1-P4) employed conductive tape, given the absence of clearly defined affordances that would differentiate the boundaries of the conductive pads on the modules. Such connection challenges were not encountered when using banana plugs, since locating the holes for plug insertion through touch proved straightforward for all participants. In response, we introduced thin 3D-printed borders, termed "board pad guides," affixed to the front side of the boards along the edges of the connector pads (see Figure 4). These guides functioned as raised barriers, demarcating conductive pads from each other and the board's inner components. In subsequent co-design sessions (S5-S8), P1 and P4 showcased the board pad guides' efficacy, observed through a significant reduction in short-circuiting errors when using tape.

At the rear side of the board covers, we explored the use of icons and braille labels to support the comprehension of modules. First, we 3D printed braille labels to detail the functionality of each module. To fit the size of the board covers, we abbreviated some label names. During our first co-design session (S1), P1 confirmed that they could independently read the labels and recognize the functionality of most modules and suggested substituting names for specific modules (e.g., changing the "DC motor" label to "fan motor"), which improved module comprehension among other co-designers (P2-P4) during subsequent sessions (S2-S8). Also during S1, P1 noted that *"while [they] can read [the 3D-printed labels], it's very scratchy on fingers"*, and suggested using self-adhesive, transparent sheets for creating braille labels. This presented an opportunity for assessing pre-existing white-colored icons underneath the braille labels, illustrating the board functionality, for low-vision users. To a certain extent, the low-vision participants (P2 & P4), were able to see these icons against the red and green-colored power and action boards. However, they both experienced great difficulty perceiving the white icons against the yellow-colored sensor boards, due to the low contrast, and recommended replacing the icons with larger, high-contrast black and white icons to improve visibility for low-vision users. We implemented these suggestions, and evaluated the icons with P4 in follow-up sessions, iteratively modifying symbols for simplicity and ease of identification (e.g., changing the initial light sensor icon to a moon and a sun).

3.2.3 Module Ordering & Orientation. A prominent challenge encountered throughout the initial sessions (S1 - S4) pertained to the dependence on researcher guidance and intervention to support participants with the ordering and orientation of modules to make correct connections. This challenge inspired the conceptualization of custom-made templates, designed to facilitate the simplified arrangement and sequencing of modules and the establishment of connections. Furthermore, our aspiration was for these templates to allow participants to easily remove the circuits they had constructed. During S5 and S6 sessions, P1 and P4 were introduced to a 3D-printed template aimed at constructing power-sensor-action circuits - wherein a power board, connected to a sensor module, controls the action board. Subsequently, this template was iterated upon in collaboration with P1 and P4 (refer to Figure 5 for three design iterations) while additional circuit template designs were also considered. These co-design sessions generated a host of valuable recommendations, including: P1 suggested deepening the slots for board insertion to enhance board stability when making connections (S6); and P4 proposed color-coding the slots to align with the different colored board

Table 2: Summary of co-designed toolkit accessory development

Co-Design Toolkit Adaptations								
Co-Design Sessions	S1	S2	S3	S4	S5	S6	S7	S8
Co-Design Participant	P1	P2	P3	P4	P4	P1	P4	P1
Toolkit Co-Designed Accessories								
Conductive Thread	X	X	X	X				
Shortened Tactually Distinct Wires		X	X	X	X	X	X	X
Daisy-Chained Banana Plugs					X	X	X	X
Board Pad Guides					X	X	X	X
High-Contrast Icons					X	X	X	X
Circuit Template					X	X	X	X
NFC Audio Descriptions							X	X

modules and introducing high-contrast black raised indicators for polarity symbols and connection guides (S7). Additionally, P1 and P4 recommended attaching headers to templates with braille labeling, enlarged printed labels, and an NFC tag to offer multiple recognition methods (S7-S8).

3.2.4 Audio Descriptions. Although the majority of participants successfully recognized module functionality and polarity, and the connection mappings using the provided adaptations (S1-S6), some required additional verbal explanations as they progressed. It became apparent that integrating this information directly into the toolkit was essential for enabling independent toolkit usage. So, we adhered NFC tags to modules and templates, each coded with component-specific information to deliver audio descriptions via an NFC reader paired with a Bluetooth speaker. We implemented the NFC-based audio descriptions to introduce the toolkit's modules and templates using the verbatim suggested by P4 during S7. During S8, we evaluated and further refined the audio description system with P1. For each component, we developed two description types: instructional and detailed descriptions. This stemmed from participant feedback, which indicated that detailed descriptions were primarily needed in the early stages of toolkit use. As participants grew more familiar with the toolkit, they found instructional descriptions sufficient for recalling information.

4 The Modified Accessible Toolkit

The modified toolkit is comprised of the circuit board modules and their holder, tactually distinct wires and their hanger, circuit templates and their stands, an NFC reader and its paired Bluetooth speaker, and an automatic conductive tape dispenser (see Figure 6). While the use of distinctive forms and colour coding was present in the original TronicBoards toolkit [54], these features have been accentuated to offer tactually distinct affordances and high-contrast iconography to BLV users. Furthermore, the accessories developed respond directly to the limitations acknowledge by the TronicBoard toolkit's authors, by developing a circuit template to alleviate the

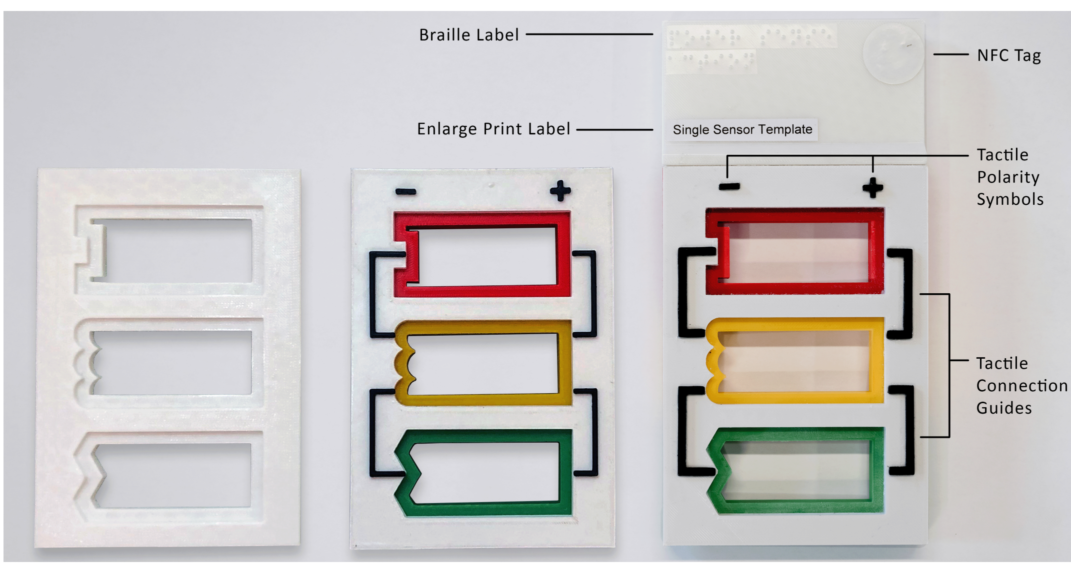

Figure 5: Initial circuit template provided to BLV co-designers (left), a co-designed iteration of the circuit template (middle), and the final co-designed circuit template (right) with accessible features annotated.

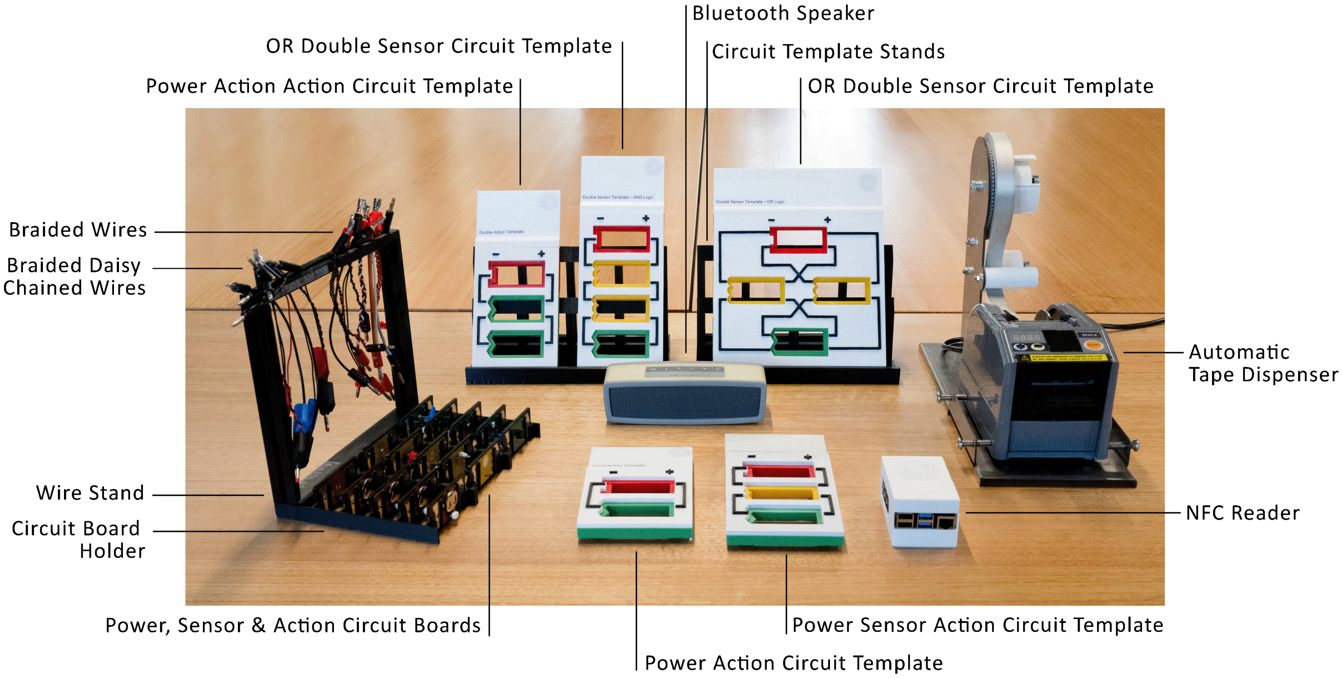

Figure 6: Labeled photograph of the toolkit adaptations from the point of view of the participant.

need for users to securely brace the boards in order to make circuitry connections.

4.1 Circuit Boards

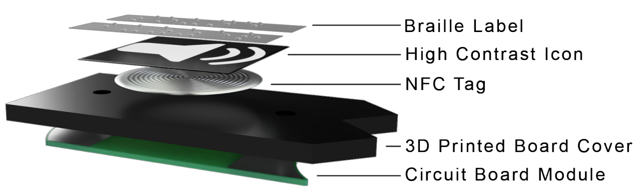

Figure 7: Exploded view showing the layered components added to an individual circuit board module.

A subset of circuit boards from the original toolkit were selected to be used for the evaluation studies, including: (1) power boards (3V battery power, USB power); (2) sensor boards (touch, tilt, light, temperature, push button switch); and (3) action boards (music, color mixer, vibration motor, sound buzzer, fan motor). The circuit boards operate by activating the action boards with the power boards, which the sensor boards can then control. Each circuit board was custom fitted with a 3D-printed board cover, NFC tag, high contrast icon, and braille label (see Figure 7).

4.2 Connectors

Two distinct circuit board connection methods including braided wires and conductive tape, were included in the modified toolkit (see Figure 6). Both connection methods allow for circuitry connections to be made between power boards, sensor boards and action boards. Braided wires consisted of a co-designed tactually-distinguishable banana plug wire set (Section 3.2.1). The automatic tape dispenser was configured to remove the backing from conductive tape before dispensing it to users. Additionally, the automatic tape dispenser was programmed to cut the lengths of tape to match the distance between circuit boards within the circuit templates.

4.3 Circuit Templates

Five distinct circuit templates (see Figure 6), each with a unique configuration, were developed to simplify the arrangement and sequencing of circuit boards: the power-action template; the power-sensor-action template; the power-action-action template; the AND logic template (power-sensor-sensor-action); and the OR logic template (power-sensor-sensor-action). These templates were designed to progress in complexity, with the power-action template housing one power and one action circuit board, serving as the simplest board configuration, and the OR logic template housing one power board, two sensor boards and one action board, forming the most complicated circuit. The power-sensor-action circuit template established the foundational design conventions that guided the development of the additional circuit templates.

4.4 Stands and Holders

A holder for the circuit boards and wires, and a stand for the circuit templates were 3D printed to contain and arrange the toolkit components for user convenience (see Figure 6). The circuit board holder and wire holder were developed as a single unit, recognizing their frequent concurrent use in circuit creation. The circuit board holder features slots to contain and order the circuit board modules; this slotting mechanism was found to be intuitive, leading to its retention across various design iterations during the co-design sessions. Positioned directly behind the circuit board holder, the wire stand features a central gap where wires are collected and inserted. The wires are suspended by their banana plugs, with stackable (daisy-chain) wires on one side and the collection of diverse textured braided wires on the other. Users can select different wires by sliding them towards the central opening. The 3D-printed template stands were developed to hold the circuit templates at an angle, preserving the working space in front of the user. Indentations have been designed into the stands, serving as tactile guides to ensure that the circuit templates are placed securely. Notably, these stands have been refined to minimize interference with users' exploration of the templates while resting on the stand, ensuring that tactile engagement with the circuit templates is unimpeded.

4.5 NFC Reader

The NFC reader (see Figure 6), is built from a Raspberry Pi 4, PN532 NFC/Radio Frequency Identification Hat and a battery pack. Upon start-up, custom scripts on the Raspberry Pi continuously monitor the NFC Hat for the presence of a nearby NFC tag. Once an NFC tag is detected, the Raspberry Pi delivers the audio descriptions to users through the connected Bluetooth speaker. To assist users in using the toolkit without limitations and to minimize cable clutter, we integrated a battery pack that powers the NFC reader. The entire system is encased in a custom-designed 3D-printed enclosure. The case has a recessed lip, designed to support users' alignment of circuit boards or templates, and concentric tactile patterns to guide users in optimal NFC tag placement for scanning. Additionally, there is a front-facing switch, with a custom, distinguishable 3D-printed switch cover, allowing users to toggle between detailed and instructional descriptions of the scanned component.

5 Evaluation of Adaptions for Tronicboards

A formal user study was conducted with BLV participants to assess the usability of the co-designed toolkit adaptations. The evaluation consisted of a familiarization period followed by structured tasks and unstructured exploration.

5.1 Evaluation Method

5.1.1 Participants. Nine BLV participants (3 males and 6 females, mean age = 47.67, SD = 16.80) were recruited from our lab's participant contact pool. See Table 3 for their demographic and disability-related information. As a result of the low-incidence of blindness and the associated difficulties in participant recruitment, many studies related to blind accessibility include a range of 6 to 12 participants [12, 48], aligning with the scope of our work. None of the participants recruited for the user study were involved in our co-design journey.

All participants self-reported as low-vision or blind and ranged in age from mid-20s to late-60s, offering a diverse spread of ages (summarized in Table 3). All participants regularly made use of accessible text in the form of audio supports. However, while all participants possessed braille reading proficiency, only three individuals indicated engaging with braille on a daily basis. Enlarged print formats were rarely used by participants with low-vision. In terms of circuit-making familiarity, three participants indicated no prior experience, three reported minimal exposure, one had significant exposure but lacked confidence in circuit construction, and two stated they possessed substantial experience and confidence in circuit making. All participants shared similar exposure to electronic toolkits except P9, who reported having substantial experience and confidence in circuit making, but expressed limited exposure to electronic toolkits. All participants indicated that they were either somewhat (four participants) or very (five participants) interested in circuit making.

5.1.2 Procedure. User studies were conducted as one-on-one evaluation sessions that lasted approximately 90 minutes, employing a form of guided exploration. Recognized as an inductive minimalist approach for teaching tool-related concepts and techniques [40], guided exploration allows participants to interact with tools before being introduced to principles and procedures.

The modified toolkit was displayed on a table in front of participants (see Figure 6 for a participant view of the toolkit layout). Participants were first invited to pick up and explore the individual circuit board modules. As they were handling the boards for the first time, they were informally asked to guess what the boards might do. Participants could guess any number of board functionalities and features in accordance with their level of interest and engagement. Next, participants were presented with the NFC reader and encouraged to discover additional information about the individual boards using the device. Participants were then introduced to the circuit templates, allowing them to examine the physical features that might suggest the intended uses of the templates and to use the NFC reader to access additional information related to each template. Finally, participants were presented with the circuit connection methods, consisting of braided wires and conductive tape.

Once participants had built an understanding of the toolkit adaptations and their applications, they were tasked with completing the first fundamental circuit template, the power-action template, using their preferred circuit connection method. Subsequently, the participants were given an unstructured free-exploration period where they could continue progressing through the circuit templates or concentrate on specific toolkit components that were of interest to them.

5.1.3 Data Collection. We conducted a modified System Usability Scale (SUS) questionnaire and a 30-minute semi-structured interview with all participants, in addition to video and audio recording the evaluation sessions. The SUS questions used in this study were derived from the work of Reinders et al. [48], who adapted these questions in consultation with a blind co-designer, ensuring the questions' relevance and appropriateness for a BLV context. Employing a semi-structured interview method, we discussed participants' experiences after having engaged with the modified toolkit, focusing on aspects such as design and

Table 3: Participant demographic information

Participant	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**
Demographics:									
Age	21	68	65	24	44	40	54	55	58
Gender	Male	Female	Male	Female	Female	Female	Female	Male	Female
Level of Vision:									
Blind		✓	✓		✓	✓	✓	✓	
Low-Vision	✓			✓					✓
Accessible Formats Used:									
Braille	✓	✓	✓	✓	✓	✓	✓	✓	✓
Enlarged Print	✓			✓					✓
Audio Support	✓	✓	✓	✓	✓	✓	✓	✓	✓
Familiarity (1: Not Familiar - 4: Very Familiar):									
Electronic Circuit Making	2	1	1	3	1	2	2	4	4
Electronic Toolkits	2	1	1	3	1	2	2	4	2
Interest (1: Not Interested, 2: Somewhat Interested, 3: Very Interested):									
Circuit Making	2	2	2	3	2	3	3	3	3

functionality, the translation of technical concepts, as well as the participants' perception of agency and independence.

5.1.4 Analysis. We conducted a thematic analysis of: comments made by participants during the modified toolkit component familiarization phase and the unstructured free exploration period; researcher observations of participant interactions throughout the study; and participant responses from the semi-structured interview. All user evaluation sessions were transcribed, using a transcription service, for review alongside the video recordings. Based on our observations from the co-design sessions, we derived an initial set of codes and themes. These codes were refined as we familiarized ourselves with the data, by deriving codes inductively [8] and refining them to increase specificity in several iterations. Specifically, we examined participants' performance expectations, task comprehension and execution, user experience, and personal sense of agency. Any ambiguities in classification were reconciled in subsequent meetings with the authors of the paper, leading to the themes being further refined and consolidated.

5.2 Evaluation Findings

We first present results from the SUS questionnaire demonstrating the overall usability of the adapted toolkit. The rest of the section is organised from the point of view of our final themes, which address the comprehensibility of the adaptations and the technology conventions expected by BLV users. Lastly, we explore our participants' perceptions around circuit making, particularly their shifts in perception towards electronics.

5.2.1 SUS Results. The SUS questionnaire achieved an average score of 80.83 (SD = 9.35), which can be interpreted as 'good' [3], demonstrating that overall, participants had positive usability experiences with the accessible adaptations for the toolkit. All participants indicated that they found the toolkit modifications easy to use and interact with (95.6), and they felt confident and comfortable using the adaptations (95.6). While participants generally found that the adaptations were not unnecessarily complex or difficult to use (68.8), four of the nine participants felt that they would be more comfortable interacting with them alongside a support person (93.4).

5.2.2 Circuit Making Comprehension. The average user study duration spanned approximately 100 minutes, during which participants, on average, successfully completed three circuits (Figure 9A). The circuitries developed by participants ranged in complexity, from fundamental power-action circuits (e.g. a battery operated vibration board (*P1-P5, P7 & P9*)), to a fan action board controlled by a temperature sensor board (Figure 8A), to a sound buzzer action board controlled by either the touch or the light sensor board (Figure 8B). Throughout all user studies a pattern of experimental learning emerged, where participants *"just learned on the go"* (*P2*), with *P1* emphasizing the importance of tactile exploration, noting that *"feeling the shapes and seeing where the*

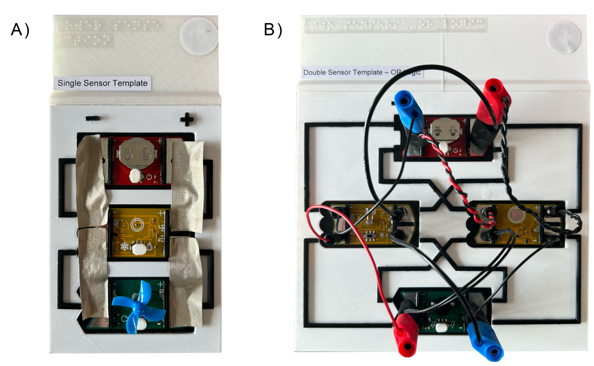

Figure 8: Example circuits created during the user study evaluations using the A) Single Sensor Template to create a temperature-sensor activated fan with conductive tape and B) Double Sensor OR Logic Template to create a touch-sensor or light-sensor activated sound buzzer with braided wires.

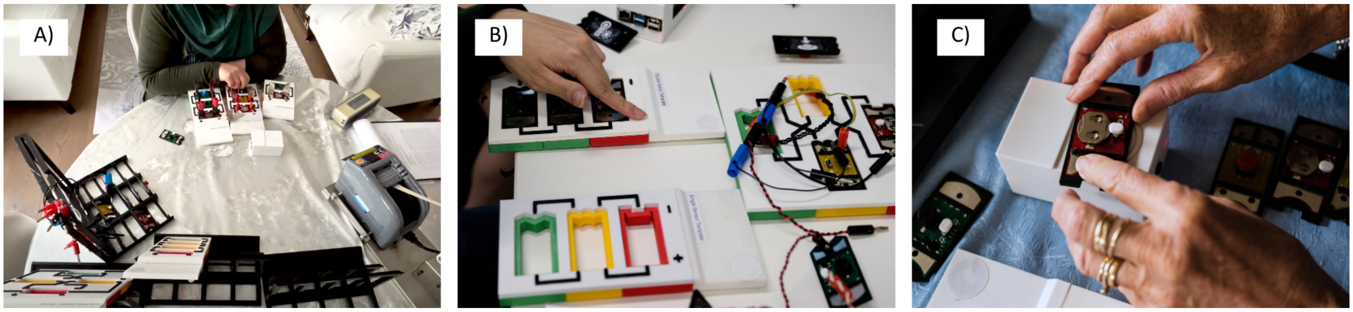

Figure 9: Participants interacting with the accessible toolkit components with A) a participant having created multiple circuits, both with conductive tape and braided wires, using the modified toolkit, B) a participant identifying the 3D-printed anode and cathode symbols, represented through a plus and minus sign, demonstrating the directional flow of electricity in the circuit, and C) a participant using their sense of touch to locate and align a circuit board module onto the NFC reader's 3D printed casing, guided by the casing's distinguishable lip.

shapes fit". The majority of participants adopted a strategic approach to familiarizing themselves with the modified or newly-introduced toolkit components, e.g., progressing *"from the simplest template, [where they] learned how to fiddle around with it, and then [they] kind of went up in complexity"* (*P4*).

5.2.3 Circuit Board Module and Circuit Template Comprehension. All participants were able to successfully identify the different board module types. The board cover's physical affordances, braille label, and instructional NFC reader supported participants in determining the functionality of each circuit board. Two participants (*P6 & P7*) commented on the consistent affordances of the board covers, which aided in identifying the distinct circuit board module types. Upon feeling the custom 3D-printed covers for the different module types, *P8* foreshadowed the use of the circuit templates through their prediction that the boards were to be used in a circuit by *"slotting into something"*.

All circuits made during the user studies were constructed using the circuit templates. Each circuit template's adherence to design conventions prompted participants to leverage their prior circuit-making experiences, within the study, to build future circuits. For instance, *P9* articulated the significance of recognizing the *"pattern"* of the template's anode and cathode orientation as the key to effectively constructing circuits using the templates (Figure 9B). The circuit templates were not only perceived as a circuit-making tool but rather a *"puzzle"* to be solved (*P1, P4 & P6*). Additionally, as someone with prior experience in circuit making, *P4* likened the circuit templates to *"breadboards, kind of just made very large"*. Participants found using templates more convenient than constructing circuits without them, with *P9* remarking that using the templates is *"a hell of a lot easier than just building [circuits] on nothing"*. However, participants also expressed their willingness to explore circuit building beyond the confines of the templates (*P1, P3, P4, P6, P8 & P9*). It was acknowledged that constructing circuits outside of the templates is anticipated to be more time-consuming (*P1 & P4*) and that some participants would prefer to gain additional exposure to the toolkit before attempting such endeavors (*P3 & P6*). Two participants (*P4 & P9*) brought attention to the importance of the board modules sitting flat within the circuit templates, with *P4* describing their *"frustration for the wires trying to move the boards [out of the circuit template]"*. In response to this frustration, *P9* proposed that magnets might be used to more robustly secure the circuit board modules in place within the template.

5.2.4 Connector Preferences. Eight of the nine participants preferred to use the braided wires, as the tactile differences between wires made them *"distinguishable"* (*P7*). However, it was noted that due to the relatively small scale of the circuit templates and shortened length of the braided wires, participants often found that they did not need to rely on the tactile differences between wires to ensure that the correct wire was being used. Furthermore, over half of the participants expressed that they attempted to interpret the different wire textures as indications of distinct circuit connector functions, such as *"resistance"* (*P3*) and *"current"* (*P9*), while speculating why the wires were non-identical in texture (*P2, P3, P5, P6 & P9*). As the only participant who preferred conducive tape, P6 expressed their appreciation for the conductive tape's *"aesthetic"* attributes, which enabled it to adhere smoothly along the circuit templates. Moreover, *P6* noted the convenience offered by the automatic tape dispenser, whereby *"just the right amount [of tape]"* was dispensed with each use. Several participants were able to theorize instances where the conductive tape may act as a useful circuit connector, such as when making *"flat"* (*P3*), *"compact"* (*P4*) or *"permanent"* (*P5*) circuits. However, the conductive tape's near imperceptible profile made it difficult for participants to discern and troubleshoot whether it was being accurately positioned on the circuit template, to establish a successful connection between the boards. Moreover, participants raised concerns about the material's wastefulness due to the challenges they encountered when attempting to reposition and reuse tape strips, ultimately leading to the selection of braided wires as the preferred circuit-making connector choice.

5.2.5 Information Access Preferences. Participants accessed information regarding component descriptions and instructions through various approaches, according to their individual preferences. As described by *P1*, *"There are three different ways that you can find out about a board ... the edge shape, ... the NFC reader.*

Then if you are not confident in memorizing ..., you can read the braille". The NFC reader was found to support participant's autonomous problem-solving (Figure 9C). Most participants used the NFC reader to *"find out"* information when unsure of a component or its functionality, explicitly demonstrated by *P5* and *P9*. In contrast, *P4* considered using the NFC reader as *"cheating"*, as they sought to solve the building of circuits with minimal assistance. Additionally, some participants placed greater expectations on the NFC reader to aid in system troubleshooting than what it is actually capable of, exemplified by *P1* who commentated that the NFC reader should *"tell me what I'm missing"*. Almost half of the participants (*P1, P2, P5 & P7*) indicated that a detailed printed braille instruction manual would support their independent use of the modified toolkit, supporting the two participant perspectives that found that the information gained from the toolkit adaptations was too limited.

5.2.6 Alignment with Existing Conventions for BLV Users. Participants drew heavily upon previous experiences and commonplace conventions when familiarizing themselves with the toolkit adaptations. This was seen when six of the nine participants attempted to place the first modular circuit board into the circuit template with the braille facing upwards (*P1, P2, P3, P5, P6 & P7*), and *P2* explained that *"normally, when we pick up braille, it has to always be on the top"*. As the templates were designed to house the boards with the circuit components facing upwards, an upside-down board would not sit flat within the template, alerting the participants that the board was not correctly orientated. Despite the initial prevalence of the circuit boards being placed upside down, once it was explained that for this toolkit, the braille faces down, this upside-down placement was not repeated by any participant. Additionally, when the six participants who had initially placed the circuit boards upside down were asked whether the toolkit should be amended so that the braille faces upwards, all participants advised that the toolkit should not be changed, with *P2* highlighting that *"if you had the braille on the front then you wouldn't be able to feel [the circuit components and switches]"*.

As all participants possessed prior experience with using audio supports, it became evident that the pace and duration of the audio descriptions, delivered by the NFC reader, did not align with the preferences of several participants. Feedback from *P1, P4, P6, & P9* highlighted that the audio descriptions were perceived as slow, with one instance of *P1* electing to bypass the audio description entirely to rely solely on reading a component's braille label. Furthermore, participants shared that they found the NFC reader to provide overly verbose descriptions (*P1, P2 & P5*), as indicated by *P2*, who noted that the NFC reader tended to *"waffle on"*. To address this issue and improve usability, three participants (*P1,P4, & P6*), suggested providing users with additional control over the NFC reader to skip information and change the speed of audio. More specifically, *P1* proposed that distinct pieces of information about each component could be organized into *"chapters"*, allowing users to navigate through chapters to locate the specific information they desired.

5.2.7 Feelings of Anxiety and Achievement. While the System Usability Scale demonstrated that participants generally had positive usability experiences when using the modified toolkit, the majority of participants raised concerns regarding the toolkit's robustness (*P1, P6, P7, & P9*) and safety aspects (*P1, P3, P5, & P7*) when working with the electronics. For instance, P1 expressed apprehension about applying force when disconnecting a wire from the circuit board, asking, *"Are you sure you can't break these? I'm so scared"*. Notably, two participants (*P1 & P7*) remarked on the electronic toolkit's risk of user electrocution, revealing their experiences of fear or danger. These comments predominantly arose when participants were assembling their first circuits.

While various participants voiced initial apprehensions towards the toolkit, all participants exhibited a sense of accomplishment upon successfully assembling circuits. For instance, *P1* referred to themselves as *"a genius"* after completing their first circuit, while *P8* described the act of successfully constructing their own hardware as *"rewarding"*. Additionally, two participants highlighted the incremental nature of their achievements, with *P4* exclaiming *"hooray"*, and *P5* remarking, *"oh, this is so much fun"* upon correctly fitting boards into a template.

While *P2* and *P5* had both disclosed that they were only somewhat interested in circuit making during the demographic survey, they expressed a perception shift after using the adapted toolkit to successfully construct circuits. This shift in perception suggests that hands-on interactions they had with the modified toolkit may have enabled the participant to alleviate their initial apprehensions.

Multiple participants also acknowledged that further exposure to the toolkit adaptations may support more *"adventurous"* circuitry exploration in the future (*P6*). Notably, two participants (*P8 & P9*), who considered themselves to be very familiar with electronic circuit making, displayed a heightened willingness to engage in experimentation. *P8* jokingly commented about the durability of the modified toolkit components, quipping, *"force it; if it breaks, that needed a replacement anyway"*, while *P9* expressed their readiness to learn through discovery and exploration, stating, *"if it doesn't work, just do it anyway"*.

6 Discussion

Our work presents how design can be used in the service of accessibility by taking an existing electronic toolkit and carefully adapting it for BLV individuals. The BLV community is often marginalised in the design of products, services and experiences - even when those artefacts of design are meant to support those same people. In this section, we discuss how our process of developing accessible toolkit accessories can be adapted for other electronic toolkits. We also discuss key design considerations identified through our work, such as the principle of redundancy in accessible design, and the role of trust and safety in enabling electronics exploration.

6.1 Towards Adapting Toolkits for Accessibility

Our work highlights the shift towards adapting, retrofitting and augmenting existing technologies to project alternatives in this space rather than creating something new to increase the diversity of electronic toolkits available to the BLV community. Although our design is presently limited to TronicBoards [54], the design features that emerged from the co-design sessions can be transferred to other modular toolkits. For example, 3D-printed covers can be used to make the individual components (e.g., LEDs, sensors, battery) of the Lilypad sewable electronics kit [10] accessible. Indeed, a similar approach has been used to make Lilypad easier to use by older adults through laser cut covers [37]. The use of 3D-printed circuit templates to support circuit composition can also be extended to other toolkits. Paired with uniquely distinguishable covers for the modular components, it enables unidirectional component placement, thereby establishing design conventions for users to follow while ensuring connection order. The LittleBits electronics toolkit [5] can be modified in this way with larger 3D-printed bases that fit into unique templates. Other researchers have also suggested the method of attaching modular circuit boards to larger bases to support the circuit-making aspirations of people with learning disabilities [32]. The use of NFC stickers with audio descriptions is also more broadly generalizable as a means to provide context sensitive information and instructions. This method has been used widely to provide inclusive gallery experiences [13], as well as support indoor navigation [1] for BLV individuals. In the context of electronics, existing toolkits can use NFC stickers for component identification and circuit-building instructions. Similarly, the use of shorter braided wires can be readily used as an accessible connector in other toolkits. The termination ends (e.g., banana plug, alligator clip, magnet, etc.) may differ but the wires themselves can be tactually distinguished and followed when making connections. More broadly, these techniques for adapting existing electronic toolkits for accessibility may also benefit other underserved groups, such as older adults and people with intellectual disabilities.

Although we can envision adapting several other toolkits such as Lilypad [10], LittleBits [5], and SnapCircuits [23] using our methods, we acknowledge that not all toolkits are modular in nature and have the affordances necessary to support enclosures, templates, and NFC tags. This highlights the need to develop technology that could be extended for inclusivity. While a toolkit may not initially be accessible, it could be designed to support and accommodate accessibility in the future. The Lilypad Arduino [11] was originally developed for e-textiles and wearable projects without accessibility in mind; however, due to its modular nature and large connection pads, it can support enclosures and alternative connectors [37]. Similarly, braille labeling and NFC tags require space that designers can support with larger single-sided breakout boards of circuit components. This allows others to 3D print enclosures to support the needs of BLV users. However, further research is needed to acquire a deeper understanding of the limitations and opportunities pertaining to toolkit augmentation, before the development of guidelines for establishing an accessible ecosystem around a toolkit.

6.2 Redundancy and Usability

Our BLV users were able to successfully acquire an understanding of the toolkit's circuit boards through diverse approaches, encompassing the visual cues of circuit board's coloring and high contrast symbols, the tactile feature of the board cover's edge shapes, the accessible inclusion of braille labels, and the narrated descriptions and usage instructions conveyed via the NFC tags. Additional redundancy was designed into the toolkit through the medium of the circuit template's physical configuration constraints. For instance, participants were unable to insert the circuit boards upside down due to the inner slot of the template; providing a physical barrier against such placement. This feature, of correctly orientating components through physical constraints, is also present in other toolkits. LittleBits provides users with haptic feedback through the polarity of magnets [5]. While the LittleBits toolkit employed tangible feedback to support users in correctly orientating toolkit components, our research leveraged physical constraints to ensure that all users, regardless of their inclination or ability to engage with audio descriptions and braille labels, had multiple means of discerning whether they had accurately chosen and oriented the circuit board module within the circuit template. To support information perceptability Story et al.[57] recommends the use of multiple modalities (in our case auditory, tactile and some visual for low-vision users) for the redundant presentation of essential information. A number of electronic toolkits have been designed with redundant features to provide targeted users with supplementary information regarding toolkit use. For example, the LittleBits go LARGE toolkit extension increased the size of its components while introducing distinct physical differentiators at each end [32]. This toolkit adaption functions in a comparable manner to the original magnetic connection feedback system; however, the adaption supports component assembly and orientation for individuals with learning disabilities. Similarly, the color coding used by TapeBlocks offers individuals with intellectual disabilities a practical method for discerning between different component types and comprehending their sequential arrangement [20]. This highlights the importance of implementing a surplus of multi-sensory comprehension opportunities to improve the accessibility of electronic toolkits for a wide range of users.

More broadly, redundancy in accessibility design provides participants with an opportunity to exercise their modality preferences for knowledge acquisition, in a capacity that meets their abilities and needs. There is some evidence to suggest that multimodal representations reduce the cognitive load for users [30]. Our research explores the significance of incorporating redundancy within a modified toolkit to enhance accessibility and usability for individuals with visual impairments.

6.3 Engendering Trust and Safety in Technology

While our research primarily focused on mitigating physical accessibility barriers associated with an electronics toolkit, the design of the accessible adaptations did not explicitly address the psychological barriers users may encounter when engaging with new technologies. A recurring theme that emerged throughout the research was the experience of apprehension when individuals encounter new technology. This apprehension encompasses concerns of inadvertently damaging the technology or potential harm arising from its use. This phenomenon has various labels, including technology anxiety and technophobia [39], and is characterized by emotional and psychological barriers that obstruct technology adoption and provoke its resistance [7].

Throughout our study, participants conveyed concerns regarding their proficiency in using the electronic toolkit adaptations. The majority of participants lacked prior experience in working with electronics, leading to uncertainty about their own competence and their threshold for electronics experimentation. Additionally, participants expressed apprehension towards the toolkit's durability, fearing that they might inadvertently damage components due to their unfamiliarity with the toolkit's robustness. Previous research has similarly reported instances where participants perceived tangible artifacts as fragile [25, 59] and expressed concern for unintentionally damaging toolkit components [15]. Although confronting unfamiliar technology-making tasks can be intimidating, it is possible to build user confidence and alleviate technology-related anxiety through consistent exposure to successful technology interactions within a safe and supportive environment [16]. Effective interventions have been found to include personalized training, education programs, and engagement with warm experts [35] in addition to developing friendly digital environments for users[39]. Indeed, Giles and Linden found that BLV participants were able to transition from initial apprehension, stemming from their inability to see the weaving activity, to a state of confidence and enjoyment once actively engaged in the task [24]. This underscores the importance of recognizing that, even when toolkits are physically accessible to a wide range of users, addressing the potential psychological barriers to entry is equally critical, especially for user groups that have historically faced exclusion.

7 Limitations & Future Work

We acknowledge that a limited number of individuals were engaged with the toolkit evaluation sessions. Moreover, all of whom identified as braille readers, which is not a representative sample of the BLV population. While braille literacy rates are often cited at approximately 10% within the BLV population, there exists a notable absence of reliable data substantiating this statistic [55]. What we do understand, however, is that a substantial proportion of individuals who are BLV, particularly those who experienced vision loss later in life — a majority demographic within this group [6], do not read braille [42]. The consequence of our non-representative evaluation sample is that braille readers often possess well-developed skills for exploring and interpreting tactile materials [27, 33, 52]; therefore, we are unable to identify whether individuals who are not proficient in braille might have perceived and interacted with the toolkit adaptations differently. In subsequent iterations of our accessible toolkit adaptation designs, we intend to incorporate a broader range of BLV perspectives to enhance inclusivity. Additionally, drawing upon participant feedback, it became evident that to support braille literacy, including a braille instruction manual in the modified toolkit, prior to deployment for BLV users, is crucial. An additional limitation of this work is the absence of a comparative study between the original and adapted electronics toolkit. This was not performed to avoid the learning effect on users and to maintain the feasibility of the study duration (within-subject design). Additionally, the sample size was insufficient to establish a control group (between-subject design). A further limitation is that we adapted a single electronics toolkit and did not extend other toolkits within this space. We acknowledge that the toolkit we chose to augment is designed with certain accessibility features that lends itself to accommodating add-on adaptations. However, as alluded to in the discussion, the use of 3D-printed templates, NFC tags for information and instructions, and tactually distinguishable connectors can be transferred to other modular toolkits, thereby broadening support for BLV participation in STEM activities.

8 Conclusion

In this paper, we presented the design of accessible augmentations to an existing electronic toolkit for BLV users. By using readily available electronic components and 3D printed templates, we co-designed an accessible version of the toolkit iteratively with BLV individuals to ensure that their needs were understood and met. We introduced the adapted toolkit to nine BLV individuals during one-on-one evaluation sessions. Our results suggest that the adapted version of the toolkit provided BLV users with positive usability experiences, supporting toolkit component comprehension and highlighted their ambitions and trepidations towards constructing electronics. Based on evaluation results, we discuss the potential for extending this work to other electronic toolkits within this space, providing implications for accessible design through information redundancy while engendering trust and safety in technology.

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