Making Tricks More Accessible: Empowering Adults with Intellectual Disabilities to Create E-textiles

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Making Tricks More Accessible: Empowering Adults with Intellectual Disabilities to Create E-textiles

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science in Human Computer Interaction

Rochester Institute of Technology

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Abstract

E-textiles are a newly emerging technology that can be seen in consumer, educational, and hackerspace environments. Specifically, the development of e-textiles requires a minimum level of familiarity with a variety of concepts; one of which is circuit design and prototyping.

Unfortunately, people with disabilities are rarely included in the design and development of e-textiles, so methods to manipulate these wearable interactive technologies are not always accessible to creators with disabilities. Therefore, we conducted this study to begin understanding how adults with intellectual disabilities perceive and interact with this new type of electronic technology.

This research explores an accessible process to enable individuals with intellectual disabilities to create their own e-textiles. Circuit puzzles, unique to each participant’s chosen circuit, were introduced to simplify the circuit designing and prototyping process. A pilot study with two participants showed that adults with intellectual disabilities can successfully create their own e-textiles provided some initial feedback regarding their circuit puzzles. We then conducted a larger study with eight participants building upon an initial pilot to further examine the effectiveness of the circuit puzzles and to determine whether participants gain a sense of empowerment through learning more about this emerging technology. This report discusses the findings of both the pilot and larger study.
Acknowledgements

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I would also like to thank my friend Eric Thompson whose musical ear I took advantage of and he helped me with any of the e-textile projects that had sound as their output. Without him, I probably never would have gotten any of the musical projects completed in time. I would also like to say thank you to my boyfriend, friends, and family for keeping me sane throughout this entire crazy process.

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Chapter 1. Introduction

E-textiles, also known as electronic textiles or smart textiles, are an emerging type of interactive technology comprising of fabrics or textiles as the base material on which electrical components are connected using conductive material such as thread or yarn. E-textiles can gather information actively (e.g. button press), passively (e.g. pulse rate detection), or act purely as an output for aesthetic purposes (e.g. light-up scarf). E-textiles, also known as electronic textiles or smart textiles, are becoming more ubiquitous in today’s society and can be integrated into a variety of inanimate objects thereby making them interactive. Due to their soft form factor they can easily be attached or integrated into a number of objects (e.g. bags, clothing, light switches) thereby making it possible to interact with these objects in new and novel ways (Poupyrev et al., 2016).

Researchers have explored how e-textiles can create opportunities for underrepresented minorities such as at-risk youths, ethnic minorities, girls/women, and those with visual impairments to learn more about programming and electronics (L. Buechley & Eisenberg, 2008; Leah Buechley & Hill, 2010; Giles & van der Linden, 2015; Giles, van der Linden, & Petre, 2018; Kuznetsov et al., 2011). However, some minority populations such as those with intellectual impairments are not typically considered in movements aimed to diversify STEM education. Around 6.5 million people in the United States and about 1-3% of the world’s population have an intellectual disability (ID) (“What Is Intellectual Disability?,” n.d.).

Providing this population with basic fabrication knowledge can empower them to make for fun, for a particular functional use, for monetary gain, and even to modify their own assistive
technology to better suit their unique, individual needs (Koushik & Kane, 2019; Meissner et al., 2017).

E-textiles have potential contributions in many different fields such as health and well-being, education, artistic expression, and social interactions (Almeida, Comber, Olivier, & Balaam, 2014; Haladjian, Scheuermann, Bredies, & Bruegge, 2017; Mauriello, Gubbels, & Froehlich, 2014; Voit, Pfähler, & Schneegass, 2018). E-textiles have been used as rehabilitation sleeves to track a patient’s progress and provide them and their orthopedists with feedback regarding the quality of exercises (Haladjian et al., 2017). They have also been utilized as educational tools for teaching girls about their bodies and reproductive systems acting as a visual aid to represent internal parts of the body and how they function (Almeida et al., 2014). E-textiles have also been used to promote social engagement in group-based exercise activities (Mauriello et al., 2014). The unique and varied interactive modalities available with e-textiles make creation and use of these technologies well suited for diverse audiences. However, e-textiles are not currently being explored with adults with ID.

This study works with adults with ID to examine the effectiveness and understandability of the circuit puzzles we developed. Over the course of three sessions participants learn what e-textiles are, how to assemble a basic circuit, and how to create their own e-textile. During this process we examined the value of the circuit puzzle as a tool for creating the circuit portion of an e-textile by observing how participants use their circuit puzzle to help them make the necessary electrical connections for their e-textile’s circuit. Specifically, this research will focus on the following research questions:
RQ1: Is a circuit puzzle an effective way of enabling participants with ID to assemble and make the necessary electrical connections for a prototype circuit with limited help?

RQ2: Are participants able to use their circuit puzzles as a reference to correctly identify the electrical connections that need to be made for the e-textile’s circuit?

RQ3: Does a circuit puzzle aid in the understanding of basic circuit-related concepts?

RQ4: Do participants gain a measurable sense of empowerment through the process of learning about and making their own unique e-textile?
Chapter 2. Background Literature

Intellectual Disabilities

Intellectual disability is a term used to describe a general learning disability that affects an individual’s intellectual and adaptive functioning abilities (“What Is Intellectual Disability?,” n.d.). ID also frequently co-occur with other mental health, neurodevelopmental, and physical conditions such as cerebral palsy or autism spectrum disorder, which may also affect their cognitive, social, or underdeveloped motor coordination skills (Falcão & Price, 2012a; “What Is Intellectual Disability?,” n.d.). Characteristics of an ID include difficulties with attention and concentration as well as poor verbal memory, logical reasoning, and abstract thinking (Falcão & Price, 2012a; “What Is Intellectual Disability?,” n.d.). However, tangibles have proven to be an effective way at promoting exploratory learning and teaching complex topics to those with ID (Falcão & Price, 2012b).

Due to the abstract and logical nature that comes with the traditional way of creating electronics, individuals with ID may find the traditional way of creating a circuit prototype to be very challenging. Abstraction and logical reasoning are cognitive processes that are typically utilized during circuit designing and prototyping processes (Chan, Pondicherry, & Blikstein, 2013). For instance, when working with electronic components, one cannot typically deduce a component’s functionality just from its physical appearance because features such as size, shape, and color typically have no correlation to how it works (Chan et al., 2013). Also, the labeling and writing on components often use symbols or acronyms to refer to common connections such as power (which can be represented by symbols such as Vin, 3V, etc.) and ground (which is typically represented by the acronym GND or the
symbol $\downarrow$) (Chan et al., 2013). There is typically also a fair level of abstraction working from a circuit schematic to a prototype, which is a very typical process that one usually does in the beginning stages of an electronics project. Through this work we further investigate the effectiveness of tangibles in facilitating learning about circuits concepts to those with ID.

**Empowerment Through Making**

*Makers* are a group of consumers who buy electrical components or prototyping kits who view *making* or *DIY-ing* as a hobby. For makers, “*making* is not only about using new technologies, but also about the possibilities of what can be created” (Meissner et al., 2017). Researchers have found that making allows a novice or beginner with no prior making experience to assume a new identity as a maker and embody a form of empowerment unique to each individual (Meissner et al., 2017). Participants with disabilities expressed the empowerment they gained through participating in the maker workshops by using their new skills and identities as *makers* to develop artifacts that acted on a problem unique to the participant, were designed to help others, and through gaining social recognition of their new abilities by showcasing their new skills (Meissner et al., 2017).

For instance, a participatory design approach was used to create a kit for e-textiles which enabled kids and teens (10-16 year olds) to successfully create their own unique projects, each of which held some form of personal meaning to them (Katterfeldt, Dittert, & Schellhowe, 2009). Qualitative data from the study revealed that working with smart textiles allowed the students to create real, meaningful objects that solve “real world” problems while also engaging them play-like process (Katterfeldt et al., 2009). A separate study using the Craftec
toolkit investigated how making could empower older adults by integrating crafting techniques they were already familiar with into the electronics-building process) (Jelen et al., 2019).

Making for those with disabilities can be a challenging task but has the potential to ultimately benefit the participant’s lives by providing them with the information and resources to make. Individuals with disabilities already make up a small population of designers. In a survey of 237 designers who posted designs of assistive technologies on the online maker community Thingiverse, 13 of these designers created AT designs to help with their own personal disability (Buehler et al., 2015). People often create their own assistive technology when the current commercially available devices do not satisfy their unique needs or are financially unobtainable (Hurst & Tobias, 2011). Providing individuals with disabilities the knowledge to make, would empower and enable them to create and modify their assistive technology to address their own specific needs (Buehler et al., 2015). Additionally, Meissner et al. discussed how the maker experience can empower those with disabilities when they are actively engaged in the making process (Meissner et al., 2017). In a study where participants with a variety of disabilities were introduced to 3D printers, laser cutters, and microcontrollers, participants attended workshops where they learned how to use these different technologies then in the final sessions, participants defined and made their own item/object/work (Meissner et al., 2017).

Similarly, an inclusive design method encouraged visually impaired participants to be more confident in their ability to create personal and interactive e-textiles (Giles & van der Linden, 2015; Giles et al., 2018).
All of the previously mentioned studies aim to make the creation of computing devices more transparent for the target user and to ‘empower’ the participants by providing the opportunity to learn how to construct their own projects as if they were the expert. Assuming the role of active creators of their own project, participants expressed feelings of empowerment and ownership, and for participants with some form of impairment, they found a way to assert control through making (Giles et al., 2018; Meissner et al., 2017).

**Circuit Puzzle Development**

One barrier to making e-textiles is a fundamental understanding of basic circuitry, which can be a difficult and intimidating process for beginners. Hollinworth et al. (2014) made a pre-existing circuit designing kit accessible for people with learning disabilities by modifying pieces to have larger, and asymmetrical bases for easier handling and constrained matching. They added magnets—and the logic that same poles repel—to minimize incorrect connections. Participants found the larger blocks easier to handle, but had problems connecting components in the correct order (Hollinworth, Hwang, Allen, Kwiatkowska, & Minnion, 2014). The circuit puzzles aim to remove some of the abstract and logical reasoning required in traditional circuit designing processes, thereby lowering the entrance barrier to circuit design for this population. In this study, we want to focus on including the participants in as much of the e-textile design process as possible, and examining how this process of creating an e-textile on their own reflects how they express their personality, ownership, and sense of empowerment through their e-textile.
Chapter 3. Methods

To answer the research questions, we conducted workshops that lasted for three sessions. The study was conducted in multiple sessions due to the complexity of the tasks that we asked participants to undertake. As stated previously, the development of e-textiles is a process that requires some knowledge in several domains and circuit design itself is a daunting task for someone with no training or background knowledge. The traditional circuit design and prototyping process requires abstract and logical reasoning, which are skills that individuals with ID may have trouble with. The puzzle metaphor is an attempt to make this process more accessible by simplifying or removing some of the abstraction and logical reasoning required during the circuit design and prototyping stage by forcing the rules that apply to typical puzzles to the circuit puzzle.

Participants

A total of 10 participants (3 male and 7 female), were recruited from Cerebral Palsy (CP) Rochester. CP Rochester is a day facility that assists and provides support for those with a range of disabilities and their families. All participants were adults with some form of ID. Participants’ ages ranged from 31 to 74 ($M = 54$). Prior to this study, two participants had prior experience with sewing and no participants had any prior experience working with electronics or e-textiles. From observations during sessions or informed by staff at CP Rochester, we know that three of the participants owned their own iPads; all primarily use them as external communication devices. Only one directly used his during our sessions. Consent to participate in this study was given by both the participant in addition to their legal guardian if the participant was unable to give legal consent for themselves.
Procedure

Participants created their own e-textiles over a series of three workshops that took place on three separate days. The workshops were split into multiple sessions due to the complexity of the topics that participants were asked to learn about and to give the researchers enough time outside of the sessions to work on other aspects of the e-textile separate from the actual circuit construction (e.g. making the circuit puzzle pieces, programming the microcontroller, gathering of e-textile materials, etc.). Separate workshop sessions were held typically 1-4 days apart to ensure that participants acquire and build upon the knowledge gained in the previous sessions and to avoid significant decay in between sessions, thereby gradually developing their own confidence to create their own e-textile (Giles et al., 2018) A pilot study (referred to as Iteration 1 for the remainder of this document) followed by two more iterations (Iteration 2 and Iteration 3) of the workshops were conducted. A few changes were made between this first iteration of the study and each following iteration of the workshop. Each session’s structure along with the changes made between each iteration of the workshop sessions is outlined below; a summarized list of what was changed between each workshop iteration can be found in Appendix E. Table 1 breaks down which participants were in each iteration of the workshops.
Each series of three days of sessions was conducted with one participant at a time. The goal of the first session was to explain the purpose of the study and gather consent from the participant, introduce the participant to e-textile technology, and discuss what type of e-textile they wanted to make. The goal of the second session was to teach the participant basic circuitry concepts and to have the participant put together their circuit puzzle. The focus of the final session was for the participant to sew their e-textile using their circuit puzzle as a reference.

**Table 1: Details which workshop iteration each participant was in.**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Workshop Iteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>First iteration (pilot)</td>
</tr>
<tr>
<td>P2</td>
<td>First iteration (pilot)</td>
</tr>
<tr>
<td>P3</td>
<td>Second iteration</td>
</tr>
<tr>
<td>P4</td>
<td>Second iteration</td>
</tr>
<tr>
<td>P5</td>
<td>Second iteration</td>
</tr>
<tr>
<td>P6</td>
<td>Second iteration</td>
</tr>
<tr>
<td>P7</td>
<td>Third iteration</td>
</tr>
<tr>
<td>P8</td>
<td>Third iteration</td>
</tr>
<tr>
<td>P9</td>
<td>Third iteration</td>
</tr>
<tr>
<td>P10</td>
<td>Third iteration</td>
</tr>
</tbody>
</table>

**Session 1**

In the first session the researcher went over the purpose of the study and provided a summary of what would be required of the participant if they chose to take part in the study. Once consent was gathered, the researcher then explained what e-textiles were and showed
participants examples of e-textiles. The first e-textile they were shown was a pendant that used a switch input and sound output, the second e-textile they were shown was a headband that had a button as an input and vibration output, and the third e-textile was a bracelet with a color sensor input and LEDs as the output. Each of these example e-textiles showcased unique inputs and outputs that participants could choose to use in their own e-textiles in whatever combination they wanted, with the exception of the color sensor; the color sensor could only be paired with the LED. After being shown the examples, participants were given time to interact with the example e-textiles before deciding which input (button, tilt switch, color sensor) and output (LEDs, sound, vibration) combination they wanted to use for their own e-textile. If a participant wanted to use the color sensor for their e-textile, they would be informed that if they wanted to use the color sensor, the only output they could use would be an LED. Participants were then asked if they still wanted to use the color sensor or if they wanted to use a different input. Once deciding on the type of object and the input/output combination to use, participants then described the type of fabric (color, texture, or patterned) they would like to use for their e-textile. The first session concluded with a questionnaire for recording participant demographics, experience with circuitry, and their initial interest and whether they had ever participated in a project that focused on science, technology, engineering, or mathematics (STEM) topics. The first session typically took around 30 minutes to complete.
Changes Made to Session 1 Protocol After Iteration 1 of Workshop

In Iteration 1 of the workshops when participants were shown the different inputs and outputs they could choose from, the circuit components were fully integrated into finished e-textile objects. We believe that by showing the participants completed examples primed them. In subsequent workshops, instead of showing participants completed e-textiles we created a demo board (see Figure 1) where participants could interact with each e-textile circuit. Through this exploration, participants could “activate” each of the inputs and directly feel, hear, and see different outputs (see Figure 2).
Between Session 1 and Session 2

Between the first two sessions the first author prepared the participants’ selected electrical components by gluing each to a uniquely shaped foamcore “puzzle piece” and programming the microcontroller. Pieces fit together to avoid incorrect connections and different colored lines drawn on the foamcore marked each component’s connection to ground, power, or other components (see Figure 3).
Session 2

In the second session the researcher began by introducing some basics circuitry concepts such as power, ground, and conductivity/conductive materials. The researcher also introduces the terminology regarding each of their circuit’s components (e.g. microcontroller aka “the brain”, input, and output) and explains how each of their circuit’s components work individually. Participants also learn about how each of their circuit’s components “talk” to each other through the use of conductive materials such as wires, alligator clips, and conductive paint. Participants are then given their circuit puzzle and asked to assemble it similar to how they would assemble a typical puzzle. Once the participant successfully assembled their puzzle in the correct order they would then make the necessary electrical connections using either conductive paint or alligator clips, depending on their fine motor skills or preference (see Figure 4 and Figure 5).

Figure 3: Example circuit puzzle and puzzle pieces.
Puzzle Design Structure

In our study, we leveraged the puzzle paradigm to utilize physical constraints to relate logical relationships between the components’ order and its necessary electrical connections (Hollinworth et al., 2014). Thus, we constructed a circuit puzzle comprising three pieces where a single distinct electrical component was attached to individual pieces (see Figure 3). Made out of foam core, each puzzle piece is shaped differently so they reinforce logical and constrained connections between the different electronic components. The unique puzzle shapes for each component requires that pieces can only be placed in a specific sequence. This sequence reflects the “order of operations” of the circuit. For instance, in the circuit in Figure 3, once the button input has been pressed the microcontroller receives a signal from the input, and in response tells the output to turn on and cycle through whatever colors the participant chose. It was important to have clear mapping between what the participant is doing and the immediate output of the circuit (Falcão & Price, 2012a). The lines on each of are meant to convey how each of the circuit components should be connected and are color coded to represent different types of connections (e.g. power, ground) (Jelen et al., 2019).
Depending on any mobility impairments that the participant had, the researcher made electrical connections under the direct instruction of the participant. Once the circuit was assembled the researcher made sure that each component was connected properly before plugging in the circuit’s battery. After the battery was plugged in the participant could interact with their unique circuit in real time. Finally, participants were asked to describe how their circuit works and how the circuit’s components “talk” to each other. The second session typically took around 45 minutes to complete.

Figure 5: P6 using alligator clips to make the electrical connections for his circuit.

Between Session 2 and Session 3

Between workshop sessions two and three the first author cut and sewed the parts of the e-textile that the participant would not be sewing the circuit too (e.g., sewing snaps to the
outside of the bracelet so the participant could wrap it around their wrist) to expedite the creation process. Circuit components were glued onto the fabric, so the participant would not have to worry about holding the component still while sewing. The researcher also modified each of the circuit components so they would be easier for the participant to sew into their e-textile by extending the metal clasps. This was done by cutting and stripping a piece of wire to removing the rubber coating, soldered one side of the exposed wire to the pin in the microcontroller, bent the wire to form a loop, then soldered the other end of the wire to form a loop as seen in Figure 6. The only parts of the e-textile that were modified by the researchers were not required for putting together or sewing the circuit. This was done to help speed up the e-textile’s overall development and to simplify some tasks that participants may find difficult due to limitations with their motor skills. For instance, some circuit components, like the Gemma v2\(^1\) (one of the microcontrollers used in this study) are made to be directly sewn into a project, meaning that the microcontroller board has holes to sew through with conductive thread to allow electrons to move through the circuit to other components.

However, these holes are small and to make a good electrical connection, the conductive thread needs to be sewn threw and back out of the hole several times. So, the repetitive task of sewing out and back through this small hole several times may be challenging for someone who has trouble controlling their fine motor skills. Other components, like speakers, are not made to be directly sewn into a project\(^2\).

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\(^1\) Adafruit Gemma v2, https://www.adafruit.com/product/1222?gelid=EAlalQobChMJ5MiBh-GC4wIVCaGzCh0- ZQ3hEAQYAASABgElg4PD_BwE

\(^2\) Speaker component, https://learn.adafruit.com/chirping-plush-owl-toy/solder-circuit
Session 3

In the third and final session, participants were given their e-textile with each circuit component glued on to their selected fabric. For this session, participants were responsible for making the connections between the components just as they had in the second session. If the participants were able to sew themselves, they repeated the process from the second session to create their e-textile’s circuit, but used conductive thread on fabric instead of ink or alligator clips on foamcore (see Figure 7). If the participant was unable to sew due to any mobility limitations, the researcher would ask the participant to identify which two pins on which components would need to be connected on their e-textile, and then the researcher would act as their hands and sew the connections between the two identified pins. While sewing (or telling the researcher how to sew) the circuit into their e-textile they referenced their circuit puzzle to recall how to connect the components. Afterwards, participants were asked about their experience working with e-textiles such as their opinions of the circuit puzzle, whether they found it useful while sewing the electrical connections, and if they could think of any other uses for e-textiles. The final session typically took about an hour to complete.
Changes Made to Session 3 Protocol After Iteration 2 of Workshop

Between the second and third iteration of the workshops different measures were used to assess whether participants gained a sense of empowerment throughout this process. In the second iteration of the workshops, participants were asked to give a short show-and-tell about their project and the process they participated in. Qualitatively analyzing the show-and-tell presentations did not reveal any deep findings to suggest this process increased their sense of empowerment. During the presentations participants responses tended to be reserved and give very short, minimalistic responses. Additionally, the staff member who was asking the questions did not know enough about the subject matter to try to dig deeper to gain a sense of what the participants really took away from taking part in this study. This is definitely something to investigate further in future work and is a limitation of this study. In the third iteration of the workshops we changed this measure to an altered version of The Arc’s Self-Determination Scale (Wehmeyer, 1995). Pre and post testing were conducted at the end of the first and third sessions.
The original Arc’s Self-Determination Scale was developed as a self-report measure for students with mild mental retardation or learning disabilities as a tool to enable them to “evaluate their beliefs about themselves and their self-determination, work collaboratively with educators and others to identify individual areas of strength and limitations related to self-determination goals and objectives, and self-assess progress in self-determination over time” (Wehmeyer, 1995). The original scale is broken down into four sections and contains a total of 72 questions.

For the purposes of this study, only the third section of the scale was used. This is because this specific section is the only one that measured psychological empowerment, this section did not rely on any other section to determine scoring, and because taking the entire four sections would be too time and mentally taxing. This single section consists of 16 questions in which participants are asked to choose the answers that best describe them. A total of 4 questions were modified for the purposes of this study (see Table 2), question order was left alone. The questions that were modified were related to specific goals such as doing well in school and getting what the individual wants. These items were modified to reflect the educational goals of the study. A staff member from CP Rochester read over the modified scale to ensure that each item would be easy for the participants to understand. Both the unmodified and modified versions of the scale can be found in Appendix G and H respectively.
Table 2: Side-by-side comparison of the modified questions from The Arc's Self-Determination Scale. The highlighted text indicates the portion that was changed in each item.

Findings from Iteration 1 that Informed Larger Study

Overall our study findings confirmed that adults with intellectual disabilities can design and create their own e-textiles within the process we employed. Specifically, participants were able to use knowledge gained from the workshop to understand how the circuits worked. In addition, exposure to the workshop encouraged enthusiasm among participants to learn more and suggest other ways that e-textiles could be utilized.

In the second session both participants successfully made electrical connections by themselves or with minimal assistance. If the participant did request assistance, it was typically because the task at hand required more control over fine motor movements than they were capable of doing themselves; which is something that both participants struggled with. By the end of the second session, both participants were able to accurately identify the different components of their circuit, and successfully described how each piece of the circuit interacted with each
P1 participant found the circuit puzzle easy while P2 found it to be more challenging. By the third session, both participants were able to reference their circuit puzzle to figure out how the next connection needed to be sewn for their e-textile. By the end of the third session, both participants successfully created their own working e-textiles (see Figure 8). Both participants chose to use a switch input but opted to use different outputs. P1 chose to use LEDs while P2 chose to use a speaker.

![E-textile artifacts created by the participants during Iteration 1 of the workshops; P1 created a bracelet (left) and P2 made a pendant (right).](image)

By the end of the project both participants thought of many potential uses for e-textiles. One participant (P1) considered how it might help her with her own disability. Both participants felt that they would be able to create a new e-textile if given a kit and a circuit puzzle, although they expressed that a picture of the completed circuit would be helpful for reference. One of the participants (P2) stated that the large size of the circuit puzzle pieces made the puzzle easy to assemble.

Iteration 1 of the workshops helped point out flaws in the original methodology and
informed changes for the future iterations of the study such as influencing the development and subsequent usage of the demo board and through the addition of measures to attempt to measure whether any participants gained some sense of empowerment. Both participants from this iteration were able to successfully create their own e-textiles while appropriately using the circuit puzzle as a guide during the sewing phase of e-textile development, with little assistance from the researcher. This along with post session interviews showed that the content of each session and the overall breakdown of the study did not overwhelm the participants with information, supporting the idea of breaking the development process into smaller pieces (Giles et al., 2018). Data collected from audio transcriptions provided unique insights into how people with disabilities imagine using this type of technology in ways that relate to their own lives, sometimes their own disability.

**Data Collection**

Data was collected during each session via field notes and audio recordings. Pictures were also taken of the participants’ final artifacts and throughout the workshop sessions to show various ways in which participants interacted with their circuit puzzle and e-textiles in general.

**Additional Data Collected in the Second Iteration**

In the second iteration of the workshops, show-and-tell presentations were utilized to gauge whether participants gained enough from this process to be more confident in making, discussing, and using electronics and whether they felt a sense of empowerment or agency within the maker community.
Additional Data Collected in Third Iteration

In the third iteration of the workshops we used third section of The Arc’s Self-Determination Scale to try to measure whether participants gained a sense of empowerment by the end of the workshop sessions. Pre-and-post tests were conducted at the end of the first session after they have been exposed to e-textiles and have decided what kind they are going to make, and at the end of the third and final session after they had finished creating their own e-textile. No survey responses had to be thrown out or cleaned up; participants were able to follow the survey instructions and select one statement per item in the scale for both the pre and post surveys.

Data Analysis

After each session the researcher reflected on observations made during the session. Audio recordings were transcribed and qualitatively analyzed using grounded theory (Strauss & Corbin, 2015); the initial codes map can be found in Appendix E. We used open coding to code the sessions and then used axial coding to generate the main themes of our findings which include: empowerment, transferability of knowledge gained, and the effectiveness of a puzzle as a metaphor. Professor Shinohara was consulted several times during this coding process to help brainstorm emerging themes and patterns. We also constructed timelines from analysis of audio recordings from the second and third iteration of the workshops to reflect on how participants performed in different tasks throughout sessions 2 and 3 and when they needed assistance and what kind. The timelines for sessions 2 and 3 can also be found in Appendix E. Pictures of the participants during the workshops and of the final e-textile artifacts were also collected. The types of objects as well as the chosen inputs and outputs
were also recorded. The pre- and post- scores of The Arc’s Self- Determination Scale were also compared for the participants in the third iteration of the workshops. Analysis focused on assessing participant’s understanding of how their circuit works and of basic electronics concepts, analyzing how participants interacted with the circuit puzzles during the assembly process, and their thoughts about the e-textile development process and about e-textile technology in general.
Chapter 5. Findings

This section reports on the results from all iterations of the workshop sessions. In this section we report on the types of objects participants made as well as the most commonly chosen inputs and outputs. The findings indicate that learning is progressive between sessions and with some assistance, participants were able to learn and retain knowledge from previous sessions and apply that knowledge in future reliant tasks. However, participants did have trouble understanding how to apply the rules of a typical puzzle to the circuit puzzle itself. We also found that positive reactions during sessions, the types of objects made and the motivation behind them, ideas of future uses for e-textiles, and positive indicators from the survey instrument gave some sense that participants gained a sense of empowerment from the workshops.

Workshop Artifacts

In this section we provide a brief analysis of the artifacts that participants made during these workshop sessions. All participants, including those from Iteration 1 of the, successfully completed their own e-textile project from the ideation phase to the final e-textile. All of the artifacts made throughout the course of this study can be seen in Table 3.
<table>
<thead>
<tr>
<th>Participant</th>
<th>Artifact</th>
<th>Object</th>
<th>Input + Output Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Bracelet</td>
<td>Switch and LED</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>Pendant</td>
<td>Switch and speaker</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>Clown</td>
<td>Button and speaker</td>
<td></td>
</tr>
<tr>
<td>P4</td>
<td>Bracelet</td>
<td>Color sensor and LED</td>
<td></td>
</tr>
<tr>
<td>P5</td>
<td>Modified her tv remote bag</td>
<td>Button and LED</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>---------------------------</td>
<td>----------------</td>
<td></td>
</tr>
<tr>
<td>P6</td>
<td>Modified his pencil case</td>
<td>Button and Speaker</td>
<td></td>
</tr>
<tr>
<td>P7</td>
<td>Fish</td>
<td>Switch and speaker</td>
<td></td>
</tr>
<tr>
<td>P8</td>
<td>Headband</td>
<td>Button and LED</td>
<td></td>
</tr>
<tr>
<td>P9</td>
<td>Headband</td>
<td>Color sensor and LED</td>
<td></td>
</tr>
</tbody>
</table>
Overall between all iterations of the workshop, the most commonly chosen input was a button (N=5), followed by a switch (N=3), and lastly the color sensor (N=2). While the most commonly chosen output was an LED (N=6), followed by the speaker (N=4), and vibrating disc (N=0).

The types of objects participants made were sorted into four categories: clothing, art, modification to pre-owned object, or functional. Overall, five participants chose to create wearable items (P1, P2, P4, P8, P9), two chose to make interactive art projects (P3, P7), two chose to add an aesthetic item to an object they already owned (P5, P6), and one participant chose to create something functional (P10). Both of modifications to pre-owned items were for cosmetic purposes, however P5 did think about how she could potentially modify her e-textile even further to help her with a problem she frequently faces at home in the final session.

**Retainment and Transferability of Knowledge**

Overall, with some help participants were able to use their circuit puzzle to successfully create a prototype of the circuit that will be integrated into their e-textile. Participants did experience
some difficulty in understanding how the rules of typical puzzles apply to the circuit puzzle, but most participants were able to assemble their puzzle with limited assistance. Participants also had difficulty understanding how to use the lines to make the electrical connections, but most only required a single explanation or reminder to understand how to use the lines.

Colored lines alone are not an intuitive way to map connections between two components. Overall, at least at one point in either session 2 or session 3, all participants either required a short explanation or reminder on how to use the lines to make the connections for their circuit. In the second session all participants required some initial explanation on how to connect the different components using the lines drawn on the puzzle pieces. However, in the third session only three participants (P6, P7, P10) required a reminder of how to use the lines.

However, all participants were able to use their circuit puzzle to determine how to make the connections on their e-textile in the third session. In fact, one of the participants (P8) realized that their e-textile mirrored the circuit they made in the second session exclaiming “They’re the same!” before the researcher had started explaining that the circuit she made in the previous session and the circuit she was about to sew were the same. Furthermore, P8 was able to understand that the connections would be the same between the two circuits and completed the e-textile circuit without any errors.

The main circuit concepts covered during the workshop sessions were the different component names and simplified explanations of how they work, what electrons are, what power and ground are, and how the circuit’s components “talk” to each other. All in all, by the end of the workshop sessions all participants were able to identify the different components of their
circuits, but not every participant was able to identify power and ground (P9, P10).

By the end of the final session, five of the participants (P3-5, P7, P10) could explain how their circuit worked by themselves. The other three participants could describe how their circuit works but only if prompted each step. For example, the following is an excerpt from P8’s explanation of how their circuit works with the researcher prompting them for each next step.

**Participant:** I start it
**Researcher:** Ya, how do you start it?
**Participant:** By pressing this
**Researcher:** What happens after you press it? **Participant:** It tells the brain I pressed it **Researcher:** Ok then what happens?
**Participant:** I’m thinking…
**Researcher:** What does the brain tell the output to do?
**Participant:** The light? It tells it to start going
**Researcher:** Ya it tells the light to turn on and start cycling through the colors

**Using a Puzzle as a Metaphor**

Some participants did express confusion while using the puzzle pieces. Participants mainly faced one of three issues: not using all three pieces, not understanding that all of the edges of the completed puzzle should be straight and stacking the pieces vertically on top of each other instead of aligning the pieces together, flat on the table. Three out of the eight participants (P3, P5, P7) were confused by the fact that they had to use all three pieces. Additionally, three participants (P5, P8, P10) had trouble understanding that the final shape of the pieces put together should be a rectangle or that all of the edges around the pieces should be straight. One participant (P9) didn’t initially understand that the flat sides of the puzzle pieces were the bottoms of the pieces and that they should all be lying flat on the table by the end of the puzzle’s assembly. Initially P9 began by stacking the pieces on top of each other and flipping
the pieces so the wrong sides (see Figure 9) were facing upwards. Each of these reflect a different paradigm of a puzzle that participants struggled to relate to their circuit puzzle.

Figure 9: Pictures of how P9 stacked pieces on top of each other and with the some of the pieces flipped upside down.

Summary of the Overall Effectiveness of the Circuit Puzzle

In summary, regarding the first three research questions:

**RQ1:** *Is a circuit puzzle an effective way of enabling participants with ID to assemble and make the necessary electrical connections for a prototype circuit with limited help?*

No, participants experienced difficulties with both the assembly and making the electrical connections. Some aspects of the puzzle metaphor that we were trying to leverage did not seem to be effective. Participants still experienced some trouble fitting the pieces together in the correct form by ignoring the rule of a puzzle that all edges should be straight, some were confused how to line up the colored connection lines to figure out which pieces fit together, and some were even confused that they had to use all three pieces of their circuit puzzle. One participant even stacked the puzzle pieces on top of each other and ignored the fact that there were tops and bottoms to the circuit puzzle pieces. Additionally, using the colored lines as a
way to represent how to connect components was not intuitive for the participants. However, with limited help participants were capable of understanding how to use the lines to make the electrical connections and most were able to retain this knowledge between the second and third sessions, with only three participants requiring reminders at the beginning of their final session.

**RQ2:** *Are participants able to use their circuit puzzles as a reference to correctly identify the electrical connections that need to be made for the e-textile’s circuit?*

Yes, participants were able to understand that the connections they made in the second session for their circuit prototype are the same they needed to make for their final e-textile, and were able to use their puzzle to figure out how to make each specific electrical connection.

**Q3:** *Does a circuit puzzle aid in the understanding of basic circuit-related concepts?*

Overall it seems as if the circuit puzzle did help aid with the understanding and recognition of basic circuitry related concepts. One area where the puzzle metaphor did help was with forcing the components into a specific order which happened to reflect how the circuit behaved. This aided in a participant’s understanding of how their circuit worked. By the end of the workshops all participants could identify each different component of their circuit and all but two participants were able to identify power and ground. Also, by the end of the workshops all but three participants were able to describe how their circuit functioned without prompting.
Empowerment

During the first workshop session a baseline was established with each of the participants to understand their past experiences and initial impressions of this unfamiliar technology. Participants were first asked whether they have ever done an science, technology, engineering, or math project before either in their adult basic education courses or elsewhere, and if not, why? Prior to this study, none of the participants have ever participated in a STEM project. As for the reasons why, all of the participants’ responses were along the lines of “The opportunity never came up” (P5, P7, P8, P9), “I didn’t think I could do an engineering project” (P3, P4, P6), or “I’m not like that” (P10).

Most participants (all but P4, P6, P10) conveyed positive reactions when interacting with the demo board. Lastly, one participant (P3) when asked if she could think of any alternative uses for e-textiles other than what she had been shown or told, her response was to help people by “encouraging them.” When questioned about what this was encouraging to people to do, she responded with “tricks.” The lead researcher then pointed to the circuits on the demo board and asked her if these were tricks, and she said “yes.” For further clarification, the participant was then asked “so [e-textiles] are encouraging them to play with electronics?” To which she confirmed with a “yes.” For most of the other participants the concept of imagining other uses for e-textiles was still a very abstract notion. Most of the participants couldn’t think of an answer for this question at this point in the study. P3 did think of an e-textile that could monitor one’s pulse while P5 thought of somehow incorporating GPS and location services into an e-textile; potentially as an alternative way of receiving directions.
During the second session all participants expressed a positive reaction when their final circuit prototype worked. Six out of the eight participants (all but P5 and P9) expressed a positive reaction when their final e-textile worked by the end of the third session. By the end of the third session half of participants said that this experience increased their interest in STEM. Five of the participants thought they could repeat this process over again with a new circuit puzzle (P3, P5, P7, P8, P10) while the other three (P4, P6, P9) believed they would not be able to repeat this process.

Overall there was some concern over the adaptation of this new technology. Several participants including P6, P7, and P9 verbalized concerns over whether or not they would be able to actually use their e-textile. Some of their concerns are problems that we are already trying to think of solutions for, such as making the on/off switches on the microcontrollers more accessible. Other concerns regarded the item’s durability, what happens if it gets wet, and questions about the e-textile’s battery (both battery life and charging). Four participants (P3, P5, P7, P10) were also able to think of other uses for e-textiles or sensors they would like to see integrated with this technology. These ideas included another idea of an interactive art piece, a patch for clothes or a bags, and a cup koozie; these ideas were primarily focused on aesthetics. The other four participants were not able to think of other ways e-textiles could be used.

The Arc’s Self-Determination Scale was administered in the third iteration of the workshops at the end of the first session and at the end of the final session. Scores are determined based on what the participant selects for each of their responses. Responses were scored a 1 if the item the participant selected reflects “psychological empowerment (e.g. believes in ability,
perceptions of control, and expectations of success). Responses were scored with a 0 if they selected an answer that does not reflect psychological empowerment. For this scale, the higher the score the more empowered the individual (min=0, max=100). Out of these four participants, two of the participants’ scores remained unchanged (P7 and P9).

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pre score</th>
<th>Post score</th>
</tr>
</thead>
<tbody>
<tr>
<td>P7</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>P8</td>
<td>88</td>
<td>94</td>
</tr>
<tr>
<td>P9</td>
<td>88</td>
<td>88</td>
</tr>
<tr>
<td>P10</td>
<td>75</td>
<td>81</td>
</tr>
</tbody>
</table>

*Table 4: Participant pre- and post-test scores*

For the two participants whose scores did change (P8 and P10), both participants selected one fewer of the response featuring an answer that *does not* reflect psychological empowerment within just the modified questions. Overall, this could potentially indicate that some participants gained some sense of empowerment from the three, but the sample size is too small to extract meaningful results from. From using this instrument, we were able to confirm that the scale items still remained easy enough for this population to understand after the modifications. However, we would like to find another scale that focuses more directly on the participant’s goals.

However, some participants’ negative reactions may have had an effect on whether they felt empowered or not during this process. For instance, in the second session P9 expressed
frustration during the circuit puzzle assembly process. This participant had the most trouble relating the properties of a puzzle to the circuit puzzle by flipping pieces upside down and stacking them. P9 had a negative reaction during the second session during which he stated “I’m not very good at putting them together… I mean I’m trying but I’m not good at it” regarding the puzzle assembly tasks. Similarly, during the third session P9 had a negative reaction during the sewing task and by the end of the session he believed he could not replicate this process of creating an e-textile. In the beginning of the third session P6 also had a negative reaction with the sewing process. His reaction was closely followed by the statement “I can’t imagine that I made it to the third session.” Also, both P6 and P9 believed that they could not repeat this process with a new circuit puzzle.

Summary Regarding Empowerment

In summary, regarding the final research question:

**RQ4:** Do participants gain a measurable sense of empowerment through the process of learning about and making their own unique e-textile?

There are indications that some participants may have expressed some sense of gained empowerment. These indications include thinking of additional uses for e-textiles, thinking of how e-textiles could be applied to help with their own disability, a problem they uniquely face, or to help others. Some participants also had improved scores in the psychological empowerment section of The Arc’s Self Determining Scale each selecting one less question pertaining to making e-textiles between the pre and post administration of the scale.
Form Factor of Puzzle Pieces

In field notes, the researcher recorded that several participants had trouble with their fine motor movements struggled with moving the pieces around more than other participants. Sometimes it looked as if the pieces were too large for them to properly grasp to pick up (see Figure 10a). When this happened participants typically shuffled the pieces along the surface of the table. During the second workshop sessions, two participants (P1 and P10) asked me to move the pieces around for them. However, several participants (P3, P6, and P8) had better control over their fine motor movements, commented about how the large size of the pieces made it easier for them to move them around. Participants primarily moved the pieces around by picking them up and placing them back down on the table, or by shuffling the pieces around on the table (see Figure 10a-b).
Overall this, and similar workshops need to consider ways we can make some of these tasks less dependent on fine motor control or think of workarounds so participants can go through this process with more independently.
Chapter 6. Discussion

Effectiveness of the Circuit Puzzle

Overall, there are ways in which the circuit puzzles seem to be effective and other areas in which the design can be improved. The circuit puzzle pieces are not intuitive enough to be used alone without some level of help. Many participants had trouble during the second session when it came time to assemble their puzzles. The puzzle metaphor might not be strong enough for this type of assembly activity because participants struggled to apply the rules of puzzles to the circuit puzzle.

The lack of feedback when connecting two of the puzzle pieces together may hamper the participants’ understanding of whether they did the task correctly or not. In a typical puzzle there is usually some feedback associated with correctly fitting two puzzle pieces together like with regular puzzles or with snap circuit kits where components snap or repel away from each other leveraging the properties of magnet.

The lines are not immediately intuitive enough for participants to understand that they relate to the way the components need to be connected. In all three iterations of the study, participants required some assistance interpreting how to use the lines to guide where they paint or place alligator clips, but all ten participants were able to make the appropriate electrical connections once they received some initial explanation. When participants needed help, typically a single reminder of how to use the lines was enough for most of the participants to understand or recall how to use the lines to connect the components. This demonstrates how the lines may not be intuitive initially, but with a small amount of
instruction participants can make logical sense regarding the information they are trying to “convey.”

During the sessions the puzzle pieces seemed to be an effective tool for using as a reference when constructing the final e-textile circuit. All participants were able to understand that the connections they made in the prototype circuit in the second session mapped to the same connections in their final circuit. However, three participants in the main workshop sessions thought they wouldn’t be able to replicate this process on their own again.

The puzzle format constrained the pieces to a uniform format that reflect the “order of operations” of the circuit. It begins with the input being triggered in some form, some information is passed to the microcontroller, and then the microcontroller instructs the output how it is supposed to behave. It was important to have clear mapping between what the participant is doing and the output of the circuit (Falcão & Price, 2012a). There were a lot of positive reactions expressed by participants when they would interact with the demo board, or their circuit prototype, or with their final e-textile. This further supports the idea that the feedback needs to be immediate and that the mapping between action and reaction is very important for this population in regards to their understanding of how a system works.

**Empowerment from E-textile Creation**

From the results of this study, we observed that the e-textile creation process has the potential to enable adults with ID to feel empowerment and gain some sense of agency within the
maker community. In this study, some of the ideas that participants generated regarding future potential uses of e-textiles benefitted or solved a problem they experienced in their lives or to help others. For instance, in the first iterations of the workshop P5 wanted to modify her finished e-textile so she could use as a proximity sensor, or like a “hot” or “cold” indicator to let her know if she is getting closer or further away from her tv remote bag; which she frequently misplaces. Similarly, in the first iteration of the study, when participants were asked the same question P1 thought of an e-textile that would help her track information for a medical condition and she said that an item similar to the one she described would be beneficial to others with her disability. And finally, P3 wanted to add a string to her finished e-textile so she could hang it in her room to show people what she’s done. Each of these examples embodies one of the three forms of empowerment that makers with disabilities can experience as described by Meissner et al (2017). P5 wants to act on a problem that exists within her real life, P1 thought of a potential e-textile use for those with a similar disability to her own, and P3 wanted to display the product of her new-found skills. Also, by end of the workshops half of the participants were able to think of additional ways in which e-textiles could be used as well as the general interest shown by participants throughout the sessions; these indicate that this population has an interest in making and becoming creators. Participants’ abilities to think of other ways in which e-textiles could be employed, with their only e-textile exposure limited to the content of the workshops, demonstrates a newfound comfortability and ability to envision other ways in which this technology can be employed. Finding ways in which we can empower this population during the making process is important to reinforce their confidence in their abilities as well as their sense of agency within the maker community.
However, participants’ expression of negative emotions comparable to frustration and self-doubt during the e-textile development process may have influenced their perceptions of their own capabilities as makers or belonging in the maker community.

For instance, both P6 and P9 both expressed frustration at one point during the workshop (either during puzzle assembly or sewing process), verbally expressed doubts in their own abilities, and did not think they would be able to replicate this process if given a new circuit puzzle.

**Accessibility of the Workshops**

The modifications that we made to the components in an attempt to make this task a bit more accessible was not enough. The participants who never had prior sewing experience found the task challenging; only some conveyed emotions of frustration. Overall, this suggests that an alternative connection method for final e-textile should be further explored. My original idea of significantly expanding the surface area through which stitches are made through did not seem to increase ease of task. It would be interesting to explore alternative ways to connect components in the puzzles as well. The paint would sometimes take a long time to dry and the alligator clips were difficult for some of the participants with limited fine motor skills to use.
Chapter 7. Limitations

One limitations of this study was the small population size. Due to the small population size both of the empowerment measures only had four participants in each method (the show and tell presentations or The Arc’s Self-Determination Scale, Section 3), and four is far too few participants from which conclusive results can be drawn; especially since one of the measures was modified. Four participants are not enough to ensure the internal validity of the original scale was not compromised.

Another limitation is how the show and tell presentations were conducted. In the show and tell presentations, participants’ presentations typically consisted of what they could remember of how their circuit worked followed by a brief description of what they chose to make. The staff member listening to these presentations didn’t really ask any follow-up questions or prompt participants to talk more about the motivations behind their project or their feelings regarding this experience. If this study were to be repeated, the workshop structure should be changed to allow for two participants and one researcher per session, so participants feel more comfortable admitting when there’s something they don’t understand and can rely on their partner as well for help and support. This would also help with idea generation and allow participants to talk about a complex topic more comfortably (Zolyomi, Gotfrid, & Shinohara, 2019). If the show-and-tell presentations were conducted differently, such as in a small-group setting or pairs where participants could build off of what each other said, helped participants feel more comfortable talking about complex topics and with idea generation, and to provide deeper, more meaningful answers to some of the motivational questions.
Chapter 8. Conclusion and Future Work

This work presents the results from a participatory design study conducted with adults with ID to assess how a circuit puzzle can aid in the circuit prototyping phase of an electronics project and whether these participants can map the electrical connections from their puzzle to their actual e-textile. This study also examined whether this process empowered participants in any way making them feel a sense of agency with the maker community.

The results of this study show that adults with ID are capable of creating e-textiles using circuit puzzles as a modified circuit prototyping technique, but some initial help is required. Most participants were able to go through all the phases of making that hobbist makers typically perform in their own electronics projects (e.g. deciding upon circuit components, outlining how the circuit is intended to behave, building a prototype of the circuit, and finally creating the final circuit) with minimal help. Participants could successfully use the circuit prototype they developed in the second session to determine how their final circuit for their e-textile needed to be connected. The results also suggest that some participants may have gained a sense of empowerment or feeling of agency within the maker community through this workshop process.

Future design recommendations for introducing e-textiles to those with learning or cognitive disabilities includes breaking the information up into smaller sections that increase in complexity as participants become more familiar with the subject matter and the importance of taking the physical limitations of your participant into account. In this study, participants were able to recall information between sessions, indicating this population is capable of
understanding and remembering chunks of complex topics, and building upon this knowledge as the sessions continued. A few participants experienced difficulties performing some of the tasks that required more fine motor skills and subsequently some expressed negative emotions during their sessions. This may have contributed to a participant’s feeling of not belonging or lack of confidence in their own abilities; so finding a way to make some of these tasks more accessible is immensely important.

Future work would include resizing and shaping the puzzle pieces. The puzzle pieces’ shape so that the pieces are a bit smaller to make them easier for participants with limited mobility to more comfortably grasp and maneuver One pair of knob and holes on the puzzle pieces should be reshaped. This may help ease some of the difficulty that participants faced during the puzzle assembly process. Another idea would be to color the bottoms a solid color as another way to differentiate the top of the puzzle piece from bottom. Alternative connection methods should also be explored to make the process of bridging the electrical connection between components easier and make this part of the e-textile creation process less frustrating and more accessible.

Apart from modifying the form factor of the kit pieces, future work would investigate how to incorporate this process into an app. An ideal e-textile creation kit for people with intellectual disabilities would include modifying the form factor of the pieces and make sure that the pieces only fit in some constrained way to reinforce the circuit’s “order of operations.” This would also include some perceivable feedback to alert the user when they have connected the pieces correctly together. This kit would also contain an accompanying app that would utilize augmented reality to allow participants to make the connections and
see their circuit work in real-time, learn and use block programming to modify how their circuit behaves in real-time using block programming.

With this kit, participants would put the component pieces together then use augmented reality to make the electrical connections in the app. Making the connections on a tablet screen would require less fine motor control than using conductive paint or the alligator clips, thereby allowing the participant more opportunities to complete the required tasks independently and rely less on others for help. The app would also overlay a real-time representation of how the electrons and signals move through the circuit. This real-time visual representation of what is happening inside of the circuit could potentially also help with aiding in the understanding the concepts such as power, ground, and how electrons move through circuits in general (Chan et al., 2013). The app would also act as a reference for when making the final e-textile connections. This app could also include elements of block programming so participants could see how different programming aspects impact how their circuit behaves, also in real-time.
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Appendix A: IRB Study Approval and Modification Forms

Form C
IRB Decision Form
FWA# 00000731

TO: Taylor Gotfrid
FROM: RIT Institutional Review Board
DATE: June 7, 2018
RE: Decision of the RIT Institutional Review Board

Project Title: E-textiles for Adults with Intellectual Disabilities

The Institutional Review Board (IRB) has taken the following action on your project named above:

☑ Approved, no greater than minimal risk

Now that your project is approved, you may proceed as you described in the Form A. Note that this approval is only for a maximum of 12 months; you may conduct research on human subjects only between the date of this letter and June 7, 2019.

You are required to submit to the IRB any:
- Proposed modifications and wait for approval before implementing them,
- Unanticipated risks, and
- Actual injury to human subjects.

Return the Form F, at the end of your human research project or 12 months from the above date. If your project will extend more than 12 months, your project must receive continuing review by the IRB.

Continuing review of research and approval of research studies is required so long as the research study is ongoing, that is, until research-related interactions and interventions with human subjects or the obtaining and analysis of identifiable private information described in the IRB-approved research plan have been completed.

Investigators are responsible for submitting sufficient materials and information for the IRB to meet its regulatory obligations, and should follow the institutional policies and procedures for continuing IRB review of research that are required by HHS regulations at (45 CFR 46.102(b)(4), 45 CFR 46.109(e), 45 CFR 46.115(a)(1)) as appropriate to the research activity.

Heather Foti, MPH
Associate Director
Human Subjects Research Office

Revised 08.17.2017
Form C
IRB Decision Form
FWA# 00000731

TO: Taylor Gotfrid
FROM: RIT Institutional Review Board
DATE: August 7, 2018
RE: Decision of the RIT Institutional Review Board

Project Title – E-textiles for Adults with Intellectual Disabilities

The Institutional Review Board (IRB) has taken the following action on your project named above:

☑ Approved, no greater than minimal risk

Amendment Changes
   1. Population Change

Now that your project is approved, you may proceed as you described in the Form A. Note that this approval is only for a maximum of 12 months; you may conduct research on human subjects only between the date of this letter and June 7, 2019.

You are required to submit to the IRB any:
   • Proposed modifications and wait for approval before implementing them,
   • Unanticipated risks, and
   • Actual injury to human subjects.

Return the Form F, at the end of your human research project or 12 months from the above date. If your project will extend more than 12 months, your project must receive continuing review by the IRB.

Continuing review of research and approval of research studies is required so long as the research study is ongoing, that is, until research-related interactions and interventions with human subjects or the obtaining and analysis of identifiable private information described in the IRB-approved research plan have been completed.

Investigators are responsible for submitting sufficient materials and information for the IRB to meet its regulatory obligations, and should follow the institutional policies and procedures for continuing IRB review of research that are required by HHS regulations at (45 CFR 46.102(b)(4), 45 CFR 46.109(e), 45 CFR 46.115(a)(1)), as appropriate to the research activity.

Heather Foti, MPH
Associate Director
Human Subjects Research Office

Revised 08.17.2017
Appendix B: Consent Form

E-TEXTILES FOR ADULTS WITH INTELLECTUAL DISABILITIES

INTRODUCTION

You are invited to join a research study that explores co-designing e-textiles with individuals with cognitive disabilities. Please take whatever time you need to discuss the study with your family and friends, or anyone else you wish to. The decision to participate or not to participate is up to you.

In this research study, we are evaluating the effectiveness and accessibility of a co-designing method to create e-textiles.

WHAT IS INVOLVED IN THE STUDY?

If you decide to participate you will be asked to design an e-textile. We expect this to take 2.5 hours over three separate sessions. The first session should take around 30 minutes, the second session should take around 30 minutes, and the final session should take around 90 minutes.

In the first session you will be introduced to different types of e-textiles and decide what kind of e-textile you will want to make. You will get to choose the type of fabric you want to use as the base and what you want the e-textile to do (e.g. flash lights in different patterns when a button is pressed).

In the second session you will construct a basic circuit. To construct the circuit you will put puzzle pieces together, where each has a different piece of the circuit on it. Circuits have different pieces and usually wires connect the pieces to make the circuit work. After you put the pieces together you will use conductive paint to act like wires in this circuit. The conductive paint will connect the pieces of the circuit together and make it work. Once you use the conductive paint you will get to see your circuit work.

In the third session, you will be creating an e-textile, building on the activities from the first and second sessions. When you make this circuit you will be using conductive thread instead of conductive paint. You will use the conductive thread to replace wires in this circuit and you will use the thread to sew connections between each of the pieces of the circuit.

If a break is needed at any point during any of the three sessions, we will take a short break.

We will audio and video record this study so that we have an accurate record of your activities and reactions during each session. These recordings will be assigned a study code and will be stored for 2 years. These recordings will only be shared with other researchers associated with this project. If these videos are used in presentations or publications, your face will be blurred.

You can stop participating at any time. If you stop you will not lose any benefits.

RISKS

During this study you may feel pressure, stress, or frustration. There is also a small risk of electrical shock. There may also be other risks that we cannot predict. We can take breaks during the study, but
you may indicate you want to take a break at any time during the study. If you do not want certain information captured as part of this study, please let us know and we will remove it from the data.

BEurreTO TAKING PART IN THE STUDY

In participating in this study there is no direct benefit for you, but it may help future researchers make the design process of e-textiles more accessible.

CONFIDENTIALITY

Your participation in this study will be kept confidential. The data gathered in this study will be confidential. The data associated with you will be referenced by a participant number. The list linking your name to your identifying participant number will be kept in a separate, password protected computer than the data. All of the data gathered during the experiment will be kept in a password-protected folder that only the researchers have access too. All images or videos that may be used for publications will have faces and any other identifiable information blurred.

INCENTIVES

For participating in this study, you will receive $15 per hour. You will also be compensated for any travel costs to the study site. This study is completely voluntary, you may withdraw from this study at any time. If you choose to withdraw from the study after the session has begun, you are still entitled to $15 per hour compensation.

YOUR RIGHTS AS A RESEARCH PARTICIPANT

Participation in this study is voluntary. You have the right not to participate at all or to leave the study at any time. Deciding not to participate or choosing to leave the study will not result in any penalty or loss of benefits to which you are entitled, and it will not harm your relationship with your day center or RIT.

CONTACTS FOR QUESTIONS OR PROBLEMS

Call Taylor Gotfrid at (707) 328 - 3314 or email Kristen Shinohara at kristen.shinohara@rit.edu if you have questions about the study, any problems, unexpected physical or psychological discomforts, any injuries, or think that something unusual or unexpected is happening.

Contact Heather Foti, Associate Director of the HSRO at (585) 475-7673 or hmftrs@rit.edu(link sends e-mail) if you have any questions or concerns about your rights as a research participant.
<table>
<thead>
<tr>
<th>Consent of Subject</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Signature of Subject</td>
<td>Date</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consent of Legally Authorized Representative</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Signature Subject Representative</td>
<td>Date</td>
</tr>
</tbody>
</table>
Appendix C: Assent Form

Project Title: E-textiles for adults with intellectual disabilities

Investigator: Taylor Gotfrid

We are doing a research study about how to make designing e-textiles more accessible. E-textiles are fabrics that have circuits integrated in them like a shirt that lights up or a wristband that vibrates. A research study is a way to learn more about people. If you decide that you want to be part of this study, you will be asked to interact with some existing e-textiles, decide what kind of e-textile you want to make, put a circuit together, and create your e-textile. This will occur over three sessions. The first two sessions will take 45 minutes and the last session will take 1.5 hours.

There are some things about this study you should know. These are the procedures: in the first session you will interact with some e-textiles, decide what kind of e-textile you want to make, and answer some questions. In the second session you will put a circuit together, see how it works, and answer some questions. In the third session you will create your e-textile and answer some questions. Creating your e-textile in the final session may take a long time. During the study you may feel pressure, stress, or frustration. There is also a small risk of electrical shock. You can indicate that you want to take a break at any time during the study.

In participating in this study there is no direct benefit for you, but it may help future researchers make the design process of e-textiles more accessible.

When we are finished with this study we will write a report about what was learned. This report will not include your name or that you were in the study. It may include a picture of you but your face and any identifying marks will be blurred.

You do not have to be in this study if you do not want to be. If you decide to stop after we begin, that’s okay too. Your parents/guardians know about the study too.

If you decide you want to be in this study, please sign your name.

I, ________________________________, want to be in this research study.

__________________________________  __________
(Sign your name here)                  (Date)
Appendix D: Session Protocols

Session 1 Protocol

1) Go over consent/assent form
2) Ask if they have any questions
3) Gather demographic data and introductory questions
4) Explain what e-textiles are
5) Show demo board
   a) Explain that each is its own circuit
   b) Explain the different parts
   c) Demonstrate each circuit
   d) Have participants explore the circuits on the demo board on their own
6) Discuss what input/output combo they would like to use
7) Discuss what kind of object they want to make
8) Discuss next steps
9) Administer the Self-Arc survey*

* This step was only performed in the second iteration of the workshops

Session 2 Protocol

1) Explain the different parts of the circuit and what they do
   a) The power source
   b) The brain (or the microcontroller)
   c) The switch (e.g. button, tilt switch)
   d) The output (e.g. LED, speaker)
2) Explain how conductive paint or alligator clips work
3) Give the participant the task of putting the circuit together
   a) Puzzle piece format
      i) The puzzle will consist of four pieces of foamcore each with a single component
         for the circuit glued on top. The circuit components need to be placed in a
         particular order so that the circuit can work once the conductive paint is used to
         make the electrical connections. So each foamcore puzzle piece will be cut in a
         way that they can only “fit” or be placed in the correct order.
   b) Conductive paint will be used to make the electrical connections between
      the components.
   c) Different colored markers or tape will outline where the conductive paint needs to go
      to make the electrical connection between each component of the circuit (e.g. red
      marker to indicate the connection between power, blue for ground, green for input of
      signal) on each puzzle piece.
   d) Once the puzzle pieces of the circuit have been put together in the correct order, the
      researcher will put the battery into the circuit and the participant will be able to see
      how the circuit works.
Session 3 Protocol

1. Explain what conductive thread is (the equivalent of conductive paint/alligator clips used in Session 2). Explain how to sew with conductive thread and how to make connections between the sensors.
2. Participants will have the circuit they built in Session 2 as reference.
3. Give the participants the fabric with the sensors glued or sewn on.
4. Have the participant use conductive thread and sew the circuit together.
5. Debriefing session.*

*In the first iteration of the workshops this included the show and tell presentation. In the second iteration of the workshops this did not include the show and tell presentations and instead included a post administration of the Self Arc survey
Appendix E: Changes Made Between Each Workshop Iteration

Here is a summary of all the changes made between each iteration of the workshops.

Changes made between Iteration 1 (Pilot) and Iteration 2 of the Workshops
- Changes made to Session 1
  - Instead of showing completed e-textiles I made the demo board as an alternative way to showcase the different inputs and outputs that participants would choose from
- Changes made to Session 2
  - None
- Changes made to Session 3
  - Added the show and tell presentations to the end of the session

Changes made between Iteration 2 and Iteration 3 of the Workshops
- Changes made to Session 1
  - Collected pre-survey data for The Arc’s Self Determination Scale
- Changes made to Session 2
  - None
- Changes made to Session 3
  - Removed the show and tell presentations to the end of the session
  - Collected post-survey data for The Arc’s Self Determination Scale
Appendix F: Initial Codes Map and Session Timelines

Qualitative Analysis
Participant Color Key

Participant 3
Participant 4
Participant 5
Participant 6
Participant 7
Participant 8
Participant 9
Participant 10
All Participants
Researcher

This is the participant’s color key for the initial codes map and for the session 2 and session 3 timelines.
All Workshop Session 2 Timelines
### Appendix G: Original Arc’s Self-Determination Scale

<table>
<thead>
<tr>
<th>Appendix G: Original Arc’s Self-Determination Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 3: Psychological Empowerment</td>
</tr>
</tbody>
</table>

#### Directions:
Check the answer that BEST describes you. Choose only one answer for each question. There are no right or wrong answers.

#### Section 3 Subtotal: 147

<table>
<thead>
<tr>
<th>Item</th>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>I tell my friends when I have new or different ideas</td>
<td>⊗, ⊘</td>
</tr>
<tr>
<td>43</td>
<td>I usually do what my friends want... or want to do</td>
<td>⊗, ⊘</td>
</tr>
<tr>
<td>44</td>
<td>I usually agree with other peoples' opinions or ideas</td>
<td>⊗, ⊘</td>
</tr>
<tr>
<td>45</td>
<td>I tell people when they have hurt my feelings... or</td>
<td>⊗, ⊘</td>
</tr>
<tr>
<td>46</td>
<td>I can make my own decisions... or</td>
<td>⊗, ⊘</td>
</tr>
<tr>
<td>47</td>
<td>Trying hard at school does not do me much good... or</td>
<td>⊗, ⊘</td>
</tr>
<tr>
<td>48</td>
<td>I can get what I want by working hard... or</td>
<td>⊗, ⊘</td>
</tr>
</tbody>
</table>

**Note:** This section includes items related to psychological empowerment, self-determination, and decision-making. Each item is designed to assess the individual's perception of their ability to make choices, express ideas, and manage emotions.
# Appendix H: Modified Arc’s Self-Determination Scale

Check the answer that BEST describes you.

Choose only one answer for each question.

There are no right or wrong answers.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</table>
| 1 | □ I usually do what I want with my friends  
    □ I tell my friends if they are doing something I don’t want to do |
| 2 | □ I tell others when I have new or different ideas or opinions  
    □ I usually agree with other peoples’ opinions or ideas |
| 3 | □ I usually agree with people when they tell me I can’t do something  
    □ I tell people when I think I can do something that they tell me I can’t |
| 4 | □ I tell people when they have hurt my feelings  
    □ I am afraid to tell people when they have hurt my feelings |
| 5 | □ I can make my own decisions  
    □ Other people make decisions for me |
| 6 | □ Trying hard at making my own e-textile doesn’t do me much good  
    □ Trying hard at making my own e-textile will help me learn more about electronics |
| 7 | □ I can make the e-textile I want by working hard  
    □ I need good luck to make the e-textile I want |
| 8  | □ It is no use to keep trying because that won’t change things  
□ I keep trying even after I get something wrong |
| 9  | □ I have the ability to make an e-textile I want  
□ I cannot do what it takes to make an e-textile I want |
| 10 | □ I don’t know how to make friends  
□ I know how to make friends |
| 11 | □ I am able to work with others  
□ I cannot work well with others |
| 12 | □ I do not make good choices  
□ I can make good choices |
| 13 | □ If I have the ability, I will be able to make an e-textile that I want  
□ I probably will not be able to make an e-textile that I want even if I have the ability |
| 14 | □ I will have a hard time making new friends  
□ I will be able to make friends in new situations |
| 15 | □ I will be able to work with others if I need to  
□ I will not be able to work with others |
| 16 | □ My choices will not be honored  
□ I will be able to make choices that are important to me |