Integrating Ability-Based Design in Printed Electronics

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Kimberly Eder

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Abstract

Integrating Ability-Based Design in Printed Electronics
Kimberly Eder
Graphic Communication Department, June 2015
Advisor: Malcolm Keif

The purpose of the study is to determine if a printed electronic device can be adaptable to the visually impaired, the role that accessible design has in the development of printed electronics, and to determine if integrating accessible design prohibits usability and performance. The findings will provide better understanding of how to modify a printed electronic paper device to suit a wider range of end users and the relationship of usability and accessibility in printed electronics

Experts in the field were interviewed to get information and feedback about the project. Also, a human research experiment was conducted. Cal Poly students, from different areas and departments were included to see if, based on the experiment results, an accessibility based design could be integrated into a pre-existing foldable printed electronic and to better understand the role of ability based design in the acceptance of a product.

The analysis of the results indicated that accessible design can be integrated into a pre-existing e-paper to improve the overall usability. However, while accessible design could be beneficial to printed electronics, the integration of accessible design will not be easily integrated until printed electronics has left its infancy stage. Accessible design is not a requirement to printed electronics but as the industry grows, manufactures are expected to create more accessible products. If designers are able to understand the requirements of end users, it can and will lead to better innovative products.

1 Introduction

Emerging Issues of Printed Electronics

Printed electronics is a growing entity in the Graphic Communication world. A copious amount of companies are working on new and exciting interactive products. With new technology comes new challenges. "Design creates culture. Culture shapes values. Values determine the future," advises Robert Peters (personal communication, 2014). With the emergence of printed electronics, it is necessary to avoid poor design and strive for proactive inclusive thinking. Printed electronics can work on creating inclusive and equitable environments that take disabilities into consideration. The problem is that printed electronics can begin to hinder disabled individuals if the designers do not design to include them. Even today, numerous designs are not made for people using screen readers or people with limited motion. These designs reinforce negative stereotypical attitudes towards the handicapped which can be hard for a child to handle. If accessible design is not considered in the prototyping stage, our world will remain or become even more of a hassle for the disabled.

In making the shift to accessible design, designers and inventors can turn away from forcing disabled individuals to conform to inflexible products and instead start to take into account that accessible design starts at the very basic level. For example, consider a user with limited sight capabilities. He or she has three options: struggle to use the product as-is, utilize an add-on accessibility aid software, or choose to buy a specialized braille display designed for people with low or no sight. An accessible design approach would be needed to provide a better suited product. Yet, the challenge against accessible design is not only being able to reliably determine a user's disabilities but being able to design future technologies that better the user's experiences without the need for excessive adaptation. I find that accessible based design can be the key to refining future technologies to make the end user's abilities the central focus.

The goals of this research are to describe what accessible design is, put forward its principles and discuss its roles in printed electronics. This research will also articulate challenges faced by accessible design and advance the conversation of disabilities to include the emerging world of printed electronics.

The Effect of Poor Design Choices on the Disabled

Plenty of designers create products that are designed to service the general population. Disabled individuals are not often considered to be in this group. Unfortunately, this can lead to problems in the future. Currently, companies have started moving many processes from analog to online environments. Processes such as hiring, benefit enrollments, and training are often conducted through the computer. As printed electronics evolve, companies many begin to adapt the technology to ensure all their employees can access the same information. Many problems that arise in implementing printed electronic products relate to unlabeled graphics, large amounts of audio with no breaks or with too many breaks, too small of interactive buttons, a lack of design consistency, overly complex language, or even strobing designs on the pages. All employers must consider what accessibility issues may arise from the new printed electronic products.

While many designers or companies can convolute the meanings of accessibility, it is vital to gain an understanding of what to look for. In order to examine what issues could be presented with the increasing use of printed electronics in everyday life, research is required to explore the present barriers the disabled face and what can be done to prepare companies and disabled individuals to deal with the new emerging issues.

Personal Interest in Emerging Problems

As an aspiring web designer, I know that disabled individuals have a hard time with the Internet. Additionally, my stepmother is disabled and cannot use the Internet because she cannot see most of the buttons and any flashing elements distract her. I can see the direct effect of poor design. It is an atrocity to see the amount of bad accessible design on the Internet and in print media. When I began to read about printed electronics, I thought that it would be great for the disabled to be able to interact with the world around them in a new way. Now pill containers can inform the user what they contain. Doors can be equipped to open when a certain chip is by them, thus eliminating the need for a person in a wheelchair to wait for someone to open the door. Yet, thinking about the idea more, I realized that most of the individuals working with printed electronics are looking for functionality and not necessarily with a breadth of end-users in mind. As a designer, I see the need to have beautiful and functional products that work for a large number of users.

2 Literary Review

Present Barriers Faced by the Disabled

There is a significant lack of accessible design in today's online marketplace, which has created a digital gap between the disabled and non-disabled person. In 2010, the U.S. Census Bureau found that almost one in five people are living with a disability. The growing number of individuals moving through the wide range of disabilities does not look to be diminishing. This is because of the constantly evolving definition of what it means to be disabled. Disability expands beyond physical restrictions to also include the interactions of the disabled with the environment. "Defining disability as an interaction means that 'disability' is not an attribute of a person," explains the World Health Organization (2011).

According to Vanderheidan (1997), a pioneer of universal design, impairment can be categorized into five main types: visual, hearing, physical, cognitive and seizure disorders. Severity varies greatly in each category, which will affect the different barriers presented. To understand how these impairments affect the user, looking at a website might be beneficial. Navigation elements on a website are often problematic for the visual and cognitive impaired. Additionally, a user with a physical impairment will need to be able to navigate the menu using only the keyboard. Those with a hearing impairment struggle with audible control feedback, and flashing elements on a web page can trigger seizure disorders.

Despite these needs being present, products are often created without a consideration for the elderly or disabled and are lacking in necessary accessible design principles. The reasons that accessibility is not embraced can range from the fear of dissatisfied customers to the extra training that designers would require. Organizations face many barriers, which prevent the application of accessible design. Some of the main obstacles against accessible design in the industry are related to perception, technical and organizational barriers (Dong et al, 2004). The European Commission found that these barriers are often problems in the structure of the firm, the negative perceptions of the disabled, and the failure to include end users in the design process (1998). Additionally, some of the barriers include misconceptions, lack of understanding, and an absence of accessibility specifications. However, some of these specifications may be easy to overlook during the design process. Some of the most common problems, according to Human Rights and Equal Opportunity Commission (2000), include websites incompatible with screen readers, interactive menus that advance too quickly, and product information with limited formatting options.

Designers could create more accessible designs with a better understanding of the end user. Because the designers often possess a limited understanding of the user, designs often lack clear menus, adaptable properties, and limited use. Additionally, the lack of documentation of accessible specifications available to a designer lends itself to sub-par products. However, since the late 1990s, accessible design began to be explored through many different types of design principles.

Prior Approaches to Accessible Design

Over the years, assistive technology (AT) has become a buzzword in technology development. AT began to morph into several different definitions as technology advanced, but AT was officially defined by the 105th Congress in 1998. The Assistive Technology Act of 1998 declares "the term 'assistive technology device' means any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities" (Civil Impulse, 2015). This definition framed AT as being an umbrella term used to describe any software or equipment technology that was used to aid a person with a disability. Most of these devices were add-ons and were often criticized for being an after-thought to the product. In general, AT devices tend to force the user to accommodate with the product while the product remains inflexible.

To counteract the polymorphic definition of disability, some organizations suggest the idea of universal design. "Incorporating UD [universal design] processes when developing E&IT [electronic and information technology] is one solution to accommodating people with disabilities that also improves the usability of the products for the rest of the population," (National Council on Disability, 1994). This type of design attempts to design for everyone instead of a particular persona. Of course, there are pools of thought that disagree with universal design. The main argument is the idea that a product can never be equally accessible to everyone.

Universal design is a set of design principles that emerged from the broad category of AT. Geared more towards architecture, these principles create a barrier-free environment using aesthetics. Despite being physically based, many of the main design principles could be applied to a variety of disciplines. Universal design principles look at equitable use, flexibility, intuitiveness, low physical effort, size and space, and a tolerance for error. According to the Center for Universal Design at NCSU, many of the principles "may be applied to evaluate existing designs, guide the design process and educate both designers and consumers about the characteristics of more usable products and environments" (Connell et al., 1997). The problem faced with universal design is that it tends to have a one size fits all ideal. This generally does not work for disabilities because of the various degrees and severity of disabilities. Generally, the idea is that universal design was meant for objects such as door handles and did not take into account prolonged activity with the item in question.

Going one step past universal design and applying design principles to interface design is universal usability. Ben Schneiderman (2000), the pioneer of universal usability in human-computer interactions, proclaims that universal usability is "having more than 90% of all households as successful users of information and communications services at least once a week" (p. 85). The key word in this definition is the phrase "successful use." By not concentrating on any one group in particular, universal usability attempts to reach the widest range of population. Schneiderman (2000) argues that to achieve universal usability, designers must "bridge the gap between what users know and what they need to know" (p.86).

Simon Harper (2007) recently observed the problematic nature of the question of universal usability. Instead of thinking about what everyone can do, it might be more beneficial to think about what a particular person could do. Harper (2007) argued, "in reality, every person is a unique individual and so this view [of universal usability] cannot possibly be sustainable or achievable" (p.111). Over-generalizing

the population can lead to an exclusion of many users. To maximize the effectiveness of universal usability, it is necessary to consider a transformation from design-for-all to design-for-one. For example, when a hearing impaired individual is interacting with a sound file, she may wish to view the sound on screen or print out the sheet music. Designing for this particular user can lead to a better product in the end for everyone by providing these extra services.

Ability-Based Design

Ability-based design could be a viable solution for achieving a design-for-one ideal. It is both a philosophy and design approach, functioning as the opposition to universal design and serving as a catalyst for shifting a designer's central focus (Wobbrock et al., 2011). Ideally, technology should be accessible to all people in any situation at any point in time. Ability based design attempts to achieve this by striving to create technology that is aware and can adapt to specific individual's abilities. By concentrating on the abilities, instead of the disabilities of the end user, throughout the design process, designers can have a clear focus on how those abilities are expressed and can understand the possible changes associated with the context and time. For example, a user could experience a change in his abilities as a result of boredom, disease, medication, and fatigue. Table 1 discusses the seven principles of Ability-Based Design. The principles are broken down into three categories: stance, interface, and system. Of the seven guidelines, only the two found in stance are required to have an ability-based approach while the last two categories are only recommended.

Seven Principles of Ability-Based Design		
1. Ability	Designers will focus on ability not dis-ability, striving to leverage all that users can do.	Required
2. Accountability	Designers will respond to poor performance by changing systems, not users, leaving users as they are.	Required
3. Adaptation	Interfaces may be self-adaptive or user-adaptable to provide the best possible match to users' abilities.	Recommended
4. Transparency	Interfaces may give users awareness of adaptations and the means to inspect, override, discard, revert, store, retrieve, preview, and test those adaptations.	Recommended
5. Performance	Systems may regard users' performance, and may monitor, measure, model, or predict that performance.	Recommended
6. Context	Systems may proactively sense context and anticipate its effects on users' abilities.	Recommended
7. Commodity	Systems may comprise low-cost, inexpensive, readily available commodity hardware and software.	Encouraged

Table 1: "Principles of Ability-Based Design"
Source: http://www.eecs.harvard.edu/~kgajos/papers/2011/wobbrock11abd.pdf

Figure 2: "Dynamic Keyboard Model"
Source: http://www.markinns.com/images/article_images/apple-keyboard-american.png

One type of technology that uses almost all principles of ability-based design is the Dynamic Keyboard Model (Figure 2). Invented by Trewin, it features keyboard typing for users with motor impairments (2004). The principles of ability-based design used by the Dynamic Keyboard Model include: ability, accountability, adaptation, transparency, performance and commodity. According to Wobbrock et al., ability and accountability are the two required principles for an ability-based design (2011). The Dynamic Keyboard Model achieves an ability principle, because, despite experiencing motor impairments, people can use a traditional QWERTY keyboard because of the adaptive typing data. Additionally, the Dynamic Keyboard Model uses the accountability principle because the software accommodates the motor impairments during use of a QWERTY keyboard system.

Trewin also created the Dynamic Keyboard Model with the principles of adaptation, transparency, performance and commodity. By creating helpful keyboard adaptations that are based on the user's naturally occurring typing behavior, the principle of adaptation is met. The Dynamic Keyboard model makes suggestions such as enabling features rather than changing setting out-of-sight of the user, which meets the transparency principle. Through observation of the user's performance, the model interprets the performance principle by responding to the user's typing behavior by interpreting key presses before they were sent to the application. Lastly, it creates commodity by being easily integrated without extra cost to unmodified keyboards. The one principle the Dynamic Keyboard Model lacked was context. This was because the environment did not necessarily change around the user, but context is an important principle.

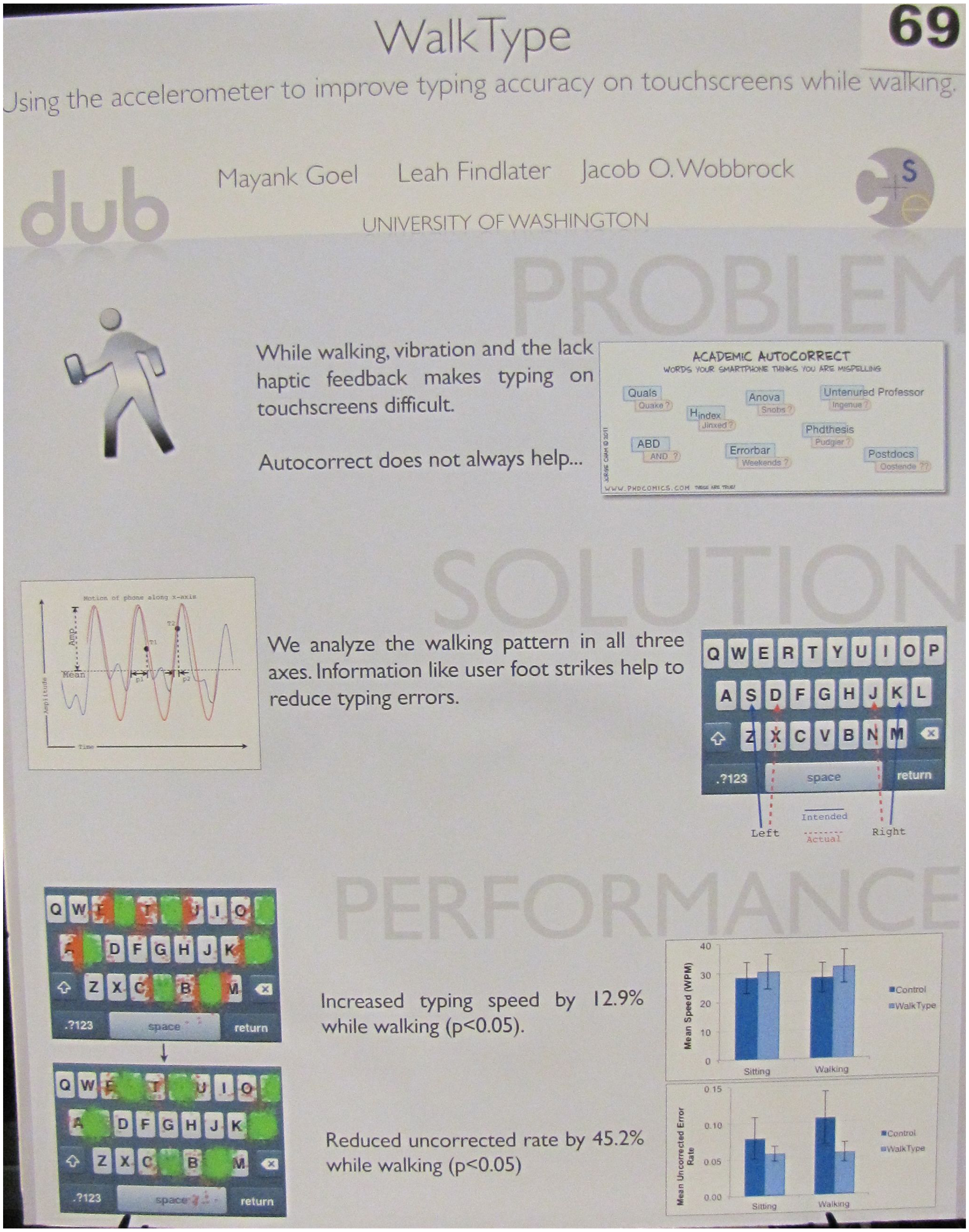


Figure 3: "WalkType Application"
Source: http://cdn.geekwire.com/wp-content/uploads/2011/10/walktypelarge.jpg

To understand the concept of context, Wobborck et al. (2011) focused on WalkType(Figure 3), an adaptive text entry system that uses accelerometer technology to accommodate someone walking. The principles of ability-based design that were incorporated into the walking user interface include ability, accountability, adaptation, performance, context, and commodity. To meet the requirements of ability-based design, WalkType focuses on ability and accountably. First, to meet accountability, the software is expected to accommodate the situational impairment of walking and push them to be more efficient. It focuses on ability because, despite experiencing a situational impairment such as walking, users were able to use the device successfully because of the adaptation of the target area sizes. Next, the WalkType software concentrates on adaptation, performance, context, and commodity. By using a simple decision tree, the software adapts the keyboard behaviors as a user clicks around as he or she is walking, which meets the adaptation principle. Next, performance is met through the system responds to the user's performance as they interact with the device based on tap location and finger travel distance during each tap. Additionally, by using pre-existing mobile devices and built-in sensors, WalkType uses the principle of commodity. Lastly, unlike the Dynamic Keyboard Model, WalkType achieves the context principle. Through the use of the mobile device's accelerometer data, WalkType changes its interface when the user takes a step.

Most of these principles were adjusted based on user interactions with the products. This means during the developmental stage of the design, each principle was addressed accordingly. By focusing on the abilities, product designers could change the conversation to a positive connotation. One field that could benefit from a more ability-focused conversation is emerging world of printed electronics.

Emerging Printed Electronics

Even as the generations increase their immersion in the digital world, the graphic communication industry has worked to remain relevant in a digital age. A recent development in the use of print technology is printed electronics. "Printed electronics defines the printing of circuits which include various components, e.g. transistors, diodes, antennas, etc., with conductive ink on the surface of paper, cardboard or plastic, etc. Usually, the ink and surfaces to be printed can largely vary to provide tailored functions" (Coatanéa, E., et al., p. 65, 2010). Printed electronics are created by printing conductive ink on a substrate, such as paper, using printing technology. Currently, there is an increasing amount of technologies that are relying on printed electronics advancements. For example, the Gartner Hype Cycle Curve (Figure 4) helps to understand how far along printed electronics has come since its initial creation. As the technology moves through different key phrases in the hype curve, it comes closer and closer to being integrated into everyday life through mass production.

One example of printed electronics is electronic paper (also known as e-paper) is made from a display technology called gyricon. A gyricon sheet is a thin piece of transparent plastic that contains millions of small beads. Each bead--half white half black--is contained in an oil-filled cavity and is free to rotate within its cavity. E-paper is electrically writable and erasable and can be re-used 1000s of times. When voltage is applied to the surface of the sheet, the beads rotate to display either their black sides or white sides. Images of pictures and text are created when a pattern of voltages is sent to the paper. The image will remain until the voltage pattern changes.

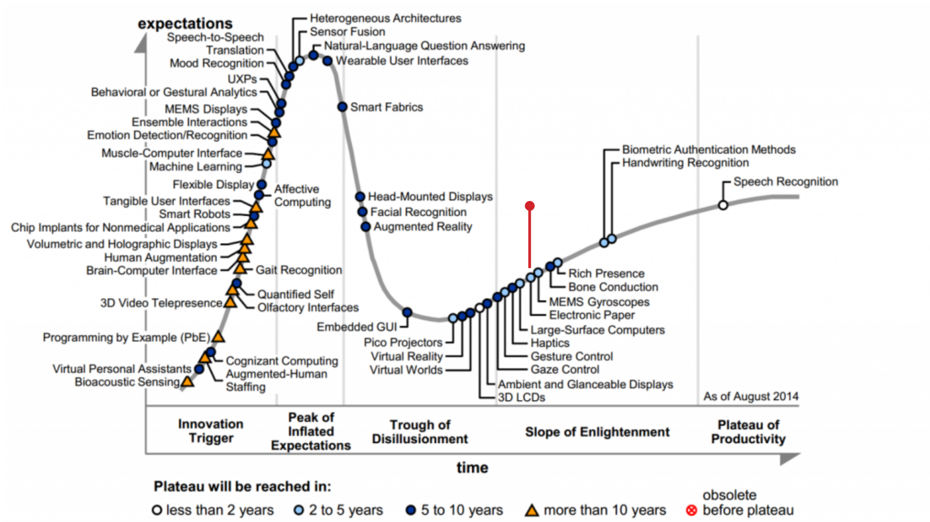


Figure 4: Gartner Hype Cycle for Human Computer Interaction August 2014
Source: http://blog.jenskooij.nl/2015/04/rapport-de-game-industrie-in-2023/

Referring to the Gartner Hype Cycle Curve, figure 4, electronic paper has moved through the Trough of Disillusionment to the Slope of Enlightenment. Electronic paper has moved from the stage of improving products to becoming a catalyst for other technologies to build on. Within two to five years, electronic paper will reach the Plateau of Productivity and be introduced into the mainstream market.

Another type of flexible printed electronic would be foldable printed circuit boards, which are created printing semi-conductive inks onto a paper substrate. The resulting paper is responsive to human touch, or can even play a sound when an area is pressed. Essentially, sheets of paper become interactive displays. For example, a textbook can be printed with interactive pages. It can contain illustrated videos of detailed instructions, flashing side notes, embedded sound buttons and eventually even receive homework help through RFID signals sent from the teacher via email. As products such as the interactive textbook are developed, individuals with disabilities may be forgotten as a result of being the outliers to the ideal user.

Ideal users, those users that most designers design a product for, are often problematic, because they are fictional-based. By not being based on real customer data, personas can lead to an exclusion of certain groups of users. Yet, ideal users could be a benefit to development process if used in a different light. With the number of disabled users on the rise, personas and ideal users could become a more diverse type of group than previously used. By choosing a specific group of users and focusing on common problems encountered, the idea of ability-based design can be integrated.

Ability-Based Design in Developmental Stage Leads to Innovation

The importance of understanding the abilities of the end user in a particular environment and time has been essential to creating innovative accessible products. Additionally, because ability-based design focuses on a few users, innovative products have been created as a result.

Dunne and Raby explained, “Populations can validate a design but individuals can inspire new thinking and therefore are invaluable at the beginning of a project” (Newell, 2011, p. 127).

To start with accessible design, designers may benefit from looking at a different ideal user – the outlier or the extra-ordinary user. These users comprise older users with only minor disabilities as well as a few users with severe ones. It may be helpful to frame the ideal user as a disabled person who will most likely use the product daily but who may have trouble using the product under certain circumstances. Once a designer understands the variety of potential users, she could broaden the design space through parallel design (Dow, 2010). Dow (2010) suggests that through parallel design, a designer could create multiple alternatives based on certain abilities of the user to have more diverse work and self-efficacy. Essentially, integrating all the alternatives into one solution can make a better product.

Conclusion

Despite all the positives that seem to come with ability-based design, it is difficult to determine if ability-based design could be integrated successfully in printed electronics. In particular, it would be difficult to truly understand user abilities. To provide accurate customer data, it is necessary to have quick and easy yet highly accurate usability tests that could check on a user's abilities, whether permanent or situational. Additionally, it would be a challenge to measure a user's abilities outside of a testing facility. Often times, people do not want to admit when they are struggling to use a device.

Printed electronics would have a much more difficult time integrating ability-based design. Designers would have to focus their energy on certain environmental factors such as light, motion, temperature, and noise levels. To be a well-designed ability-based design, the device would be able to adapt itself to the varying environmental factors. Currently, most devices tend to ignore the environmental factors that are surrounding a user and opt to require a user to adjust their environment to the device.

However, this positive thinking will create a more equitable environment for all people and printed electronics are still at the stage that would benefit greatly from ability-based design. By refocusing previous methods of accessible design, ability-based design has shifted the focus from disability to ability. This research provided an explanation of printed electronics and had a brief discussion on the barriers faced by the disabled. It addressed various types of accessible designs and described the benefits of ability-based design. Hopefully, this work will serve as catalyst for creating a future where all technology is accessible to everyone.

3 Methodology and Procedures

The goals of this research were to describe accessible design, put forward its principles, and discuss its role in printed electronics. Additionally, this research will also articulate usability challenges in a marketplace printed electronic and advance the conversation of disabilities to include the emerging world of printed electronics. The objectives of this study are to:

1. Determine if a printed electronic device can be adaptable to the visually impaired
2. The role that accessible design had in the development of printed electronics
3. Determine if accessible design prohibited usability and performance

Data Collection Plan

Printed electronic experts were interviewed to determine how they thought disabilities were considered in the development of printed electronics. Faculty members from the Graphic Communication department: Xiaoying Rong and Malcolm Keif were interviewed.

Cal Poly professors, Dr. Xiaoying Rong and Dr. Malcolm Keif were interviewed to understand her and his perspective on the level of accessible research conducted for printed electronics and the future of implementing it. In addition, Brandon Larson, of Redbull High Performance Team, was interviewed to discuss the positive impact accessible printed electronics could have on human performance and broke down the purpose of this research as this: "Technology is another tool you can use in a series of things you do." All individuals were asked the same questions to gain a clear understanding of how implementing accessible design can add or take away value to a product's design (Appendix A).

In addition to the interview, the plan involved an experiment using a modified foldable printed electronic device. Through trial and error, it could be determined what additions could be made to the device to help it become more accessible. A group of 20 students were chosen for one trial. The subjects were students from the population at California Polytechnic University San Luis Obispo and each group were given instructions before participation in the experiment.

During the trial, each person was given a foldable printed electronic device to interact with. They first interacted with the device blindfolded and then experienced the device with sight in order to experiment with different levels of disability. The data was collected on a questionnaire given to them electronically at the end of the trial. Questions were asked about the components of usability, ease of use, preference for this type of device and why, and their overall comments and impression of the product (Appendix B). After extensive review, the Human Subjects Committee at Cal Poly (also called Institutional Review Board, or IRB) approved the questions and research protocol used.

Data Analysis Plan

After the experiment was over, responses to the questions and comments by the interviewees were noted. The data was consolidated into a grouped data sheet. This showed the different levels of accessibility and in what ways it was most effective. Data collected from the experiment showed how the printed electronic device was accessible or not accessible and the effect on a person's preference it had. A product's level of usability when challenged with a user's disability can be noted. By observing the way a user's disability hindered the completion of a task, the overall usability of a product can be measured.

4 Results

First of all, some questions were asked to experts in the printed electronics field for evaluation of the relationship between accessibility design and developing printed electronic products. The intent of these interviews was to analyze the involvement of disabilities in the developing stage of a product, the overall level of usability when accessible design is implemented, and to determine if printed electronics could benefit the disabled community in the future.

The same questions were asked to all the participants with the exception of an extra question asked to Brandon Larson of Redbull High Performance. The first two questions were: In your experience-in general, are the needs of people with impairments population sufficiently being met by products provided by the Graphic Communication industry (such as printed electronics)? and How accessible are alternative printed electronics for impaired in terms of cost, time of production, and availability?

Dr. Malcolm Keif and Dr. Xiaoying Rong expressed the idea of using Braille as the traditional way to accommodate a disabled individual but were careful to emphasized the fact that printed electronics can provide opportunities to communication through other senses as well. "In general, there is no special assistance provided by most graphic communication printing products except Brailler. Printed electronics may help in the way of providing voice direction and light stimulation rather then flat and static printing" (Rong, Appendix A). Rong also noted that designing a printing product that incorporated a voice and interaction feature was a complicated process. Depending on the nature of the printed electronic, being either a "printed product with an interactive element" or an "electronic product," the cost and functionality will be totally different. Dr. Keif expands on, "Because the application is in its infancy, I'd say little work has been put into accessibility of alternatives. Typically, accessible products come as markets gain maturity. Cost, time and availability are not there yet" (Keif, Appendix A). Rong agreed with Keif; she stated, "Printed electronics are costly now. And the productivity is too low to meet the possible needs for the [disabled]" (Rong, Appendix A).

The next two questions dealt with possible legality issues and if any government funding was available for accessible products. The questions asked: What kind of funding does the state or any other entities provide for projects that embrace a more accessible functionality? and Are there any laws and regulations on accessibility related to printed electronics? Dr. Rong and Dr. Keif indicated they were not aware of any laws or funding; Rong claimed, "I am not aware of products specifically designed for people with impairments. Most products [are] just to add interactive functions for general population" (Rong, Appendix A). Dr. Keif remarked, "I know of none. I suspect things like building codes/signage would apply, whether conventional or [printed electronics,] PEs. Really would be more application based, whether or not PEs" (Keif, Appendix A). Brandon Larson had felt he was not involved enough in the graphic communication industry so could not comment on the first four questions.

The next question was: Have you had any experiences where a developing product was improved when disabilities were taken into account? While Dr. Keif and Dr. Rong indicated they have had no experience, Brandon Larson noted on his experiences. "I tend to always think about the full range of usage of any product or tech I design. In this area, considerations for hand strength, eye sight, sense

of touch, awkward motions and ergonomic movements are critical to bettering design. These types of considerations are a good step to take bridging the gap for impaired populations. The only times when fewer topics are taken into account and disabilities possibly overlooked are for application specific designs – such as an astronauts suit or a piece of specific sporting equipment" (Larson, Appendix A).

A second question relating to designing earbuds that could help distinguish between the left and right one easily where small tactile modifications were actually a big improvement to the product. Expanding on the developmental process of this product, Larson commented, "It's along the lines of really thinking about the frustrations of a user and being very aware of those shortcomings. You then need to put yourself in that position and internalize the problems by experiencing them. I realized that looking at my ear buds was an additional step if I had already touched them... so touch should be the indicator. If the ear buds are seen first, something to differentiate left vs right is needed... maybe one is colored differently? You can do this for almost all disabilities… tie your dominant hand behind your back for a day, wear a blind fold to experience the world without sight, wear a fat suit, etc etc… designers need to experience the world of the end user in order to understand their requirements" (Larson, Appendix A).

The next question asked was: Should disabilities be taken into account during the developmental stage or work better as an after thought after the original design is successful? According to the United States Access Board's website, "Accessibility is easier to achieve if considered at the beginning of and throughout the design process. Manufacturers shall consider access to telecommunications by individuals with disabilities throughout product design, development, fabrication and delivery, as early and consistently as possible." It also clarifies that manufacturers can satisfy section 255 and 4.7 as long as disabled individuals are recognized as potential customers and treat that population in the same manner as other groups of potential customers. ("TAAC Final Report 4.0 Process Guidelines.") Dr. Rong, Dr. Keif, and Larson all agreed that it depended on the purpose of the product and who the main general user was.

Dr. Rong determined that it depends on what the purpose of the product is, and stated, "It depends what type of disability the product serves. I think most electronic products have access assist functions for disabled people. For poor vision, voice access would be helpful. It also depends on what type of product it is. For text contents, such as books, magazines, voice is also helpful. I felt it is very limited what type of product can be redesigned to add disability functions" (Rong, Appendix A).

Dr. Keif noted specifically on the technical challenges; "Certainly designing [with] accessibility considerations would be ideal. The problem during the innovation stage is that usually the technical challenges are so great that adding additional complexities (which I am guessing most accessibility features do add complexities) are generally not desirable during the invention stage" (Keif, Appendix A).

Additionally, Larson added, "It really depends on the application. The application, target market, audience, user group should dictate the requirements of the product. Generally products are designed to meet the needs of the center of the bell curve. For instance the design of a fork for the masses would likely be designed very differently than a fork for someone with Parkinsons who may not be able to steady the fork during eating, prompting alternative designs…

…The same holds true for many other applications. Additionally, cost drivers often play a larger role in design and may make design to cover all uses and user abilities very challenging" (Larson, Appendix A).

The next question asked: If you do consider disabilities when designing a product, what disabilities do you generally concentrate on? Dr. Rong and Dr. Keif both commented on the traditional approaches of incorporating different sensory elements. Dr. Keif expanded, "If you are thinking traditional sense challenges, engaging multiple senses would be helpful. If one includes learning disabilities, then adding reinforcing alternatives could be good. Certainly sight, auditory, tactile, etc." (Keif, Appendix A).

The next question concentrated on product usability: Do you agree that designing products based on the end-user's abilities can enhance human performance of that product? Why or why not?

Larson agreed that a well designed product can change the way a user experiences life and explained, "Yes – the more a product is design for a well defined use case correlating to the users abilities, the more empowering the product becomes to that person. It is, however, only through very careful design looking at and fully understanding how design impacts the experience someone has with the product – that will make the product a success for that person or not. Design is not a trivial task. Proper design can change lives, regardless of it is for able or disabled users" (Larson, Appendix A).

Dr. Keif agreed and discussed the relationship between the accessibility and learning styles. He stated, "I agree. It is the same principle as learning styles. Individuals learn and retain information in different ways. So, it would stand to reason that making products with multiple-learning approaches would aid learning. I suspect the same is true with impaired populations. It also extends the scope and accessibility of products" (Keif, Appendix A).

Dr. Rong also agreed but asked the question of the extent of the functionality. She said, "Will you make an electronics product with more functions or a printed products with limited functions to serve the disabled end-users?" (Rong, Appendix A).

The next question sought an answer to why most products don't seem to be accessible yet: In your opinion, why do most companies not design printed electronics for disabilities?

Dr. Keif stated that it was simply the added complexity that prohibits integration. He claimed, "As noted above, the additional complexity is often avoided during the invention stage. As greater understanding of production capabilities is gained, the enhanced features are easier to add. When I say easier, I don't mean easier to build into the design….more that it is easier to produce because the initial production challenges have typically been mastered" (Keif, Appendix A). Dr. Rong agreed that the limited functions of printed electronics could not be beneficial yet to the disabled community.

The last question was: How can printed electronics benefit a person with disabilities? Despite the limited functions of printed electronics, Dr. Rong stated printed electronics could be used for, "Maybe for possible interaction with the products. For example, for people with poor vision to access certain text content by reading to them" (Rong, Appendix A). Dr. Keif added, "I am guessing by adding secondary and tertiary stimuli" (Keif, Appendix A).

Adding her overall comments, Dr. Rong stated, “I think the product determines whether electronics, not just printed electronics is needed for disabilities. Although printed electronics can be low cost and produced on flexible substrates, however, the functions of printed electronics are limited. Some printed electronics are flexible version of silicon electronics, such as battery, solar cells, etc. If the discussion is for using flexible electronics components, it will benefit for lowering the weight, providing more flexible devices” (Rong, Appendix A).

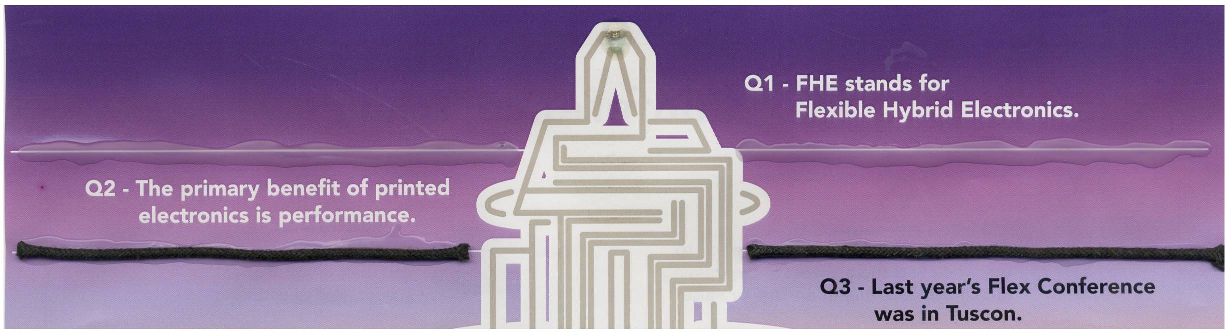


Figure 5: In order to make the printed electronic more accessible, it was necessary to test a series of materials to determine the best fit in scope of price and functionality. The first line demonstrates the glob of glue method and the second was the application of a string. Both did not work as well as the wooden ridges which can be seen in Appendix B.

Incorporating Accessibility to a Pre-Existing Foldable Printed Circuit Board

Next, an exploration of materials was used to understand ways to modify a pre-existing foldable printed electronic. This printed electronic (called e-paper for simplicity) is a true or false quiz that features a printed circuit and a flexible thin-film battery. To use the device, the user folds the paper onto itself to line the side up to a printed line. They can press the true or false buttons and a light at the top will light up either green or red. Since this printed electronic relied almost entirely on visual functionality, it would be very hard for a visually impaired person to use this printed electronic.

The first step was to figure out an easier tactile way to represent the lines that the paper needed to line up to. Materials considered were globs of glue, string, hooks, and wooden ridges (Figure 5). The glue did not seem to work because when blindfolded, the paper would simply slide over the glue. Next, I experimented with string. The string was beneficial because it was flexible, but faced the same problem as the glue; it was hard to find the string with visual impairment. Next, hooks were attempted to be integrated in the sides of the lines. Conceptually, this seemed easy enough. Unfortunately, for someone blindfolded, it was impossible to hook the small hole into the hook in order to engage the e-paper’s LED light system. Last, wooden ridges were glued into place. Despite causing flexibility of the e-paper, it did provide a perfectly tactile ridge that was easily identifiable while blindfolded. Subjects were able to simply slide the paper from the top of the electronic device and find the first ridge rather easily.

Next, it was important to create tactile buttons. Originally, it was hoped to find buttons that would provide feedback when pushed. Unfortunately, all the models of buttons found could not initiate an acceptable connection between the bottom surface of the button and the printed circuit. To make

the buttons recognizable, a round polyester plastic piece with a sticky back was incorporated to the surface of the button. This was beneficial because the clear properties of the polyester rubber was able to display the True and False text below.

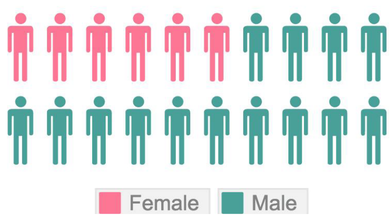
Last, to constitute the device truly accessible for the visually impaired, it would be necessary to integrate a speaker system that could read the question once the paper was lined up under the ridges then confirm if the answer pushed was right or wrong. Because of the limited time and resources of this research, this functionality was not integrated into the device.

Conducting the Experiment

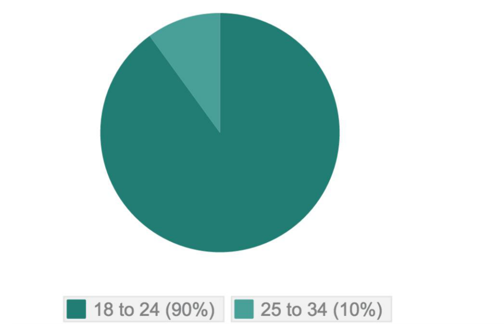
Moreover, a human research experiment was conducted with students from Cal Poly. The purpose of this experiment was to measure the relationship between usability and accessibility to understand whether designing for disabilities increased the overall usability of the product. By presenting the printed electronic that was previously modified, it can be determined if the overall functionality of the product was improved.

Twenty test subjects were from the California Polytechnic University population were selected at random. After the experiment, each individual answered a simple questionnaire pertaining to their experience with the foldable printed electronic (Appendix B). These are the results:

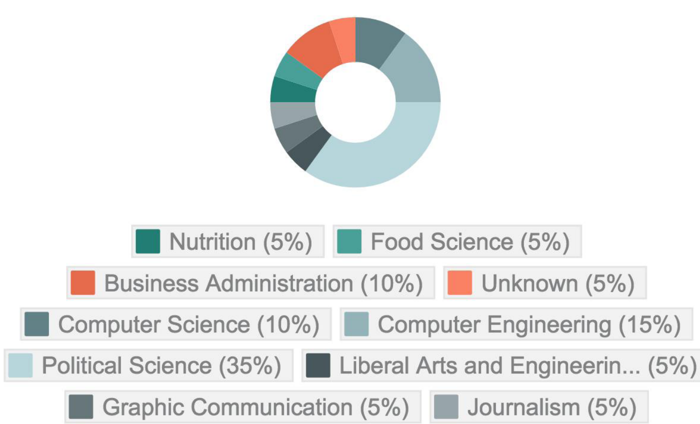
1. What is your gender?



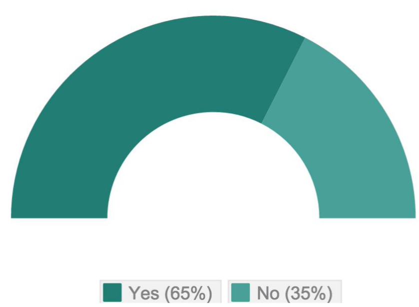
2. What is your age?



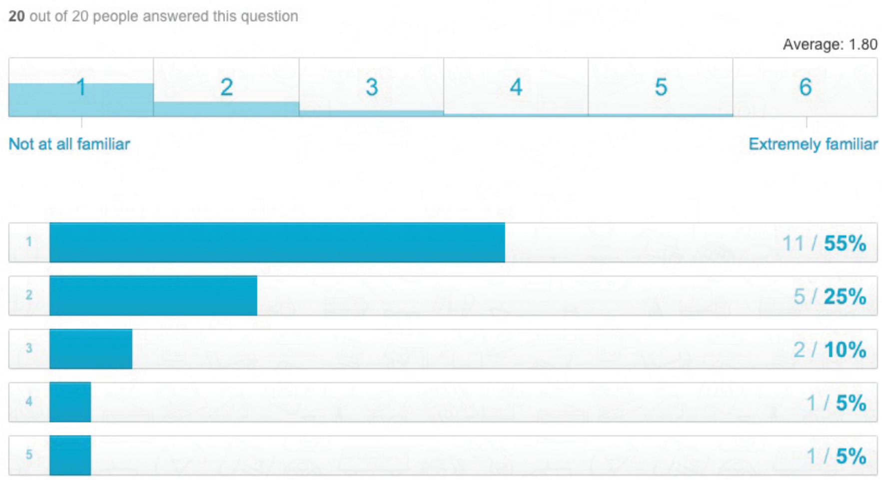
3. What is your major?



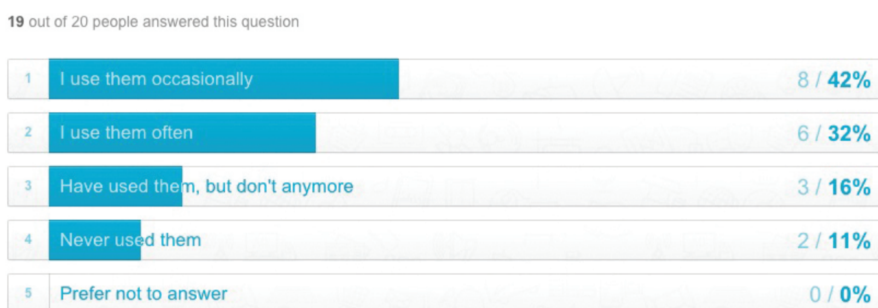
4. Do you or someone you know have a physical, mental or sensory disability?



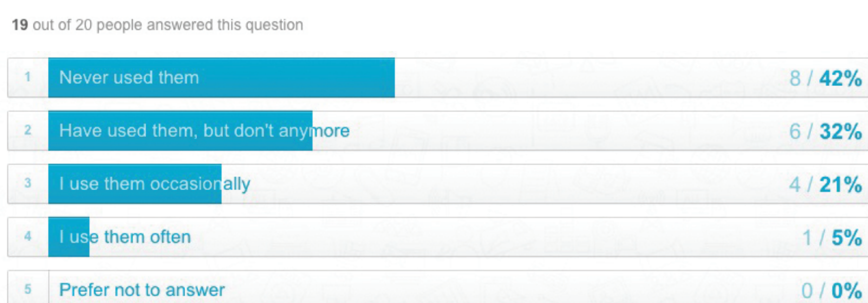
5. Printed electronics involves the manufacture of electronic components and equipment with the aid of normal printing processes. How familiar are you with the field of printed electronics in general?



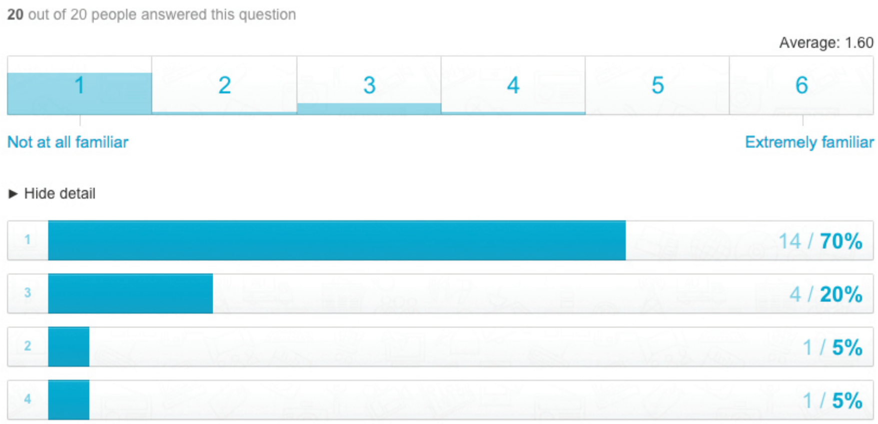
6. How frequently do you use the accessibility settings, such as Zooming, invert colors, grayscale, modifying text, or subtitles on your electronic devices?



7. How frequently do you use printed interactive electronic products such as interactive greeting cards that light up when you touch them?

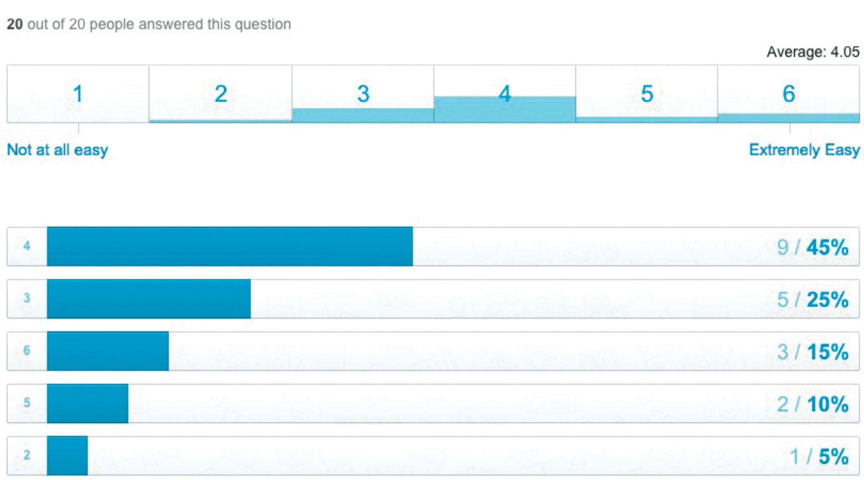


8. Before this trial, how familiar were you with this specific printed electronic?

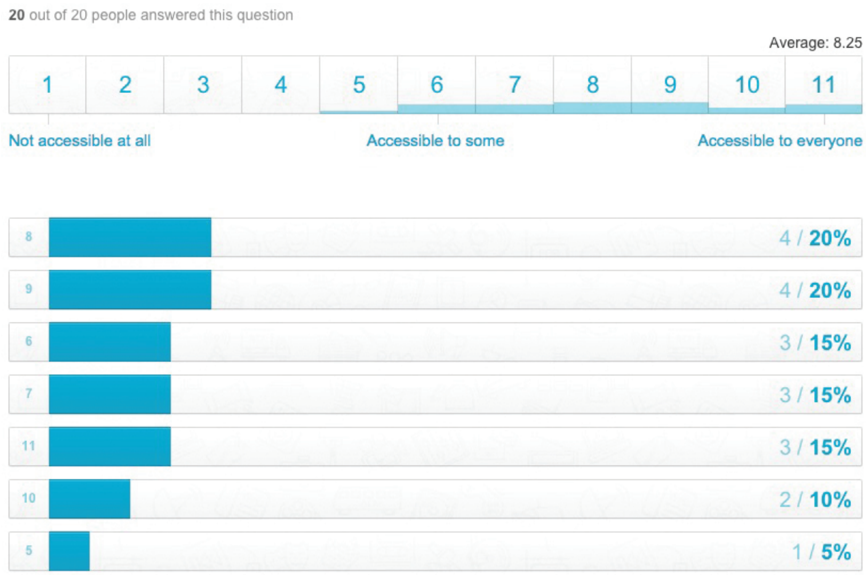


9. What is your impression of this product?

12. How easy was it to use this printed electronic product?



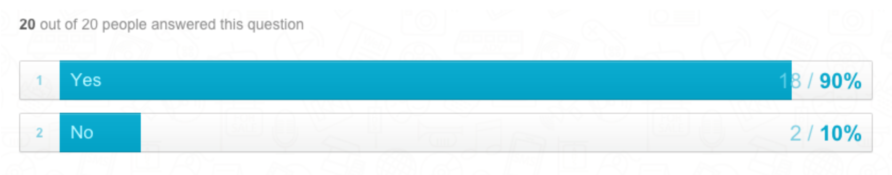
12. What level of accessibility do you feel this product has?



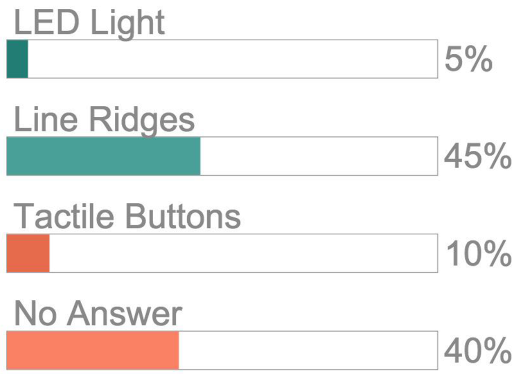
13. Why did you chose that score?

- None of the test subjects rated the accessibility below a 5 which indicates that they all believed the modified printed electronic to be accessible to some.
- Many of the test subjects which gave an accessibility rating between 5-7 discussed how accessibility was compromised because of the ineffective button design but with modification could be easier to use.
- Test subjects that gave the product a rating between 9-11 replied that the device would be accessible to all whether they had a visual or hearing impairment.

14. Do you feel this product was designed with accessibility in mind?



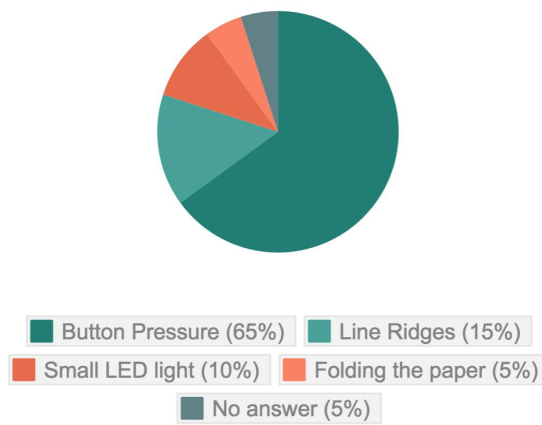
15. Did any features stick out to you as being the most helpful?



The top replies for this question dealt with the ridges, LED light and buttons:

- 9 subjects replied that the ridges were the most helpful.
- 1 subject replied the LED light was the most helpful.
- 2 subjects indicated the textured buttons were the most helpful.
- Some of the top replies included: While blindfolded, the ridges helped line up the page and the texture of the round buttons made it easy to feel them and use them; LED light alerting the user whether or not they had the correct response and did like that one button was placed diagonally to the other which made it easier to remember which was which.

16. What did you find the most frustrating with this device?



Replies pertaining to the buttons included:

- “Having to press down quite hard on the buttons for them to work, and not being able to know if it had registered or not or if I needed to do it again.”
- “When you pressed the button it didn't always make a good connection so you had to do it multiple times”
- “The feedback from the button pushing wasn't very tactile. If it clicked or had a more noticeable push down it would be easier to use.”

Replies pertaining to the line ridges included:

- “I didn't know when I was at the top ridge.”
- “Lining up the edge of the paper with the ridges in the paper”

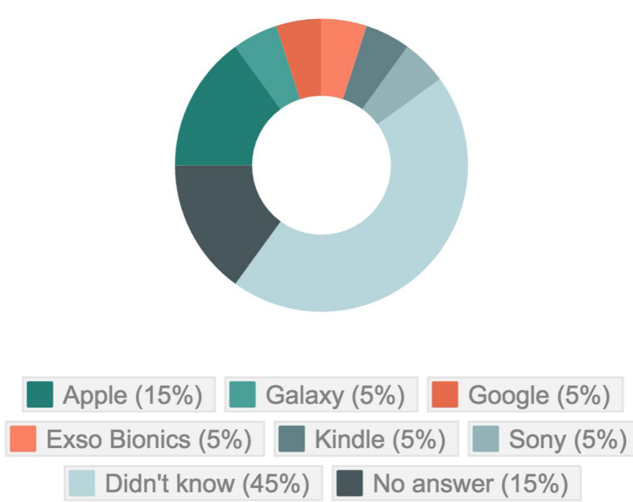
Replies pertaining to the LED light included:

- “The light telling you if you got the question correct or not was very small and difficult to see in my opinion.”
- “I was unable to see the red/green light when I was blindfolded, and so therefore, unable to know whether I was correct, other than being told that I was correct/incorrect. So I rely on the verbal response of another person to use this product in the end. It would have been nice to use it without any assistance, if I were a handicapped person that might be frustrating for me.”

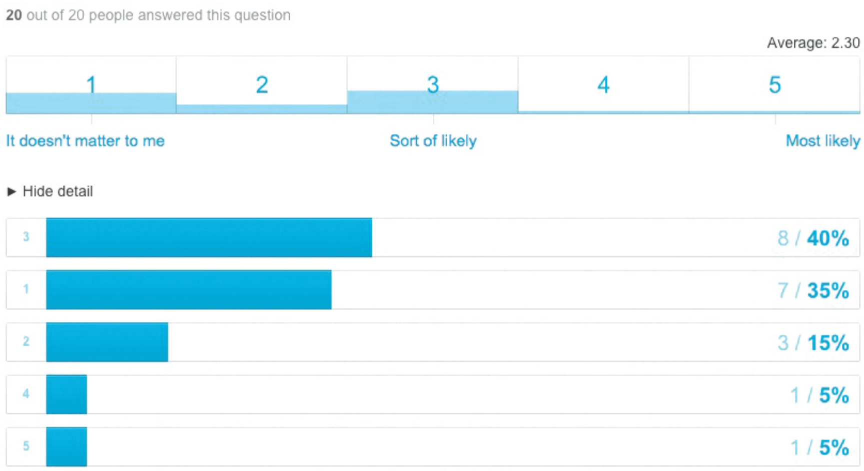
17. How would you improve this design?
Replies included:

- “I would make the ridges more obvious, for people who have a sight impediment. I would also try to improve the button sensitivity.”
- “On the test, add 2 hooks on each side so that the paper aligns easily. And the buttons were slightly hard to press, I didn't know if the signal went through or not.”
- “Make the lights on it brighter?”
- “Make the connection more sensible”
- “Use a substrate that forms a better connection”
- “A way to differentiate true and false, maybe by having a small bump on true”
- “Perhaps an advanced prototype could vibrate or make a beeping sound when the correct/incorrect answer is chosen to allow a sight-impaired person using it to know when they have answered correctly/incorrectly without having to rely on the verbal responses of another person.”
- “Make the buttons you have to answer with more user-friendly.”
- “I would make the button telling you if you got the question correct or not be bigger. I might also add something to the top of the paper so the user knows where the paper starts and ends.”
- “Incorporate some kind of feedback when pushing down the buttons.”
- “Maybe a small noise and have them slightly different for true and false so you can be sure you pressed the tight one.”
- “Make the ridges bigger. Also, how are people to know whether or not they chose correctly if no one else is there to tell them”
- “Making the buttons easier to press, and making the starting point more distinct from the rest.”
- “I would make the true or false buttons make a noise when I pressed them.”

18. When you think of good accessibility focused electronics, what brands come to mind?
Many subjects felt that all mobile and computer devices were expected to be accessible to everyone. The top brands indicated by the test subjects included:



19. How likely are you to buy an accessibility focused product over its competitor?



20. Why did you chose this answer?

- Test subjects that answered that it didn't matter to them explained that accessibility is not a top priority and indicated felt they did not need it because he didn't have any disabilities.
- Test subjects that answered they were sort of likely explained that they did not necessarily need an accessibility based product for herself but if she was buying a device for a family member or friend who had impairments or disabilities, she may be more likely to purchase devices or electronics with accessibility features.
- Test subjects that indicated most likely explained that it just means the product was designed so it can be easier to use.

5 Conclusions

After the experiments were conducted with students and the experts in the field responded to the questionnaires, the analysis of the results indicated accessible design could be a substantial benefit in printed electronics. Through the experiment, it was determined that a pre-existing e-paper device was able to be partially adapted to fit the needs of the visually impaired.

To meet the requirements of ability-based design, the modifications focused on the two required principles, ability and accountably. First, to meet accountability, the printed electronic was expected to accommodate the situational impairment of being blindfolded and push them to be more efficient in using the printed electronic device. It focuses on ability because, despite experiencing a situational impairment such as being blindfolded, users were able to use the device successfully because of the adaptation of the wooden ridges and tactile buttons. Additionally, by using pre-existing printed electronics, the modifications meet the principle of commodity. More modifications would be necessary to implement other principles such as adaptation, performance, and context. By using a simple decision tree, the printed electronic could adapt the connection location and feedback audio to help guide a user to the correct location in order to achieve the adaptation principle. Next, performance could be met through a feedback system that responds to the user's performance as they interact with the device based on buttons that adapt to various pressures and connection locations. Lastly, context could be incorporated with a speaker system that increases in volume if it detects the room's atmosphere to be very loud.

Many of the test subjects enjoyed using the e-paper device and wanted to see more of the technology integrated elsewhere. On the other hand, the time and cost it would take to develop the e-paper to have the speaker system didn't not seem plausible without a few more individuals working on it. Not only would it need to be programmed, the printed electronic would need to be reprinted to incorporate the speaker's circuits. Furthermore, many test subjects felt that it was more important to make the button to LED light connection work first before more feedback systems should be added. The modifications made to the printed electronic such as the tactile buttons and wooden ridges improved the functionality of the device and increased the product's usability. By understanding the abilities of the end user, successful modifications were made to the e-paper.

On the other hand, the idea of integrating accessible design in the developmental stages at this point does not seem to be entirely plausible. Cost is the main prevention of the integration of accessible design in developing printed electronics. Unfortunately, if the product is seeking to make a profit, there does not seem to be any federal funding to help ease the cost of extra development time. However, by simply changing the way a designer thinks about a problem could help create a better design that is not costly. Brandon Larson indicated that an exceptional design can be found by putting yourself in the end user's shoes to truly understand their requirements.

The packaging and medical industry have demonstrated a considerable amount of interest in printed electronics development and has emphasized the importance of being able to service a wider spectrum of customers. Not only can printed electronics create a "wow" factor, it can actually provide ways for

companies to reach certain accessibility expectations. For example, the United States Access Board has created certain properties that medicine labels must have for the impaired. Interactive printed electronics can bridge those challenges faced now by adding sound and interactive touch elements.

To become more competitive in the future, the graphic communication industry must or should start to integrate ability-based design. Even though the public does not seem to seek accessibility based products exclusively, it is apparent that the public expects products to have those capabilities. Because Cal Poly is non-profit research based, it is possible to find grant funding for projects that integrate accessible design. If Cal Poly is able to determine certain design properties that can generally be used by a wide variety of individuals, once the cost of printed electronics drops, the graphic communication industry can start to easily incorporate these design principles into the updated versions of those products. The United States Access Board stated that manufactures are expected to incorporate accessible design when creating updated versions of products. Additionally, certain accessible design actually adds value to the product. Even a small modification such as tactile earbuds can increase a product's desirability and can all be started with a simple notion towards the disabled.

As progressively more people move away from the desktop to other means of media, the typical user is now surrounded by distractions. All of these new distractions challenge the usability of the product in ways that have never been endured before. Unfortunately, computer users are still unaware of the circumstances in which they are having to endure. Electronic device accessibility, whether a printed electronic or a electronic device, is no longer just a problem with people with disabilities; electronic device accessibility is for everyone. Every user's abilities are affected in one way or another and if a company wants to design products that matter; they must start to consider all the new circumstances. By using an ability-based design approach, designers can explore better and more intuitive solutions because they are no longer limited by a user's disability.

Appendix A

Elite Questionnaire filled by Xiaoying Rong from Cal Poly on 06/04/15

1. In your experience- in general, are the needs of people with impairments population sufficiently being met by products provided by the Graphic Communication industry (such as printed electronics)?

   In general, there is no special assist is provided by most graphic communication printing products except Brailler. Printed electronics may help in the way of providing voice direction and light stimulation rather then flat and static printing.

2. How accessible are alternative printed electronics for impaired in terms of cost, time of production, and availability?

   Printed electronics are costly now. And the productivity is too low to meet the possible needs for the needs. Design printing product integrate printed electronic for voice and interaction is complicated. It also depends on whether the product is defined as electronic product or printed product with interactive element. The cost and functionality are different for two types of products.

3. What kind of funding does the state or any other entities provide for projects that embrace a more accessible functionality?

   I am not aware of products specifically designed for people with impairments. Most products just to add interactive functions for general population.

4. Are there any laws and regulations on accessibility related to printed electronics?

   I am not aware of this.

5. Have you had any experiences where a developing product was improved when disabilities were taken into account?

   I am not aware of this.

6. Should disabilities be taken into account during the developmental stage or work better as an after thought after the original design is successful?

   It depends what type of disability the product serves. I think most electronic products have access assist functions for disabled people. For poor vision, voice access would be helpful. It also depends on what type of product it is. For text contents, such as books, magazines, voice is also helpful. I felt it is very limited what type of product can be redesigned to add disability functions.

7. If you do consider disabilities when designing a product, what disabilities do you generally concentrate on?

   I felt voice control, sound, are the most helpful functions.

8. Do you agree that designing products based on the end-user's abilities can enhance human performance of that product? Why or why not?

   Yes, with disability population in mind while a product will benefit more users. However, the cost and possible technologies to achieve the functions are the challenges. Again, it will end up with such question, will you make an electronics product with more functions or a printed products with limited functions to serve the disabled end-users.

9. In your opinion, why do most companies not design printed electronics for disabilities?

   Printed electronics have very limited functions that can possibly be helpful to disabilities.

10. How can printed electronics benefit a person with disabilities?

    Maybe for possible interaction with the products. For example, for people with poor vision to access certain text content by reading to them. I cannot think about other products.

11. Any other comments, suggestions or questions to contribute to this study?

    I think the product determines whether electronics, not just printed electronics is needed for disabilities. Although printed electronics can be low cost and produced on flexible substrates, however, the functions of printed electronics are limited. Some printed electronics are flexible version of silicon electronics, such as battery, solar cells, etc. If the discussion is for using flexible electronics components, it will benefit for lowering the weight, providing more flexible device.

Elite Questionnaire filled by Malcolm Keif from Cal Poly on 06/02/15

1. In your experience- in general, are the needs of people with impairments population sufficiently being met by products provided by the Graphic Communication industry (such as printed electronics)?

   I'd say the only real historical attempt for folks w/ special needs has been the use of braille. PE open up the opportunity to engage additional senses, beyond sight and touch. I'd say there's opportunity.

2. How accessible are alternative printed electronics for impaired in terms of cost, time of production, and availability?

   Because the application is in its infancy, I'd say little work has been put into accessibility of alternatives. Typically, accessible products come as markets gain maturity. Cost, time & availability are not there yet.

3. What kind of funding does the state or any other entities provide for projects that embrace a more accessible functionality?

   That is a good question and I have no idea. Perhaps you can investigate that further.

4. Are there any laws and regulations on accessibility related to printed electronics?

   I know of none. I suspect things like building codes/signage would apply, whether conventional or PEs. Really would be more application based, whether or not PEs.

5. Have you had any experiences where a developing product was improved when disabilities were taken into account?

   Honestly, no. Too new.

6. Should disabilities be taken into account during the developmental stage or work better as an after thought after the original design is successful?

   Certainly designing w/ accessibility considerations would be ideal. The problem during the innovation stage is that usually the technical challenges are so great that adding additional complexities (which I am guessing most accessibility features do add complexities) are generally not desirable during invention stage.

7. If you do consider disabilities when designing a product, what disabilities do you generally concentrate on?

   If you are thinking traditional sense challenges, engaging multiple senses would be helpful. If one includes learning disabilities, then adding reinforcing alternatives could be good. Certainly sight, auditory, tactile, etc. To be honest, I have very minimal knowledge about the various forms of disabilities so you would need to investigate that more.

8. Do you agree that designing products based on the end-user's abilities can enhance human performance of that product? Why or why not?

   I agree. It is the same principle as learning styles. Individuals learn and retain information in different ways. So, it would stand to reason that making products with multiple-learning approaches would aid learning. I suspect the same is true with impaired populations. It also extends the scope and accessibility of products.

9. In your opinion, why do most companies not design printed electronics for disabilities?

   As noted above, the additional complexity is often avoided during the invention stage. As greater understanding of production capabilities is gained, the enhanced features are easier to add. When I say easier, I don't mean easier to build into the design....more that it is easier to produce because the initial production challenges have typically been mastered.

10. How can printed electronics benefit a person with disabilities?

    Not certain but I am guessing by adding secondary and tertiary stimuli.

11. Any other comments, suggestions or questions to contribute to this study?

    No Comment.

Elite Questionnaire filled by Brandon Larson from Red Bull High Performance on 06/02/15

1. In your experience- in general, are the needs of people with impairments population sufficiently being met by products provided by the Graphic Communication industry (such as printed electronics)?

   I have little experience in the area of the needs of impaired populations so I am not versed enough to know if needs are met by the G.C. industry.

2. How accessible are alternative printed electronics for impaired in terms of cost, time of production, and availability?

   No Comment

3. What kind of funding does the state or any other entities provide for projects that embrace a more accessible functionality?

   No Comment

4. Are there any laws and regulations on accessibility related to printed electronics?

   No Comment.

5. Have you had any experiences where a developing product was improved when disabilities were taken into account?

   I tend to always think about the full range of usage of any product or tech I design. In this area, considerations for hand strength, eye sight, sense of touch, awkward motions and ergonomic movements are critical to bettering design. These types of considerations area a good step to take bridging the gap for impaired populations. The only times when fewer topics are taken into account and disabilities possibly overlooked are for application specific designs – such as an astronauts suit or a piece of specific sporting equipment.

6. Should disabilities be taken into account during the developmental stage or work better as an after thought after the original design is successful?

   It really depends on the application. The application, target market, audience, user group should dictate the requirements of the product. Generally products are designed to meet the needs of the center of the bell curve. For instance the design of a fork for the masses would likely be designed very differently than a fork for someone with Parkinsons who may not be able to steady the fork during eating, prompting alternative designs. The same holds true for many other applications. Additionally cost drivers often play a larger role in design and may make design to cover all uses and user abilities very challenging.

7. If you do consider disabilities when designing a product, what disabilities do you generally concentrate on?

   No Comment.

8. Do you agree that designing products based on the end-user's abilities can enhance human performance of that product? Why or why not?

   Yes – the more a product is design for a well defined use case correlating to the users abilities, the more empowering the product becomes to that person. It is, however, only through very careful design looking at and fully understanding how design impacts the experience someone has with the product – that will make the product a success for that person or not. Design is not a trivial task. Proper design can change lives, regardless of it is for able or disabled users.

9. In your opinion, why do most companies not design printed electronics for disabilities?

   No Comment.

10. How can printed electronics benefit a person with disabilities?

    No Comment.

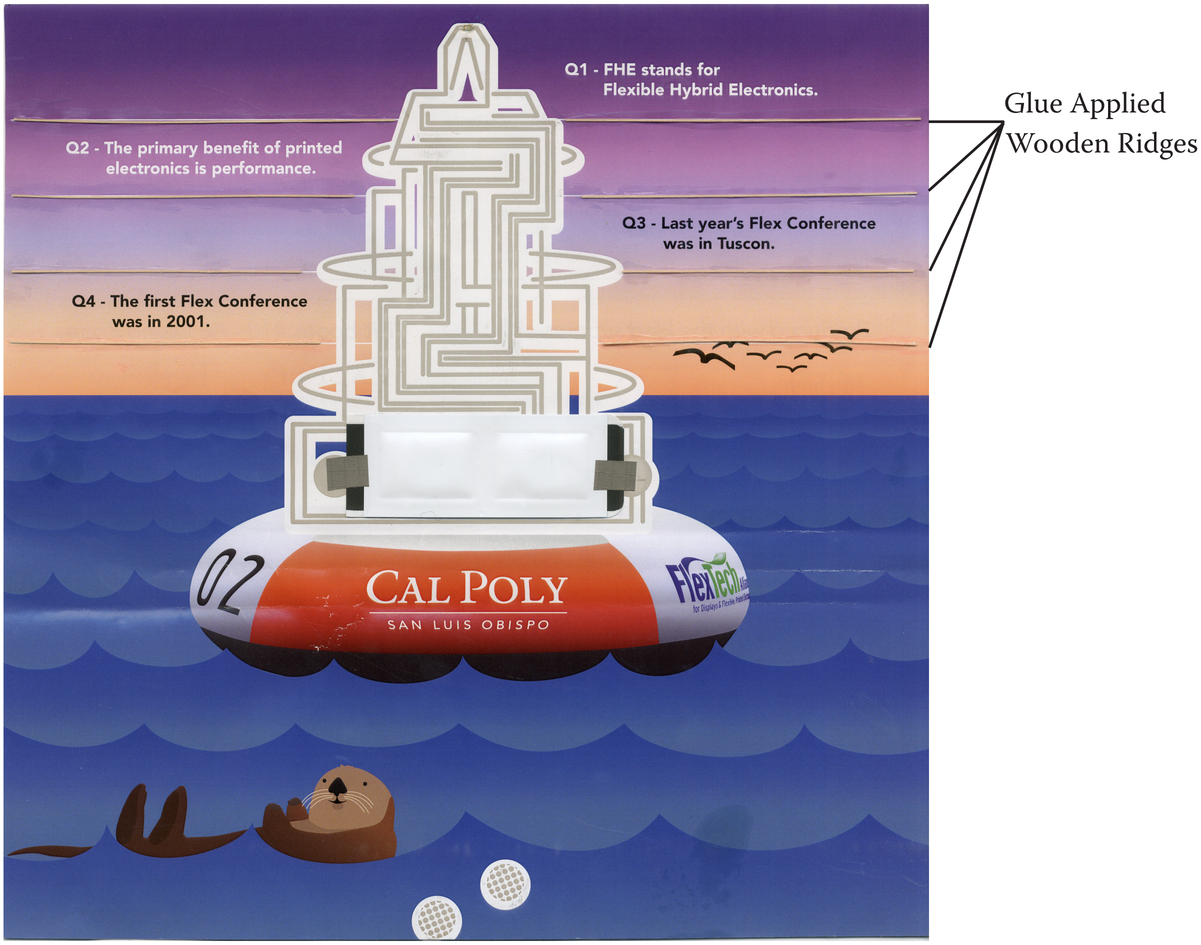
11. Any other comments, suggestions or questions to contribute to this study?

    No Comment.

12. You were telling me about a time when you were helping to design earbuds that could help distinguish between the left and right one easily. You were saying that small tactile modifications were actually a big improvement to the product. Could you expand the developmental process with of this a little bit more?

    It's along the lines of really thinking about the frustrations of a user and being very aware of those shortcomings. You then need to put yourself in that position and internalize the problems by experiencing them. I realized that putting looking at my ear buds was an additional step if I had already touched them... so touch should be the indicator. If the ear buds are seen first, something to differentiate left vs right is needed... maybe one is colored differently? You can do this for almost all disabilities... tie your dominant hand behind your back for a day, wear a blind fold to experience the word without sight, wear a fat suit, etc etc... designers need to experience the world of the end user in order to understand their requirements.

Appendix B


Q1 - FHE stands for Flexible Hybrid Electronics.
Q2 - The primary benefit of printed electronics is performance.
Q3 - Last year's Flex Conference was in Tuscon.
Q4 - The first Flex Conference was in 2001.
02
CAL POLY
SAN LUIS OBISPO
FlexTech
Glue Applied Wooden Ridges

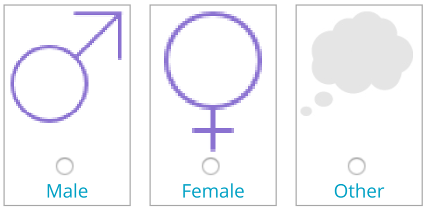
Plastic polyester buttons were applied to help distinguish the buttons location

Questionnaire used during testing

1 About you...

a. What is your gender?

None of the following questions can be used to identify you. Also note that all of your answers will be kept strictly confidential and will only be used in aggregate.



b. How old are you?

- 18 to 24
- 25 to 34
- 35 to 44
- 45 to 54
- 55 to 64
- 65 or older

c. What is your major?

Ooops! You must make a selection

d. Do you or someone you know have a physical, mental or sensory disability?

◯ Yes ◯ No

Printed electronics involves the manufacture of electronic components and equipment with the aid of normal printing processes. How familiar are you with the field of printed electronics in general?

Remember that there are no right or wrong answers. We'd just like to hear your honest opinion.

◯	◯	◯	◯	◯	◯
1	2	3	4	5	6

Not at all familiar — Extremely familiar

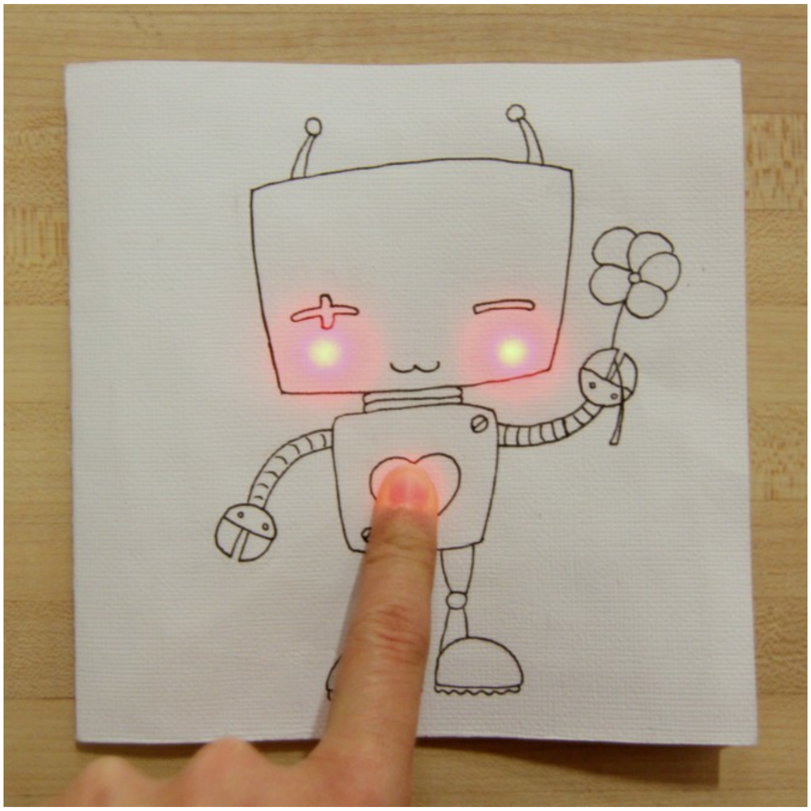
---

3 How frequently do you use...

a. ... the accessibility settings, such as Zooming, invert colors, grayscale, modifying text, or subtitles on your electronic devices?

◯ I use them often ◯ I use them occasionally ◯ Have used them, but don't anymore
◯ Never used them ◯ Prefer not to answer

b. ... printed interactive electronic products such as interactive greeting cards that light up when you touch them?



○ I use them often ○ I use them occasionally ○ Have used them, but don't anymore
○ Never used them ○ Prefer not to answer

Before this trial, how familiar were you with this printed electronic?

Remember that there are no right or wrong answers. We'd just like to hear your honest opinion.

○	○	○	○	○	○
1	2	3	4	5	6
Not at all familiar					Extremely familiar

---

5 What is your impression of this product?

○ 1 ○ 2 ○ 3 ○ 4

How easy was it to use the printed electronic product?

Remember that there are no right or wrong answers. We'd just like to hear your honest opinion.

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6

Not at all easy — Extremely Easy

7 Why did you choose that score?

Remember that there are no right or wrong answers. We'd just like to hear your honest opinion.

What level of accessibility do you feel this product has?

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10 ○ 11

Not accessible at all — Accessible to some — Accessible to everyone

9 Why did you choose that score?

Remember that there are no right or wrong answers. We'd just like to hear your honest opinion.

10 Do you feel this product was designed with accessibility in mind?

○ Yes ○ No

11 Did any features stick out to you as being the most helpful?

Remember that there are no right or wrong answers. We'd just like to hear your honest opinion.

12 What did you find the most frustrating with this device?

Remember that there are no right or wrong answers. We'd just like to hear your honest opinion.

13 How would you improve this design?

14 When you think of good **accessibility** focused electronics, what brands come to mind?

Remember that there are no right or wrong answers. We'd just like to hear your honest opinion.

How likely are you to buy an accessibility focused product over its competitor?

1	2	3	4	5
It doesn't matter to me		Sort of likely		Most likely

16 Why did you choose that score?

Remember that there are no right or wrong answers. We'd just like to hear your honest opinion.

17 Overall Comments

Submit

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