MATUTO, MAGBASA, MAGLARO: LEARNING TO READ BRAILLE THROUGH PLAY

by

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Abstract

In 2016, Digital Learning for Development and All Children Reading released a "Grand Challenge for Development" urging researchers to explore the barriers that children with sensory disabilities in the Philippines face regarding learning how to read. Close to half a million people are blind and many more have low vision in the Philippines. The primary goal of this study was to engage in the co-design process to create a device to help children in the Philippines and Canada with visual impairments learn braille.

Questionnaires that aimed to identify the barriers of using existing devices for reading were released to participants in the Philippines and Canada. Results showed that problems with existing devices were associated with device accessibility, portability, durability, usability and function. Participant feedback was further analyzed and incorporated in the brainstorming of a device that could help teach braille to children with visual impairments in the Philippines and Canada. Using results from a weighted evaluation matrix analysis and feedback from partners in the Philippines and Canada who taught reading to persons with visual impairments, a design was selected to prototype. Two prototypes were created. The most current prototype was an interactive pegboard that mimicked four braille cells. The device asked the user to form a letter or spell a four-letter word in braille using pegs, then either congratulated or corrected the user depending on the user's performance. Usability testing showed that participants liked the device and found it easy to use and interactive. Suggestions for improvement included adding various modes for users of varying reading levels, reducing the size, weight and cost of the device and adding a headphone port.

Results from this study highlight advantages of engaging in the co-design process and provide important data for other researchers developing devices for persons with visual impairments.

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Chapter 1

Introduction

1.1 Introduction

According to the World Health Organization (WHO), there are an estimated 285 million people in the world living with visual impairments [1]. In Canada it is estimated that half a million people live with significant vision loss that affects their quality of life [2]. Many people with visual impairments (low vision or blindness) have difficulty gathering information from their surroundings or communicating with others [3], [4], [5]. Education, job opportunities and social participation are limited as a result [2], [3], [4]. In September of 2016, Digital Learning for Development and All Children Reading released a "Grand Challenge for Development" to explore the barriers that children with sensory disabilities in the Philippines face that impede their ability to learn and read. This "Grand Challenge" identified the need for improved assistive technologies to help children with sensory disabilities learn to read. In the Philippines, close to half a million people are blind and many more have low vision [6]. Often, children in the Philippines with visual impairments (VI) do not have access to the necessary resources needed to assist with learning how to read [7], [8].

There were three goals of this research:

1. Identify the barriers that children in the Philippines and Canada with VI face in regards to using existing devices that help them learn to read.
2. Engage in the co-design process and develop or modify a device that could help children of the Philippines and Canada with VI learn how to read.
3. Determine the extent to which the created device was able to fulfill the needs identified from Goal 1.

1.2 Thesis Layout

This thesis follows the co-design process which involved soliciting information from end-users, iterating on several design concepts, and developing a useable tool to teach reading to individuals with visual impairments. The chapters following this introduction are:

- Chapter 2: Background information regarding assistive technology for the VI, the need for improved technology for the VI, and the co-design process are presented.
- Chapter 3: This chapter explores the limitations of reading devices used by persons with VI of the Philippines and Canada. Device needs and limitations within the categories of accessibility, portability, durability, usability and function are identified.
- Chapter 4: A description of the device that aims to help children with VI in the Philippines and Canada learn to read is presented. Iterative design and testing is described.
- Chapter 5: Results from usability testing of the most recent prototype are discussed.
- Chapter 6: Included in this chapter is a summary of contributions of this thesis and recommendations for future work.

Chapter 2

Background

2.1 Co-Design Process

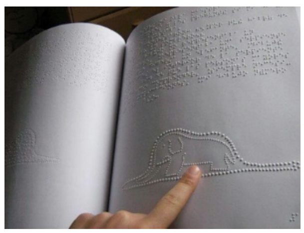
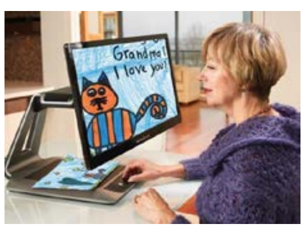
According to Phillips and Zhao, it is estimated that 29.3% of assistive devices are abandoned [9]. Some reasons for abandonment include worsening in physical status, non-acceptance of the device, insufficient/lack of information and training and inappropriateness of the device [9], [10], [11]. To reduce device abandonment, multiple studies have shown that incorporating end-users in the evaluation, prescription and/or creation of their own devices can lead to lower abandonment rates [10], [12]. Co-design is “an umbrella term covering both ‘community design’ and ‘participatory design’. As such, [co-design is defined as] the effort to combine the views, input and skills of people with many different perspectives to address a specific problem” [13].

Couvreur *et al.* presented a study where a client with a disability, Fred, was unable to lift his head entirely, resulting in a decrease in his field of view. Fred had a negative attitude toward assistive devices, but agreed to engage in the co-design process to find a device to help him. As an interdisciplinary team consisting of Fred, his caregiver, an industrial design student, an occupational therapy student and other stakeholders, Fred’s team was determined to devise a solution to help him. Throughout the design process, Fred was able to identify his needs and provide feedback and suggestions for improvement on the device that was created for him by the team. Due to his positive interactions with the team and his ability to provide input on the project, by the end of the project, Fred was very happy with his device and even volunteered to promote his assistive device for a local television crew [14]. This study showed the positive effects of incorporating end-users in the design process. As well, other than increasing device adoption, research shows that incorporating end-users throughout the design process can lead to better concept generation, a decrease in numbers of iterations needed, a reduction in the time and cost of development through the identification of design flaws early in the process and better attitudes [11], [14].

2.2 Assistive Technology for the Visually Impaired

Assistive technology is an umbrella term that encompasses both assistive products (or devices) and related services [15]. The International Classification of Functioning, Disability and Health (ICF) defines assistive products or technology as "any product, instrument, equipment or technology adapted or specially designed for improving the functioning of a disabled person" [16]. To help improve the quality of life of persons living with VI, there has been an increase in the development of assistive technologies [17], [18]. Some areas of assistive technology development for the visually impaired or blind include mobility, navigation, object recognition, social interaction and printed information access [8], [17]. Table 1 displays some examples of devices or tools used for reading by persons with visual impairments.

Table 1: Examples of devices used by persons with VI to help learn to read or to read – Refreshable braille display [19], braille book [20], screen reader [21], magnifier [22]

	**Refreshable braille displays** use an electromechanical system to form the raised dots of braille by pushing pins through holes on a flat surface [18]. By connecting a refreshable braille display to a computer, its user is able to read the text on screen by feeling the raised dots on the braille display.
	**Braille books** are created similar to regular print books, however, no ink is used. Instead, transcribers transcribe regular print into a braille format. The transcribed content is sent to a braille printer, where paper is embossed with braille dots [23].
	**Screen readers** allow their users to access information on a screen through audio. When a user scrolls over readable content with his or her cursor, the screen reading software tells the user the content [24].
	**Video magnifiers** use cameras to magnify content onto a television screen or computer monitor. Typically magnification level and focus can be adjusted based on user preferences [25].

Braille is a system, invented in 1809 by Louis Braille, that uses raised dots to allow persons who are visually impaired to read [26], [27]. Letters or symbols are formed within a space called a cell [26], [27]. A full cell consists of six dots, arranged in a formation of two columns and three rows [26], [27]. Depending on which dots are raised, symbols representing either an alphabet letter, number, punctuation mark, or whole word can be formed [26], [27]. To read braille, readers gently glide their fingers over a surface, such as paper, embossed with braille to feel the patterns of raised dots [26], [27]. In 2010, it was reported that in Canada, only 10% of persons with visual impairments could read braille [28]. The lack of braille education is partially attributed to several social factors. In 2012, Rogers created a survey for pupils who were learning braille and print simultaneously. Rogers' findings revealed that it was unlikely for some pupils to use braille because it would make them appear different from their peers. Another factor leading to the rejection of braille was family influences. Some parents of children learning braille thought of braille as an "outward sign of [their children's] difficulties and wanted [their children] to be 'normal'." For children with parents who did not support braille learning, there was slow progress when learning braille which sometimes led to the full rejection of braille [29].

2.3 The Need for Improved Technologies for Individuals with Visual Impairments

According to All Children Reading, "Literacy unlocks human potential and is the cornerstone of development. It leads to better health, broadens employment opportunities, and creates safer and more stable societies" [30]. The lack of reading skills development of children during primary education often results in poor educational progress and eventually, limited economic opportunities [30]. In Canada it is estimated that half a million people live with significant vision loss that affects their quality of life [2]. Unfortunately, of the population of working-age adults with vision loss in Canada, only one-third are employed [2]. To improve the chances of employment for persons with visual impairments, a study by Ryles suggested that teaching braille to children "may encourage them to develop the positive lifelong habit of reading as adults" [31]. Ryles's results showed that participants who had learned to read braille as their original primary medium had a significantly lower unemployment rate compared to participants that had learned to read print as their original primary medium [31].

Russomanno *et al.* stated that for blind computer users, the preferred method of “reading” electronic text is through speech because “it is relatively inexpensive (or even free) when compared to braille and requires no additional hardware” [32]. However, this method of “reading” may not be optimal due to mind wandering. Varao-Sousa *et al.* described mind wandering as the process where a reader finds his or her mind wandering to thoughts unrelated to the text they are reading [33]. In another study by the same authors, findings showed that participants experienced less mind wandering when engaged in active modes of reading such as reading aloud in comparison to listening [34]. Thus, Russomanno suggested that active reading of braille could be better for information transmission for a blind reader and could lead to better comprehension of text compared to plain listening [32].

The World Health Organization states that 39 million people worldwide are blind and 246 million have low vision [35]. Of this population, 19 million children are visually impaired, and 1.4 million are irreversibly blind for the rest of their lives [35]. For these children, visual impairment often leads to serious social challenges such as lack of future employment, decreased social participation and barriers to education [2], [3], [4]. To help combat childhood illiteracy, Digital Learning for Development and All Children Reading (ACR GCD) urged researchers to explore the barriers that children with sensory disabilities in the Philippines face that impede their ability to learn and read [36]. There are an estimated half a million people in the Philippines who are blind and many more who are visually impaired [6]. Unfortunately for blind or visually impaired persons in the Philippines hoping to learn to read, there is a lack of accessibility to specialized materials necessary for this process [8]. This is a problem because “the inability for a blind person to read is one of their greatest disappointments” [8]. ACR GCD believes that many of the barriers that children with sensory disabilities face in regards to learning how to read could be addressed through technology-enabled innovations [36]. However, what are these barriers that children with visual impairments in the Philippines and Canada are facing in regards to using existing devices that help them learn to read? Also, how do the barriers of the people of the Philippines compare to the barriers that persons with visual impairments in Canada face?

2.4 Purpose

There were three goals of this research:

1. Identify the barriers that children in the Philippines and Canada with visual impairments face in regards to using existing devices that help them learn to read.
2. Engage in the co-design process and develop or modify a device that could help children of the Philippines and Canada with visual impairments learn how to read.
3. Determine to the extent to which the created device was able to fulfill the needs identified from Goal 1.

Chapter 3

Identifying User Needs and Technical Specifications

3.1 Chapter Overview

This chapter presents the results from a questionnaire designed to identify the barriers that children in the Philippines and Canada with VI face in regards to using existing devices that help them learn to read. Also shown is the brainstorming and decision making processes followed to select a device that could help children with VI in the Philippines and Canada learn braille.

3.2 Methods

This section showcases the process conducted by the study investigator to develop and choose a design to prototype. The steps taken include creating and distributing a preliminary questionnaire, using QFD matrices and the Kano method, engaging in the parallel design process, using a weighted evaluation matrix and conducting semi-structured interviews.

3.2.1 Questionnaire

Questionnaires that aimed to identify the barriers that children with VI in the Philippines and Canada face regarding using devices that help them learn to read were distributed to both countries through project partners.

3.2.1.1 Ethics

Ethics approval for this questionnaire was granted from Queen's University's General Research Ethics Board under the Project Title: GMECH-040-16 Technology-enabled innovations to assist children with visual impairments or blindness in the Philippines (Appendix 6.3).

3.2.1.2 Questionnaire Creation

Three different questionnaires were created in FluidSurveys to determine the barriers that children in the Philippines and Canada with VI face in regards to using existing devices that help them learn to read. The three questionnaires were similar to each other, but phrased differently to target each participant group. All questionnaires comprised of four main sections: General Information, Specialized Schools or Programs, Reading Environment and Reading Devices. For the questionnaire for teachers, there was an additional section: Teaching Reading to Persons with VI. For a list of questions asked to participants learning to read, please see Appendix 6.4.

3.2.1.3 Participants

Individuals living in the Philippines or Canada were invited to complete the questionnaires if they were either:

- below the age of 18, living with visual impairment and learning how to read;
- any age, living with visual impairment and had already learned how to read;
- or teaching reading to persons with visual impairment (e.g. teachers, parents of children with VI, etc.)

Participants were recruited by partners in the Philippines and Canada who worked with persons with VI. Letters of Information for the study were given to these partners, and if these partners believed an individual qualified for the study, the partners would show them the Letter of Information and allow the individual to decide whether to participate. Questionnaires were distributed in the Philippines because the need for improved assistive technologies was identified by ACR GCD. As the study investigator was located in Canada, questionnaires were sent to Canadians as well.

3.2.1.4 Questionnaire Completion

If the individual agreed to participate in the study, they would be provided a link to the online questionnaires on FluidSurveys. Questionnaires were completed between early December 2016 and late January 2017.

3.2.2 Quality Function Deployment (QFD)

The QFD method identified device needs from the questionnaires and prioritized them among and between participant groups. Three QFD matrices were made relating to each participant group. For each QFD matrix, the identified device needs, also known as the customer requirements, were listed in the first columns; technical specifications were written along the first rows of the matrices; either strong, moderate or weak relationships were determined between the customer requirements and technical specifications; and on the bottom of the QFD matrices, the relationships between customer requirements and technical specifications were scored. A high technical specification score (relative to other technical specification scores) indicated targets to increase customer satisfaction.

3.2.3 Kano

The Kano model was used to obtain a visual representation of how each identified device need would contribute to customer satisfaction. Device needs were put in one of four groups relating to varying customer satisfaction. These groups were: Attractive, One-Dimensional, Indifferent and Must Haves. Attractive needs add satisfaction to the customer, but their absence does not detract from customer satisfaction [37]. One-dimensional needs can either satisfy or dissatisfy the customer based on whether or not they are present [37]. Indifferent features neither add nor detract from the satisfaction of the customer [38]. Must Haves are needs that on their own cannot satisfy a customer, but will lead to customer dissatisfaction if they are missing [37].

3.2.4 Parallel Design Process

To generate a variety of device design ideas, the parallel design process was followed. Nielsen and Faber state that some advantages of using parallel design include speeding up time-to-market by exploring design alternatives simultaneously and better usability of designs [39]. Results from the questionnaires, QFD matrices and Kano model were presented to six members of the Building and Designing Assistive Technology (BDAT) Lab. Five members had backgrounds in mechanical engineering, while the other member was an occupational therapist. Each lab member and the study investigator were given 30 minutes to independently brainstorm and draw sketches of potential devices to help children of the Philippines and Canada with VI learn to read braille. When time had expired, each lab member presented his or her ideas, after which pros and cons of each design were identified. Once all design ideas had been presented and critiqued, a new set of conceptual designs, based on the best features of the initially brainstormed ideas, were established.

After meeting with her peers, the study investigator merged the pros of the different potential ideas of her peers to create a new set of potential device ideas.

3.2.5 Weighted Evaluation Matrix (WEM)

A weighted evaluation matrix was used to determine which potential design would be able to best satisfy the needs identified from the questionnaires. Identified needs were listed along first column of the matrix. The weighting for each need was calculated out of 100%, based on the frequency with which each identified need was indicated in the questionnaires, and listed in the column beside the corresponding need. Along the top of the matrix was each design idea. Scores 0-2 were assigned by the study investigator to each device for each need depending on how well the device would be able to satisfy each need. A score of 0 meant that theoretically the device would not be able to meet the need, a score of 1 meant that it would somewhat meet the need and a score of 2 meant that it would be able to meet the need. Following the assignment of scores, each score was multiplied by the weighting of each need, and total scores for each design were calculated.

3.2.6 Interviews

Two semi-structured interviews were conducted with partners in the Philippines and Canada.

3.2.6.1 Ethics

Ethics approval for usability testing was obtained from Queen's University's General Research Ethics Board under the Project Title: GMECH-043-17 Matuto, Magbasa, Maglaro: Learning to read in braille through play (Appendix 6.5).

3.2.6.2 Semi-structured Interviews

All names in this section were changed to ensure participant anonymity as stated in GMECH-043-17. Semi-structured interviews with a partner in the Philippines, Maria, and a partner in Canada, Susan, were performed after the WEM analysis had been completed. Both partners teach reading and braille to persons with VI. The interview with Maria was conducted via phone call, while the interview with Susan was carried out in person. The main purpose of these interviews was to obtain feedback on the different device ideas. They also provided the study investigator with an opportunity to learn more about how braille is learned, and the tools and devices used to teach braille in both the Philippines and Canada.

3.3 Results

3.3.1 Questionnaire – Philippines

Participants were recruited by a partner in the Philippines to complete a questionnaire that aimed to identify the barriers that children in the Philippines face in regards to using existing devices that help them learn to read. The following results reveal data gathered from the participants' responses to the questionnaires.

3.3.1.1 Participants

A total of 42 participants from the Philippines completed the questionnaires. There were 21 responses received from participants with VI who were learning how to read, 11 from persons with VI who had already learned how to read and 10 from individuals who teach reading to persons with VI.

3.3.1.2 General Information

Figure 1 shows the level of visual function of the participants of the three participant groups. Levels of visual function were disclosed by the participants when answering the questionnaire.

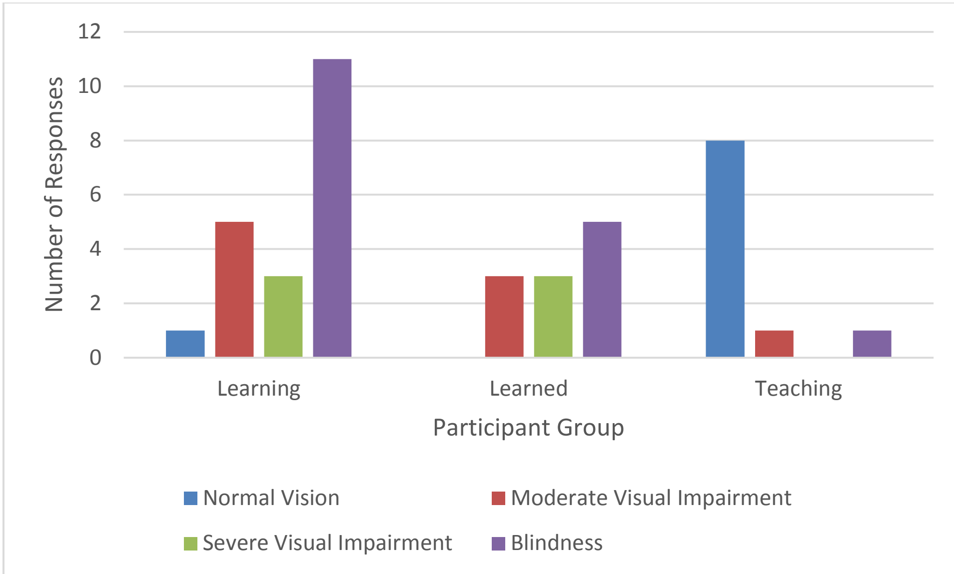


Figure 1: Level of visual function of participants from the Philippines

From observing Figure 1, it was evident that most of the participants who were either learning or had already learned how to read were blind, while most of the teachers had normal vision.

Figure 2 summarizes the languages that the participants were either learning, had learned or were teaching reading.

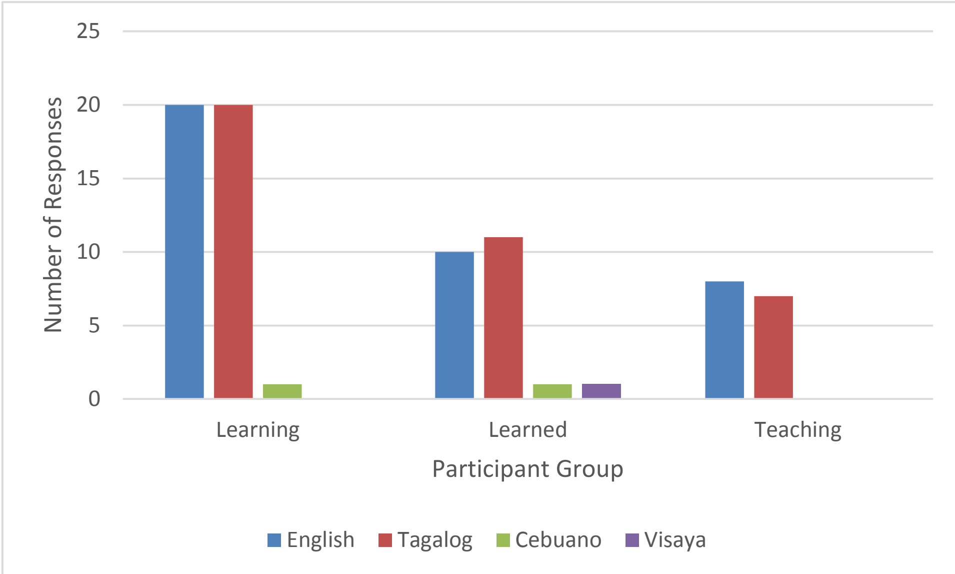


Figure 2: Languages that participants from the Philippines were either learning, had learned or were teaching reading

Figure 2 revealed that most participants were either learning, had learned or were teaching reading in both English and/or Tagalog.

Table 2 reveals why participants from the Philippines wanted to learn, had learned or believed their students wanted to read.

Table 2: Reasons for learning to read

Reason	Learning	Learned	Teaching	Total
Educational purposes	3	8	5	16
Independence	3	2		5
Skill Enhancement	4			4
Daily living	4			4
Personality development		1		4
For fun	3			3
Key to advancing in life			3	3
Travel		3		3
Communicate	1		2	3
In case he/she goes blind	2			2
Help with socialization	1		1	2
Help with work	1			1
Wants to teach people with VI	1			1

As seen from Table 2, most participants wanted to learn, had learned or believed their students wanted to learn to read for educational purposes. Many other participants wanted to learn, had learned or believed their students wanted to learn to read to develop social skills or to aid with everyday activities. For a list of quotes from participants regarding why they were learning, learned or believed their students learned how to read, please refer to Appendix 6.6.

3.3.1.3 Reading Environment

When participants were asked where they liked to read, or read most often, they revealed the locations shown in Figure 3.

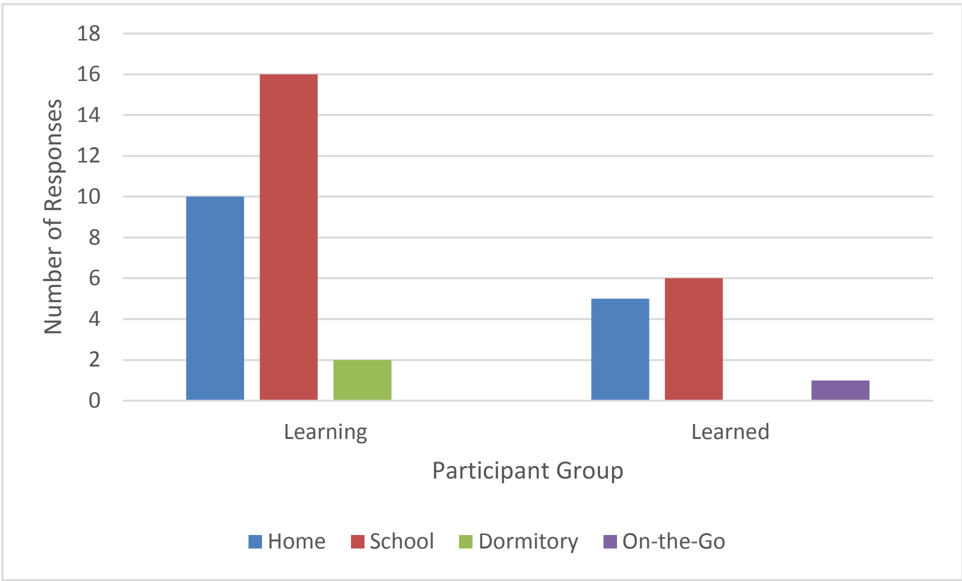


Figure 3: Locations where participants from the Philippines read

Most participants read either at home or at school as evidenced by Figure 3.

3.3.1.4 Teaching Reading to Persons with Visual Impairments

When teachers were asked how many students they taught, two said that they taught five or fewer, four taught between six and twenty students, one taught more than twenty and another taught more than 100 students. These results showed that the number of students that the participants taught varied between fewer than five and more than 100. Responses from participants did not specify whether these numbers represented how many students were taught at one time or combined.

3.3.1.5 Reading Devices

Feedback from the ‘Reading Devices’ section of the survey revealed that many devices are available and used in the Philippines to help people with VI learn to read or to read. Some examples of the devices included (braille) books, computers, cellphones and screen readers. A full list of devices identified by the participant can be found in Appendix 6.7. The participants identified the pros and cons of the different devices they used or had heard about. These pros and cons were grouped into five categories: accessibility, portability, durability, usability and function. From this process, a total of 43 device needs were found. A list of these device needs with how frequently they were mentioned in the questionnaires can be seen in Table 3.

Table 3: Device needs identified by participants from the Philippines

Device Needs	Total Responses
Accessibility	9
• Affordable	22
• Available in the country	7
	38
Portability	10
• Not bulky	8
• Lightweight	5
• Good battery life	5
• Does not need to be plugged in	1
	29
Durability	7
• Hardware	0
o Not fragile	3
o Does not rip easily	1
• Software	0
o No technical errors/malfunctions	3
o No viruses	3
o No upgrades required	1
	18
Usability (Easy to use)	7
• Adjustable letter size/zoom feature	11
• Adjustable font	7
• Convenient to use/handy	5
• Adjustable colour contrast	4
• Can get work done easily	3
• Easy to navigate/good layout	1
• Anti-glare	1
	39
Function	0
• Feedback	3
o Can read Tagalog / any language	2
o Good pronunciation	2
o Talks back	3
▪ Text to Braille	2
▪ Text to speech	1
o Descriptive/Emotive speech	1
• Effective learning tool	3
o Tactile learning feature	1
o Has pictures	1
• Multifunctional	7
o Screen Reader / Reads content	12
o Dictionary/Thesaurus	4
o Info accessible through multiple devices	2
o Internet	1
o Helps locate research on computer	1
• Reliable	1
o Always reads	1
	48

Device needs relating to the function, or what the device does, were commented on most frequently in the questionnaires (Table 3). Other important requirements included accessibility and usability.

Each participant group identified different device needs. Figure 4 shows the frequency that each device need group was mentioned.

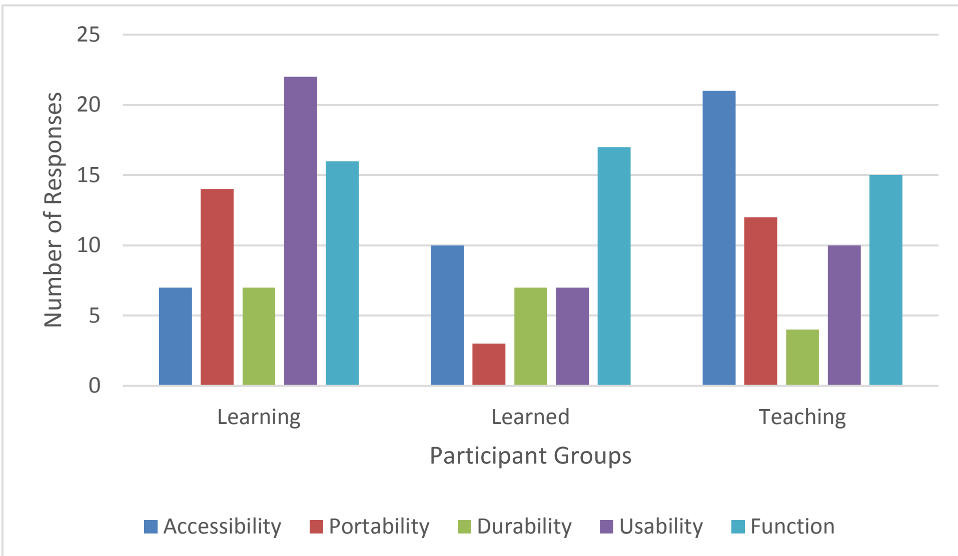


Figure 4: Frequency of device need groups mentioned by participants from the Philippines

Figure 4 showed that each participant group prioritized different device needs. For example, the group learning to read focused on the usability of devices, the group who had already learned how to read prioritized the function of the devices and the group teaching reading highlighted the accessibility of devices most prominently. From these results, the study investigator decided to further analyze the results using the Quality Function Deployment method to determine which needs to prioritize.

3.3.2 Questionnaire – Canada

The questionnaire that was distributed to participants from the Philippines was also distributed to participants in Canada by a Canadian partner, Susan.

3.3.2.1 Participants

Canadian responses were more limited than those from the Philippines. Five questionnaires for each of the three participant groups were expected, but in total, only six questionnaires in Canada were completed. There were no participants with VI who were learning how to read, but there were three participants who had VI and had already learned how to read, and another three participants who taught reading to persons with VI. The three participants who had already learned how to read were blind. Blindness is defined by the WHO as “visual acuity of less than 3/60, or a corresponding visual field loss to less than 10°” [5].

3.3.2.2 Summary of Questionnaires from Canada

Since only six participants from Canada completed the questionnaires, the study investigator was unable to obtain a full understanding of the barriers that persons with VI in Canada face in regards to using existing devices that help them learn to read; however, some key observations were made. Specifically, when responding to the question “What are the best features of this device [that you use(d) to teach (or learn) reading]?”, the participants identified that devices that were low-cost, available to the user, durable, multi-functional, fast and could connect to various devices (eg. computers, cellphones, etc.) were preferable.

When asked if there were any devices that they had heard of any devices that could help them read but did not have access to. The following responses were received:

"[He] doesn't want to own every available version of the same product."
"[I] already own a more expensive display so [I] can't really justify buying another one."

These responses identified that although the participants had access to newer and potentially more developed technology, they already were content with the devices they owned, and did not feel the need to acquire the latest devices/technology available.

When asked about what kind of device would be most beneficial in terms of learning how to read, four responses identified that the development of a refreshable braille display that could display half to a page of braille would be helpful.

3.3.3 Quality Function Deployment

Three different QFD matrices (one for each participants group) were created. For each QFD matrix, user identified device needs were included and technical specifications were determined. The QFD matrices can be found in Appendix 6.8. Table 4 summarizes the highest scoring technical specifications from each participant group's QFD matrix.

Table 4: Ranking of technical specifications from QFD matrices

Rank	Learning	Learned	Teaching
1	Cost	Cost	Cost
2	Engaging	Engaging	Engaging
3	Material strength	Intuitive use	Volume (Size)
4	Battery life	Teaches how to read in multiple languages	Intuitive use
5	Volume (Size)	Maintenance	Material strength
6	Mass	Battery life	
7	Maintenance	Material strength	
8		Volume (Sound)	
9		No viruses/glitches/malfunctions	

The most common, highest scoring technical specifications among participant groups include ‘cost’, ‘engaging’ and ‘material strength’ (Table 4).

3.3.4 Kano

All device needs were sorted into the four groups of the Kano model. The Kano model generated for this design iteration can be seen in Figure 5.

Device needs were sorted according to the study investigator’s best judgement. This judgement was influenced by the feedback from the preliminary questionnaires. For example, most questionnaires indicated that the participants learned to read or taught reading in both English and Tagalog. Thus, the ‘teaches how to read in both English and Tagalog’ criterion was deemed a ‘Must Have.’

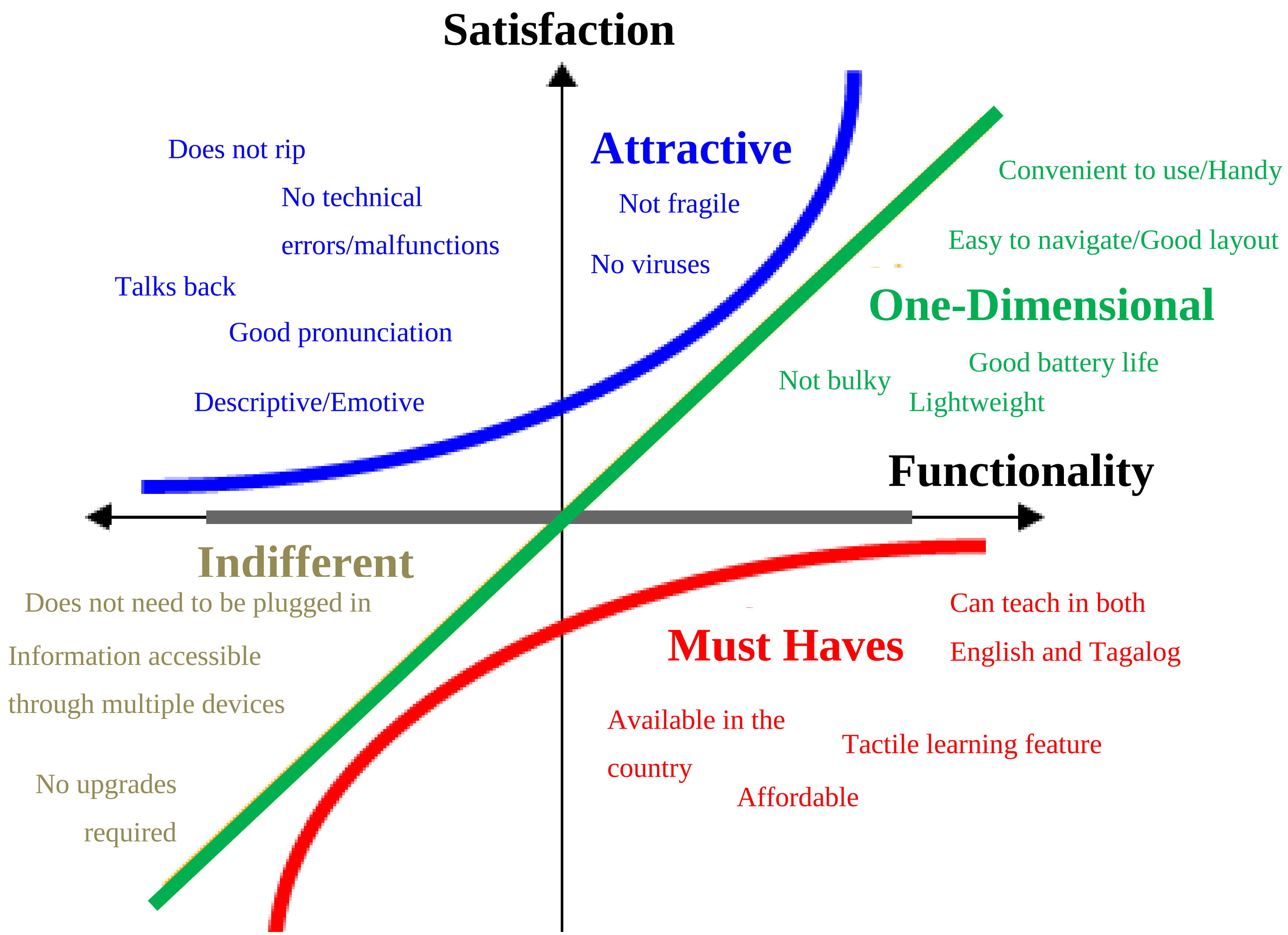


Figure 5: Kano model of device needs identified by participants

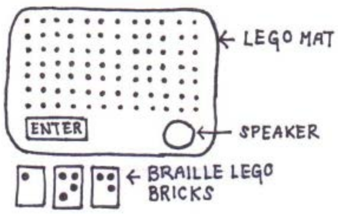
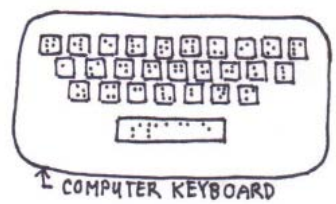
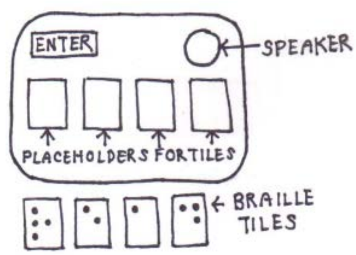
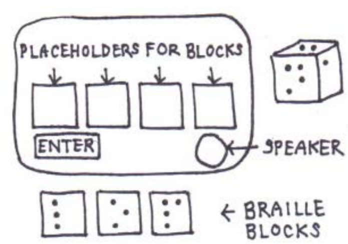
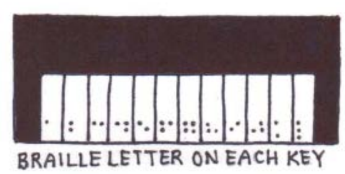
3.3.5 Parallel Design Process (Potential solutions)

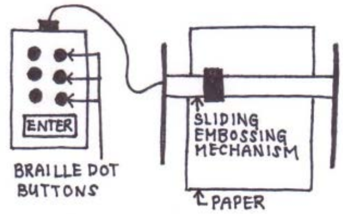
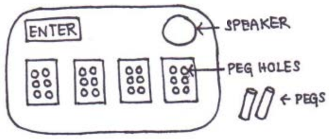
Both the QFD and the Kano were presented to the BDAT Lab members and informed the parallel design process. When presenting the results of the Kano model to her lab group, the research investigator explained how all device needs in the group 'Must Haves' were necessary for any of the ideas to be brainstormed. All other device needs could increase user satisfaction, but were not necessary for a final device. Seven individuals participated in the brainstorming session. From this session, 17 unique device ideas were identified. The various preliminary ideas can be seen in Appendix 6.9.

After the preliminary device ideas had been presented, the study investigator, and the members of the BDAT Laboratory brainstormed new device ideas using the best qualities from the preliminary devices. Seven "merged devices" were established and can also be seen in Appendix 6.10.

The research investigator chose to exclude M5 and M6 as potential designs to prototype, as theoretically they would not be feasible due to time constraints. The study investigator independently critiqued and adjusted the seven remaining device ideas. These modified conceptual designs were considered for prototyping and can be seen in Table 5.

Table 5: Descriptions and sketches of conceptual designs

Design #	Description	Concept Sketch
1	**Braille LEGO brick board** • The board tells the user a word or sentence to write in braille using braille LEGO bricks and says the word once the full word is on the board. • It can connect to other boards to race against friends.	
2	**Keyboard with braille stickers** • A computer or tablet tells the user which key is pressed. • Once a word is typed, it tells the user what was spelled. • The device can connect to multiple devices such as computers, tablets, etc.	
3	**Braille letter, word maker** • The device is comprised of a board with four holes in which to place braille letter pieces. • Once four letter pieces spell out a word in the place holders, the device sings a song related to the word.	
4	**Braille blocks** • Blocks with braille letters on each face (6 faces) can be inserted into slots on a board to spell words. • The board tells the user a word or sentence to write in braille using the braille blocks and says the word once full word is on the board. • It can connect to other boards to race against friends.	
5	**Piano keyboard with braille sticker buttons** • Stickers with braille letters embossed on them are placed on a piano keyboard. • The device tells the user a word or sentence to write in braille using the piano keys and says a word if it is spelled correctly. • It can incorporate a game to go with it	

6	**Braille button embosser** • This device has six buttons representing dots of one braille cell. • If a user wants to write a letter, they press the buttons that represent the raised braille dots of a desired letter. • Once the appropriate buttons are pressed, the device recites the letter. • By pressing the braille buttons, paper is embossed.	
7	**Braille pegboard** • This device is comprised of a board with 24 holes arranged in groups of six that replicate braille cells. • It also includes pegs that represent braille dots when placed in the holes. • When the board says a letter, the device user places pegs in the holes to replicate braille letters.	

3.3.6 Weighted Evaluation Matrix

Table 6 shows the weighted evaluation matrix generated by the study investigator that was used to evaluate the seven device ideas developed from the parallel design process. Weightings were determined based on how frequently design needs were identified by the participants from the questionnaires. The number of times that each need was mentioned was calculated. Each sum was then divided by the total number of mentioned needs, resulting in a percentage weighting.

Table 6: Weighted evaluation matrix (S= Score, WS = Weighted Score)[1]

Design Needs	Weight (/100%)	Design #1		Design #2		Design #3		Design #4		Design #5		Design #6		Design #7	
		S	WS	S	WS	S	WS	S	WS	S	WS	S	WS	S	WS
Affordable	15.5	1	15.5	2	31.0	2	31.0	1	15.5	0	0.0	0	0.0	2	31.0
Available in the country	6.9	1	6.9	1	6.9	2	13.8	1	6.9	1	6.9	1	6.9	1	6.9
Not bulky	5.5	1	5.5	1	5.5	2	11.0	0	0.0	0	0.0	1	5.5	0	0.0
Lightweight	4.2	1	4.2	1	4.2	2	8.5	1	4.2	0	0.0	1	4.2	0	0.0
Does not need to be plugged in	1.9	2	3.8	2	3.8	2	3.8	2	3.8	1	1.9	2	3.8	2	3.8
Good battery life	4.2	1	4.2	1	4.2	1	4.2	1	4.2	0	0.0	1	4.2	1	4.2
Does not rip easily	1.5	2	3.0	2	3.0	2	3.0	2	3.0	2	3.0	2	3.0	2	3.0
Not fragile	2.5	2	5.0	0	0.0	2	5.0	2	5.0	0	0.0	1	2.5	1	2.5
No technical errors/malfunctions	2.6	1	2.6	1	2.6	2	5.1	1	2.6	1	2.6	1	2.6	1	2.6
No viruses	3.0	2	6.0	2	6.0	2	6.0	2	6.0	2	6.0	2	6.0	2	6.0
No upgrades required	1.5	2	3.0	2	3.0	2	3.0	2	3.0	2	3.0	2	3.0	2	3.0
Easy to navigate/good layout	1.3	0	0.0	1	1.3	1	1.3	1	1.3	1	1.3	2	2.6	2	2.6
Convenient to use/handy	2.9	1	2.9	2	5.7	2	5.7	1	2.9	0	0.0	0	0.0	0	0.0
Can teach in Tagalog/any language	2.0	2	3.9	2	3.9	0	0.0	2	3.9	2	3.9	2	3.9	2	3.9
Good pronunciation	2.0	2	3.9	2	3.9	2	3.9	2	3.9	2	3.9	2	3.9	2	3.9
Talks back	3.6	2	7.2	2	7.2	2	7.2	2	7.2	2	7.2	2	7.2	2	7.2
Descriptive/Emotive speech	1.7	1	1.7	1	1.7	2	3.4	1	1.7	1	1.7	1	1.7	1	1.7
Tactile learning feature	1.3	2	2.7	2	2.7	2	2.7	2	2.7	2	2.7	2	2.7	2	2.7
Info accessible through multiple devices	1.8	1	1.8	2	3.6	0	0.0	1	1.8	2	3.6	0	0.0	0	0.0
Total Score			**83.6**		**100.1**		**118.4**		**79.4**		**47.6**		**63.5**		**84.8**

[1] Eleven design needs were omitted from this table because they were identified from the questionnaire by participants with some vision. Following the analysis of the questionnaire results, it was decided that a device that could be used by persons with blindness would be created or modified.

By interpreting Table 6 it is apparent that Design #3, the ‘Braille letter, word maker’ ranked the highest with a score of 118.4. Design #2, the ‘Keyboard with braille stickers’ ranked second with a score of 100.1, while Designs #7 (‘Braille pegboard’) and #1 (‘Braille LEGO brick board’) ranked third and fourth with similar scores of 84.8 and 83.6, respectively. Design #4, ‘Braille blocks’, ranked fifth with a score of 79.4.

3.3.7 Interviews

Semi-structured interviews were conducted with partners in both the Philippines (Maria) and Canada (Susan) who taught reading to persons with visual impairments to learn more about the braille learning process and obtain their thoughts on the design ideas.

3.3.7.1 Interview with Maria

When talking with Maria, she stated that before she taught them braille, her students had to develop their tactile skills. Students were given pieces of cloth of different textures and had to feel for which fabrics were the same. Other activities focused on developing tactile skills included opening bottles (to increase dexterity and strength) as well as putting blocks into containers one-by-one. After these skills had been sufficiently developed, the students would begin learning the braille alphabet using toy eggs and egg cartons that had been cut in half to mimic the six dots of a braille cell (Figure 6). Students were instructed to put the toy eggs in the egg cartons in specific patterns replicating braille letters. Once the students were familiar with the different braille letters, they learned how to use a slate and stylus to write in braille and a brailler to type in braille.

Figure 6: Tool used by Maria to help teach braille. This arrangement of golf balls in the egg carton represents the braille letter ‘C’

Maria also provided her thoughts on five potential solutions that ranked highest when using the WEM (Table 7). She also suggested that if possible, adding a ‘game’ aspect to a device could improve her students’ engagement levels when using a device.

Table 7: Design feedback from Maria

Design #	Maria's Feedback
1	• The device would be used for beginners and toddlers in Grades 1-2. • It would have a lot of pieces (LEGO) that the students might lose. • Having many pieces might make the device difficult for students to use. • Maria ranked this design third out of five.
2	• This design is similar to an existing device (JAWS). • Maria felt "half-hearted" regarding moving forward with this idea. • Maria ranked this design fifth out of five.
3	• Even though the device could only teach in English, it could still be a beneficial teaching tool. • However, her students might get bored of hearing the same songs. • Maria ranked this design fourth out of five.
4	• Maria liked this design idea more than Design #1 since although both devices are similar, this one would require fewer pieces. • It would be likely that fewer pieces would get lost in comparison to Design #1. • This device tied for first with Design #7.
7	• This device would be beneficial for young children who were being introduced to braille. • Maria liked that this idea was similar to the egg carton activity that already exists. • The added features (i.e. the device telling the students which letter to replicate and feedback as to whether the student was correct) would eliminate the need for a parent or teacher present. • This device tied for first with Design #4.

Maria liked Design 4 ('Braille blocks') and Design 7 ('Braille pegboard') the most. Her least favourite design was Design 2 ('Keyboard with braille stickers'). Before commencing the prototyping stage, the study investigator sought guidance from one of her partners in Canada, Susan.

3.3.7.2 Interview with Susan

The semi-structured interview with Susan revealed similarities regarding how children with VI develop braille skills when learning to read between the Philippines and Canada. Children taught by Susan were first trained to recognize shapes and textures. Susan had a book with various plastic shapes on each page that she used during her lessons. She would ask her students to identify which shapes they were touching and whether there were additional smaller features on those shapes (such as a rectangular door with a small circular doorknob). Once her students had sufficiently developed their tactile skills, they learned the braille alphabet. Susan used a paint pallet with six holes (three rows, two columns) and small balls to teach braille. The balls, when placed in the pallet in specific arrangements, would represent the dots of a braille cell for the different letters. This activity was the same as the egg carton activity explained by Maria. Once her students knew the letter arrangements, they would progress to using a brailler to type in braille.

3.3.8 Selecting a Design to Prototype

The WEM identified that Design 3 would be the best design to prototype. However, when Maria was interviewed, Designs 4 and 7 were chosen as her favourites. The interview with Susan identified that a similar existing learning tool (egg carton) was also used in Canada. The study investigator chose to move forward with Design 7 to enable potential use of the device in both the Philippines and Canada.

3.4 Discussion

The study investigator, end-users and other stakeholders were involved in each step of the co-design process. Results from the questionnaires and semi-structured interviews all contributed to the creation and selection of the designs. Of the 42 participants from the Philippines who completed the questionnaire, 17 were blind. It was determined that to best meet the needs of these participants, the device should be able to teach braille. The questionnaire also revealed that most participants were either learning, had already learned or were teaching to read in both English and Tagalog. The study investigator decided that the device had to be able to teach braille in both English and Tagalog. Participants also revealed that reading occurred both at home and school. From these findings, it was determined that the device should be usable both at home and school. Since the teachers revealed that they taught between five to over one hundred students, it was decided that creating a device that would be usable without the assistance of a teacher could be advantageous to students learning to read.

Forty-three device needs were identified by the participants of the Philippines. These needs were sorted into five categories: accessibility, portability, durability, usability and function. The device need most frequently mentioned was “affordable”. In Manila, the average salary is 383 226 PHP which is equivalent to approximately $9 400 CAD [40]. In comparison, the average salary for a worker in Toronto is $58 618 CAD [41]. Participants in Canada identified that a problem with devices used to learn how to read or to read was that they already owned the most expensive version of a certain type of device, so it did not make sense to purchase another. On the other hand, in the Philippines, respondents expressed that they experienced difficulties in simply accessing devices because they either were unavailable in the country, or were too expensive. The economic differences between countries highlighted the importance of keeping the cost of the device as low as possible so that people in both countries would have access to the braille learning device.

While 75% of the cost of assistive devices in Ontario are paid by the Ontario Ministry of Health through the Assistive Devices Program, in the Philippines, devices for personal use require the individuals themselves to cover the full costs. Many individuals do not have money to spend on these devices and alternatively, may only have access to the devices at their schools. In the Philippines, schools are responsible for obtaining the devices either independently or through donors. Thus, social systems are an additional barrier that prevent device users from accessing the devices they need.

To inform the parallel design process, QFD and Kano was used. To satisfy the greatest number of and/or most important device needs identified by the participants, the technical specifications that needed to be prioritized included ‘cost’, ‘engagement level’ and ‘material strength’. Although there were many device needs identified from the questionnaires, using the Kano model allowed the researcher to determine which ones to prioritize.

When comparing the results from the WEM and the semi-structured interview, it was observed that the design rankings were different. The top five designs of the WEM from best to worst were Design 3, Design 2, Design 7, Design 1 then Design 4. Maria ranked Designs 4 and 7 equally, followed by Designs 1, 3 and 2. The subsequent interview of Maria led to a re-evaluation of the best design. Had she not been interviewed, it is likely that the designer would have begun the prototyping stage on Design 3, a design that was not desired by at least one key stakeholder. Both Designs 4 and 7 were ranked poorly using the WEM, but positively by a potential end-user. This suggests the importance of including the stakeholders in the design process and strengthens the importance of co-design. There are several advantages to involving users in the design process. For example, findings by Kujala found that the co-design process could reduce the number of iterations needed; improve the levels of acceptance of the design; and reduce the time and cost of development through the identification of design flaws early in the process [42]. Additional advantages included better concept generation and an overall increase in user satisfaction [11], [43].

Ideally, end-users would be engaged in all parts of the design process including the creation of the QFD matrices, WEM and prototyping stages. However, additional time and monetary costs necessary for these engagements to occur reduce the ability to include end-users in all stages of the process. Thus, there is a trade-off between how much input can be sought and integrated.

Overall, findings from this study revealed that engaging in the co-design process can help reduce designer biases regarding the designer's interpretation of what the user wants. It is recommended that designers, end-users and other stakeholders be involved in the device development process to ensure usable, fit-for-use devices that stakeholders actually want, are created.

3.5 Limitations

Question phrasing was one limitation of the questionnaires. There was room for confusion based on participant interpretation. For example, participants who were learning or had already learned how to read were asked "Where do you read most often?" It is unclear whether participants who were learning braille were actually answering the question "Where do you learn to read most often?" instead. To reduce the changes of ambiguity, it is recommended that if this process was to be repeated, follow-up interviews with participants who completed the questionnaires be conducted to clarify any vague responses. Alternatively, instead of the questionnaires, an interviewer could conduct interviews to ensure understanding. As well, some of the device needs were not clearly defined by the participants. For example, 22 responses highlighted the affordability of their devices, but no quantitative amount was specified to be "affordable".

Observing only the sum of all of the responses may not have given a true representation of participant group preferences as the number of participants from each group varied. Larger user group numbers may have had larger influences on weighting priority based on which needs were identified. If this study was conducted again, it would be better if a follow-up questionnaire could be released, asking participants to rank each identified device need based on importance.

The WEM scores were determined based on the opinions of the designer. Although the designer aimed to be as unbiased as possible, different observers may yield different results. A follow-up questionnaire completed by the participants that ranked each need based on importance or additional interviews with end users would also help reduce designer bias.

Another limitation of this study was that only one end-user was asked to rank the conceptual designs in each country. Both perspectives were from one group of participants (braille teachers). If this study were to be repeated, more participants representing more participant groups should be included in the analysis.

3.6 Conclusions

Based on user feedback, Design #7 (‘Braille pegboard’) was chosen to be further developed. This study showed that the greatest barrier that persons in the Philippines with VI face in regards to using existing devices that help them learn to read was that they are not accessible. Specifically, many devices are too expensive or not available in the Philippines. Efforts must be made to create accessible, portable, durable, easy to use and well-functioning devices so that persons in the Philippines with VI can to learn how to read.

It is imperative that designers work with end-users and other stakeholders to ensure that devices being made suit user needs. Without input from end-users, devices that are created may not satisfy user needs, leading to dissatisfaction, wasted resources and device abandonment.

Chapter 4

Prototype Creation and Preliminary Testing

4.1 Chapter Overview

Presented in this chapter are two prototypes of BraillePad, a device designed to help children in the Philippines and Canada learn braille. Usability tests conducted on both prototypes are also described.

4.2 Prototype 1

As indicated from Chapter 3, the ‘Braille pegboard’ was chosen to be prototyped. A photo of the first prototype (P1) can be seen in Figure 7.

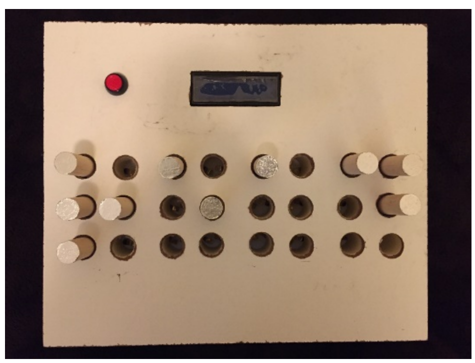


Figure 7: Top surface of Prototype 1

P1 consisted of 24 holes (i.e. four groups of 3x2 holes, scaled to mimic four full braille cells). Hole spacing and diameter were scaled according to braille standards [44]. This device had the capability of asking the user to spell words in either English or Tagalog. To use the device, the user wore headphones and plugged them into an MP3 shield, then plugged the battery into the device’s microcontroller to turn it on. Once on, the device told the user to, “Please press the start button.” Upon pressing the button, the device asked the user to either form a letter in braille or spell a four-letter word in braille. Then, using the pegs, the user attempted to place them into the holes corresponding to the dots of the braille letter or letters. If the user's answer was correct, BraillePad congratulated them then said a new letter or word to spell in braille. If the user's answer was incorrect, it told them they were wrong and let them enter a new answer.

4.2.1 Hardware

The prototype included mechanical construction and electrical components. Hardboard was used for the main structure of P1. For the top surface, holes were drilled or cut using a jigsaw. Tubing (3/4") was cut and used as peg guides as well as legs for the device. Brass fasteners were glued to areas on the middle layer of hardboard in the middle of peg guides to act as switches when in contact with the pegs. The other ends of these brass fasteners were soldered to wires. These wires were connected to a breadboard located at the bottom of the middle layer of hardboard. Pegs were cut from 5/8" wooden dowels. Aluminized tape was stuck to the ends of the pegs to activate the switches. A front-view of P1 can be seen in Figure 8.

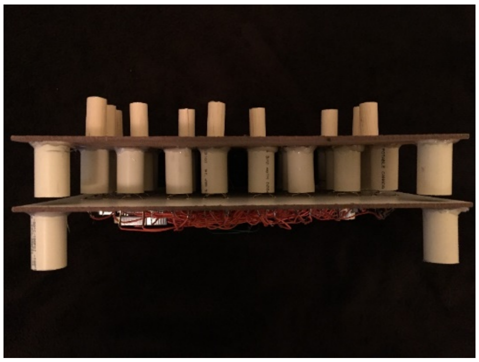


Figure 8: Front-view of Prototype 1

The electrical components allowed for auditory information to be provided to the user and feedback of the user response. A Hitachi HD44780 screen was used. It was secured to the top, middle hole using Velcro. This screen displayed everything that was said by the device so that parents or teachers without visual impairment could repeat the device's auditory cues as required. A push button was placed on the top left corner of the device. An Arduino Mega 2560 microcontroller was also attached to the bottom of the middle hardboard layer using Velcro. The SparkFun MP3 Player Shield was mounted to the Arduino Mega 2560 to output sound. To turn on the device, a battery pack with a 9V battery was plugged into the microcontroller. The bottom of the device can be seen in Figure 9.

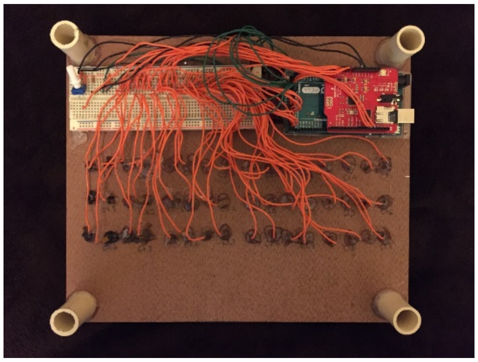


Figure 9: Bottom view of Prototype 1

A bill of materials for P1 can be seen in Table 8. All prices are in Canadian dollars.

Table 8: Bill of materials for Prototype 1

Part #	Material or Part	Number of Parts Purchased	Distributor	Dimensions or Quantity/Part Purchased	Price/Quantity Purchased	Quantity Used	Total Cost of Quantity Used
1	Hardboard	1 board	Rona	1/8”X24”X48”	$5.39	1/8”X20”X24”	$1.12
2	Wooden Dowel	1 dowel	Rona	5/8”X72”	$4.09	5/8”X57”	$3.24
3	CPVC Pipe	1 pipe	Rona	3/4”X10’	$11.99	3/4"X47”	$4.70
4	LCD Screen	1 screen	QKits	N/A	$7.10	1	$7.10
5	Aluminized Tape	1 roll	Home Depot	48mm X 9m	$7.89	48mmX20cm	$0.18
6	Brass Fasteners	1 box	Staples	100	$6.59	12	$0.79
7	16 GB Micro SD	1 card	QKits	N/A	$15.00	1	$15.00
8	Button	1 button	QKits	N/A	$0.39	1	$0.39
9	Breadboard	1 board	Digi-Key	N/A	$5.54	1	$5.54
10	Potentiometer	1 pack	Digi-Key	10 potentiometers	$10.23	1	$1.02
11	Arduino Mega	1 Arduino	Sparkfun	N/A	$56.00	1	$56.00
12	MP3 Shield	2 shields	Sparkfun	N/A	$60.81	1	$30.41
13	Glue Gun Glue	1 pack	Walmart	40 sticks	$7.49	10	$1.87
14	Resistors	1 pack	Digi-Key	50 resistors	$1.58	25	$0.79
15	Wires	2 spool	QKits	25 feet	$14.20	50 feet	$14.20
16	Battery Holder	1 holder	Sparkfun	N/A	$3.60	1	$3.60
17	Battery	1 pack	Walmart	2 batteries	$5.97	1	$2.99
18	Headphones	1 set	Walmart	N/A	$4.94	1	$4.94
19	Solder	1 roll	Home Depot	86 grams	$7.49	10 grams	$0.87
20	Headers	4 headers	QKits	N/A	$4.00	1	$4.00
						HST	$20.64
						Total Cost	**$158.75**

As seen from Table 8, the total cost of materials to create P1 was $158.75 CAD. Excluded from this analysis are overhead costs (eg. labour, electricity, etc.).

4.2.2 Software

All code was written in the Arduino Integrated Development Environment (IDE). To program the Arduino, the study investigator input a set of C/C++ functions [45]. The study investigator programmed the device to recognize the 26 letters of the Latin alphabet, 113 English words, the letters 'Ñ' and 'NG' from the Tagalog alphabet and 125 Tagalog words. The English words were chosen from a Kindergarten spelling list [46], while the Tagalog words were chosen from a Tagalog alphabet book [47].

Figure 10 shows the flow chart of the code used for the P1. Prior to device use, the study investigator programmed the device to speak in either English or Tagalog. Both letters and words were provided as options for device users to accommodate for varying braille skill levels.

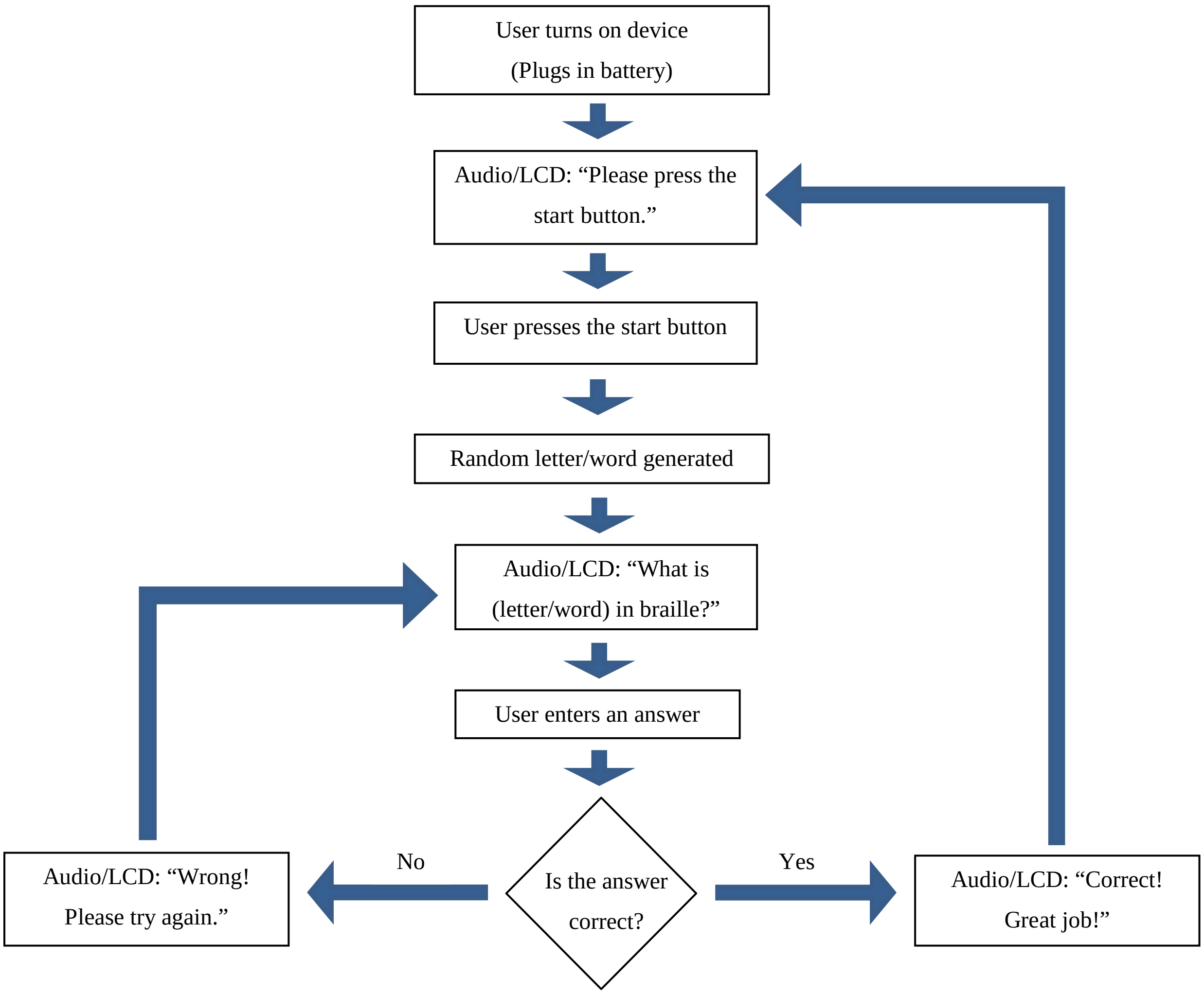


Figure 10: Flow chart of code used for Prototype 1

4.2.3 Wiring Diagram

All switches were connected to the Arduino Mega as shown in Figure 11.

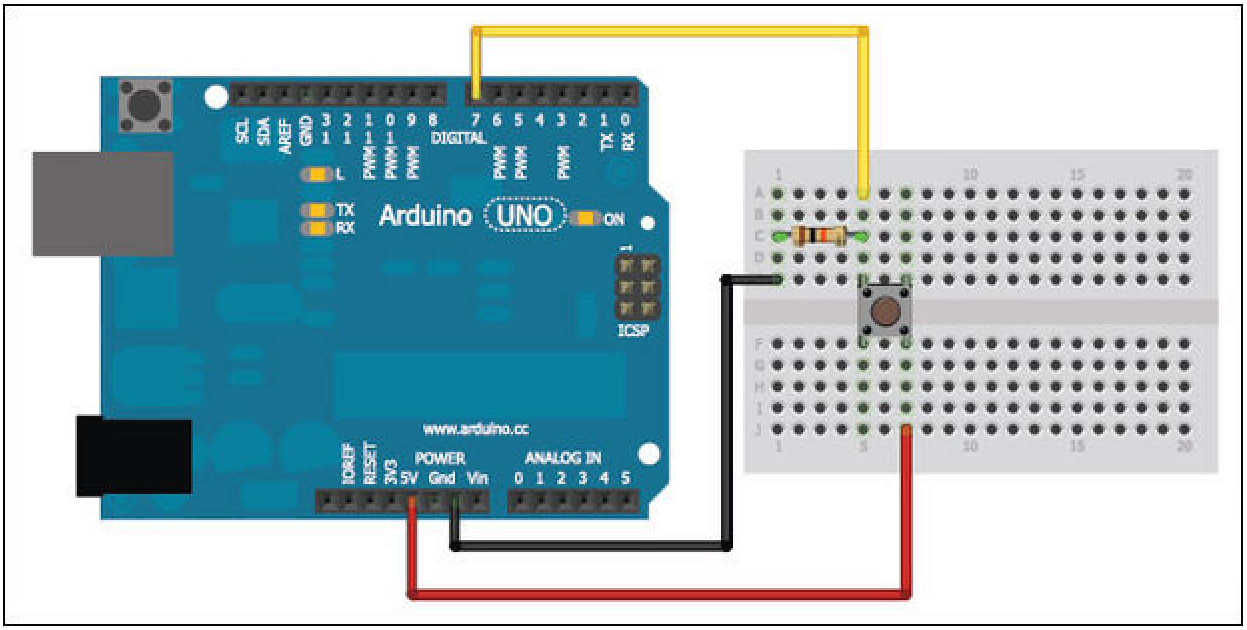


Figure 11: Simplified circuit illustration of how a switch on the device was connected to the Arduino [48][2]

4.3 P1 Results

All preliminary testing of P1 was performed by the study investigator. This testing aimed to identify discrepancies between intended device function and actual device function.

4.3.1 Preliminary Testing of Prototype 1

Specific activities performed with P1 included placing it into the study investigator's backpack, carrying the device to campus (20 minute walk), listening to the device's audio output using headphones, placing

[2] Please note that Figure 11 shows an Arduino Uno, but an Arduino Mega 2560 was used for Prototype 1.

the pegs into the holes (eyes open and closed) with the sense of touch and testing the device's response to a correct and incorrect answer.

Pros

Usability: Audio output was clear and the LCD screen was helpful if ever the study investigator was unable to hear the audio. All parts of the device could be easily accessed, and it was not difficult to feel each hole and place the pegs in the holes.

Function: P1 showed that the concept of putting pegs in holes to form braille letters could be accomplished.

4.3.1.1 Cons

Accessibility**:** Although no analysis regarding how much a user would spend on P1 was completed, it was predicted that a price of over $158.75 would be too expensive.

Portability: P1 was too large to easily fit in the study investigator's backpack (Backpack dimensions: 2.75"L x 16.75"H x 8"D) and was therefore deemed difficult to transport.

Portability/Durability: The structure of P1 was not sturdy. It was quite fragile due to the large quantity of unprotected wires and hardboard layers that were not attached to each other. P1 was also difficult to transport without the fear of wires detaching or breaking.

Usability: The intention of the device was that the user would simply place a peg in a hole to activate a switch; however, it was found that the pegs were not heavy enough to activate the switches. The user had to press on the pegs forcefully to hopefully attain contact between the aluminized tape on the pegs and the brass fasteners on the bottoms of the holes. In addition, the brass fasteners beneath the holes did not properly align with the holes due to difficulties during the manufacturing process. This misalignment made contact between the aluminized tape and the brass fasteners even less reliable. Also, after the creation of P1, it was learned that some students with VI dislike having earbuds in their ears.

Function: The study investigator also realized that the device was not teaching her braille by it only telling her if she was right or wrong. If she did not know the correct answer, the device was not able to teach her how to correct her answer.

Feedback is an essential component of universal design to ensure that the learner understands why an error has been made and how to effectively improve. It was important to consider a feedback mechanism in the second prototype of the design. The theory of behaviourism supports the concept of corrective feedback. There are two forms of corrective feedback that could potentially be integrated including the Giving Answers Strategy (GAS) and the Prompting Answers Strategy (PAS). In the GAS, the teachers provide the strategy, while the PAS requires a supportive environment [49]. It was determined that the PAS would first be followed in the second prototype by providing an opportunity for the student to self-assess. For three trials, the device would support this feedback which would then be followed by the GAS in which the device would indicate the correct placement of the pegs.

4.4 Prototype 2

Prototype 2 (P2) was very similar to P1, however, different materials were used for its structure, and changes were made to its code to improve the braille learning process. Images of P2 can be seen in Figure 12 and Figure 13.

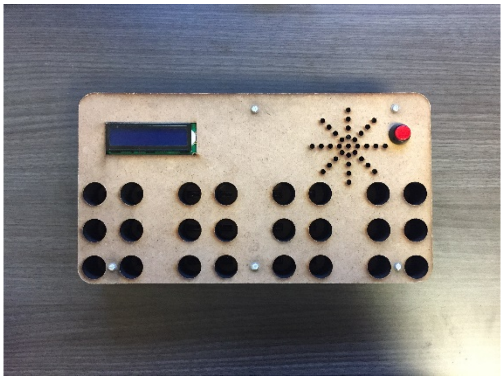


Figure 12: Top view of Prototype 2

Figure 13: Isometric view of Prototype 2

Similar to P1, hole spacing and size were scaled according to braille standard [44]. To improve switch activation consistency, microswitches were aligned beneath the holes. Pegs were weighted to allow the user to simply place the pegs in the holes to activate a switch instead of holding the pegs down. Additionally, to improve the braille learning process, if a user placed the pegs in incorrect holes, the device allowed the user to have two more tries, after which it told the user how to correct his or her answer. Following an incorrect answer, P2 told the user which braille cells were incorrect. P2 also had a speaker system instead of a headphone port so that users did not need to use headphones.

4.4.1 Hardware

Layers of medium-density fibreboard (MDF) were used for the main structure. Holes were cut into the MDF using a laser cutter. Instead of brass fasteners, microswitches were soldered onto a printed circuit board (PCB) to indicate when pegs were in the holes. The Arduino Mega 2560 microcontroller, LCD screen and button from P1 were reused. A speaker was added to the device so that the user did not have to use headphones. Pegs were weighted using washers. A bill of materials for this prototype can be seen in Table 9.

Table 9: Bill of materials for Prototype 2

Part #	Material or Part	Number of Parts Purchased	Distributor	Dimensions or Quantity/Part	Price/Quantity Purchased	Quantity Used	Total Cost of Quantity Used
1	Washers	1 box	Home Depot	150 washers	$9.53	114 washers	$7.24
2	Wooden Dowel	2 dowels	Home Depot	3/4"X48"	$6.90	3/4"X53"	$3.81
3	Screws (for pegs)	1 box	Home Depot	100 screws	$9.98	19 screws	$1.90
4	LCD Screen	1 screen	QKits	N/A	$7.10	1 screen	$7.10
5	16 GB Micro SD	1 card	QKits	N/A	$15.00	1 card	$15.00
6	Button	1 button	QKits	N/A	$0.39	1 button	$0.39
7	MDF	2 panels	Home Depot	1/4"X2'X4'	$13.74	1/4"X2'X64"	$9.16
8	Washers	1 pack	Digi-Key	10 washers	$0.98	5 washers	$0.49
9	Bumpers	1 pack	Digi-Key	10 bumpers	$3.84	6 bumpers	$2.30
10	Standoffs	1 pack	Digi-Key	25 standoffs	$9.89	5 standoffs	$1.98
11	Microswitches	1 pack	Digi-Key	25 switches	$23.92	24 switches	$22.96
12	Resistors	1 pack	Digi-Key	50 resistors	$1.58	25 resistors	$0.79
13	MP3 Shield	2 shields	Sparkfun	N/A	$60.81	1 shield	$30.41
14	Arduino Mega 2560	1 Arduino	Sparkfun	N/A	$56.00	1 Arduino	$56.00
15	Battery Holder	1 holder	Sparkfun	N/A	$3.60	1 holder	$3.60
16	Battery	1 pack	Walmart	2 batteries	$5.97	1 battery	$2.99
17	Speaker	1 speaker	QKits	N/A	$3.68	1 speaker	$3.68
18	Ribbon Cable	1 cable	QKits	N/A	$3.23	1 cable	$3.23
19	Wires	2 spool	QKits	25 feet	$14.20	1 foot	$0.57
20	Printed Circuit Board	5 boards	General Circuits Co.	N/A	$191.00	1 board	$38.20
21	Metal Screws (for assembly)	1 pack	Digi-Key	10 screws	$1.58	5 screws	$0.79
22	Plastic Screws	1 pack	Digi-Key	10 screws	$2.10	6 screws	$1.26
23	Potentiometer (Pot)	1 pack	Digi-Key	10 pot	$10.23	1 pot	$1.02
24	Solder	1 roll	Home Depot	86 grams	$7.49	5 grams	$0.44
25	Header 1	1 pack	Digi-Key	1 header	$0.31	1 header	$0.31
26	Header 2	1 pack	Digi-Key	1 header	$0.76	1 header	$0.76
27	Header 3	1 pack	Digi-Key	2 headers	$12.16	2 headers	$12.16
						HST	$29.71
						Total Cost	**$258.25**

The total cost of materials for P2 was $258.25 CAD. All costs relating to labour, energy use and equipment rental were omitted from this calculation.

4.4.2 Software

Code from P1 was modified to improve the braille learning experience of P2. Prior to device use, the study investigator still had to program the device to communicate in either English or Tagalog depending on user preference. A flow chart of this modified code can be seen in Figure 14.

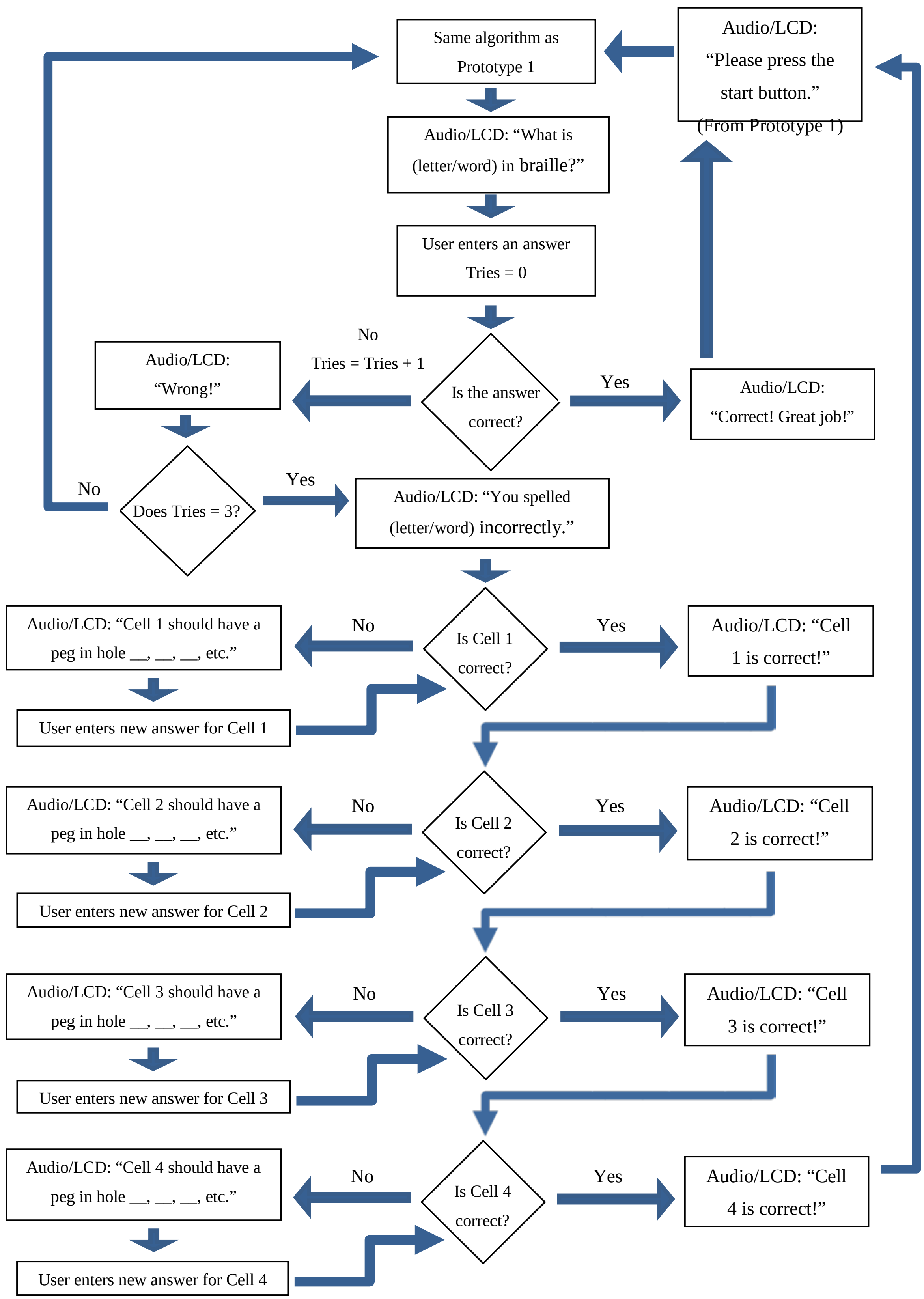


Figure 14: Flow chart of code used for Prototype 2

4.5 P2 Results

4.5.1 Preliminary Testing of Prototype 2

The study investigator conducted preliminary testing on P2 to identify whether P2 improved upon the problems identified from P1 preliminary testing and to ensure that future participants would be able to test the device. These pros and cons are further discussed.

4.5.1.1 Pros

The main aspects of the second design are discussed relative to the functional requirements: portability, durability, usability, and function.

Portability: P2 was much smaller than P1 and could fit inside the study investigator's backpack. The dimensions of the backpack were 12.75"L x 16.75"H x 8"D.

Durability: P2 did not have any exposed wires, had a full outer shell and all components were contained within the shell. Thus, it was less likely that any internal components would break.

Usability: The use of microswitches and weighted pegs made using the device a lot easier. Instead of having to forcefully push the pegs into the device to activate the brass fastener-aluminized tape switches like from P1, the user could instead place the pegs into the holes to activate the microswitches.

Function: The addition of the correction feature to P2 enabled the user to learn braille without assistance from external sources or teachers. Also, this correction feature made the interaction between the user and the device feel like a game, making the braille learning process fun and engaging.

4.5.1.2 Cons

However, the cons can also be addressed relative to the functional requirements as further discussed.

Accessibility: The cost to create P2 was more than P1, increasing from $158.25 to $258.25. Again, although no analysis regarding how much customers would be willing to spend on the device had been conducted at this point in the testing process, it was predicted that P2 would be too expensive.

Portability: P2 was heavier than P1 because its shell was made from several layers of MDF and the pegs had washers attached to them for the purposes of adding weight.

Durability/Usability: Although the microswitch-weighted pegs mechanism was an improvement upon P1's switch mechanism, the microswitches still did not activate consistently. This inconsistency was sometimes annoying for the study investigator, as she was sometimes sure that her answer was correct, but an inactivated switch would result in the device telling her she was wrong.

4.6 Discussion

Although P1 was able to prove that the concept of using a pegboard and pegs to create jumbo braille letters was possible, it failed in many other aspects. Specifically, the device was too fragile to be tested by participants. P1 was built without side panels so that the study investigator could easily access wires or other internal components. In addition, P1 had to be hand-carried since it was too large to put in the study investigator's backpack, which made it very annoying to transport.

From the perspective of testing components of P1, there were issues with electrical contact. Since the aluminized tape did not consistently make contact with the brass fasteners, the user had to forcefully press the pegs down in hopes that the three parts would touch. Initial testing was anticipated for P1, but it was deemed unfit to test. It was foreseen that the inconsistent switch mechanism would cause frustration to the testing process and distract the participants from providing feedback on anything other than that feature.

It was also determined that modifications to the code had to be made to ensure that it would be an effective braille learning device. Since it lacked a correction algorithm, the user was left not knowing the correct answer.

When P1 was compared to the results of the initial questionnaires, it was evident that the device did not meet the requirements of the users, specifically it lacked portability, durability, usability and function. Changes had to be implemented in the development of P2 to ensure that this device would be more satisfactory to users.

P2 improved upon many features of P1. Specifically, since P2 used a PCB instead of brass fasteners and a breadboard with multiple wires, it was much less fragile. The use of the PCB also allowed P2 to be thinner than P1, and could therefore be more easily transported. Furthermore, P2 utilized mechanical switches, activated by weighted pegs, instead of requiring contact between brass fasteners and aluminized tape. By changing the switch mechanism, although the mechanical switches were not completely reliable, they would still allow users to test P2 without needing to forcefully press the pegs into the device. The code for P1 was still used for P2, however, a correction feature was added. If users spelled a braille letter or word incorrectly, the correction feature would give the user two more tries, after which the device would tell the user which cell or cells was incorrect and where the pegs should be placed. This feature was necessary to provide feedback because learning strategies require iteration. During testing of P1, if ever the user did not know the correct answer, the user would not be able to learn the correct answer using P1.

The interactive correction feature added to P2 made the braille learning process feel like a game for the study investigator. According to Raed, “Gamification is the application of game features… into non-game context for the purpose of promoting motivation and engagement in learning. [50]” By gamifying, learners may obtain instant feedback of their progress and be assured that their newly acquired knowledge has a significant impact on themselves or their environments [51]. Thus, the interactive features P2 could make learning braille more fun, motivating and engaging in comparison to existing braille learning devices that do not utilize gamification.

The ARCS Model is a method for improving the motivational appeal of instructional materials [52]. This model is comprised of four major conditions: Attention, Relevance, Confidence and Satisfaction [52]. In terms of attention, the first condition, attention must not just be obtained, but also sustained. One strategy to obtain and hold attention, as suggested by Keller, is participation [52]. Specifically, motivation can be achieved by using games, role plays, etc. By having an interactive feature with auditory feedback for its users, BraillePad felt like a game. As the game progressed through the levels, one could go from learning letters to learning words. This provided relevance as the user understood that once they knew how to form letters, the words would enable them to also read. Confidence was integrated with auditory feedback to support the user. It will be important in the next version to carefully determine the best method to enable confidence in the user. Finally, satisfaction is evident as the user can actually succeed at the game by learning the letters and words. Integrating the ARCS format into the game design improves motivation and increases propensity to learn.

4.7 Conclusions

Testing performed by the study investigator on P1 provided evidence that the prototype was not ready to be tested by end-users. As a result, a more durable, reliable version (P2) was created. When designing, an iterative design process is needed to improve upon problems of previous prototypes.

4.8 Future Work

For future prototypes, the designer should add an on/off switch to the device so that users do not need to plug the battery into the device. There should also be a button to allow users to scroll through different learning modes (e.g. English letters, English words, Tagalog letters and Tagalog words).

Chapter 5

Prototype 2 Usability Testing

5.1 Chapter Overview

Included in this chapter are results from usability testing of P2 by persons with VI who were either learning braille, had already learned braille or were teaching braille to persons with VI.

5.2 Testing Methods

Testing of P2 was performed either by watching a video or physical, in-person testing. The link to the video was distributed in the Philippines, while physical testing was performed in Canada. Both methods of testing were followed by the completion of a feedback questionnaire.

5.2.1 Ethics

Ethics approval for usability testing of P2 was obtained from Queen’s University’s General Research Ethics Board under the Project Title: GMECH-043-17 Matuto, Magbasa, Maglaro: Learning to read in braille through play (Appendix 6.5).

5.2.2 Participants

Individuals living in the Philippines or Canada were invited to participate in usability testing if they were:

- below the age of 18, living with visual impairment and learning how to read in braille;
- any age, living with visual impairment and had already learned how to read in braille;
- or teaching braille to persons with visual impairment (eg. teachers, parents of children with VI, etc.)

5.2.3 Video Testing in the Philippines

A video was made so that feedback regarding the potential of P2's usability could be obtained from persons in the Philippines. The video consisted of an explanation of the project, a description of the device, instructions on how to use the device, and demonstrations of the device being used when in both English and Tagalog modes. A total of seven participants completed the follow-up questionnaire in FluidSurveys. All participants taught braille to persons with visual impairments.

5.2.4 Physical Testing in Canada

While the video option was available in the Philippines, participants in Canada were able to physically test the device. Participants were first given a description of the device. The different parts of the device were described, and instructions on how to use it were explained. The device was then programmed to only ask the participants to display braille letters in English using the device. No participants who physically tested the device taught or read braille in Tagalog. The first ten trials required participants to form letters that were randomly generated by the device. Within these 10 trials, the study investigator would ensure that the participants had experienced a correct response on the first attempt, a correct response after the first or second attempts and three incorrect responses in a row, since the device performed different functions depending on the user's performance. If the user did not experience all three device responses while trying the device, the study investigator would ask the user to insert pegs in either the correct or incorrect holes on purpose. Following these 10 trials, the device would be reprogrammed to ask the user to spell only four letter English words in braille for approximately 10 trials. Again, the study investigator would ensure that the participants had experienced a correct response on the first attempt, an incorrect response after the first or second attempts and three incorrect responses in a row. After trialing the device, the participants were given a link to a FluidSurveys questionnaire so that feedback could be obtained. Sixteen participants physically tested the device, however, only 14 of those participants completed the follow-up questionnaire (Appendix 6.11).

5.3 Results

In the questionnaires, participants were given statements, and in response, they were asked whether they strongly agreed, agreed, neither agreed nor disagreed, disagreed or strongly disagreed with those statements. The percentage of responses for each of the statements are reported in Table 10. Suns represent responses from participants from the Philippines, while maple leaves represent responses from participants in Canada.

Table 10: Likert scale – Percentage responses of participants[3]

Statement Posed to Participants	**Strongly Agree**		**Agree**		**Neither Agree nor Disagree**		**Disagree**		**Strongly Disagree**	
	☀	🍁	☀	🍁	☀	🍁	☀	🍁	☀	🍁
This device is too heavy.	43	33	14	42	14	25	29	0	0	0
This device is too large.	14	33	71	42	14	25	0	0	0	0
The instructions were very clear.	57	77	43	23	0	0	0	0	0	0
This device was very easy to use.	43	79	57	21	0	0	0	0	0	0
The LCD screen was very useful.	29	46	71	23	0	0	0	8	0	23

From observing Table 10, it can be seen that most participants agreed that the device was too heavy and too large and that the LCD screen was very useful. All participants agreed to some extent that the instructions were very clear and that the device was very easy to use.

Participants were also asked questions to which they responded with either a yes or no. The questions and percentage of responses received for each are shown in

[3] For the fifth statement regarding the LCD screen, in the questionnaire, instead of the option “strongly disagree”, the option “did not use” was given for participants with blindness who tested the device.

Table 11. Suns represent responses from participants from the Philippines, while maple leaves represent responses from participants in Canada.

Table 11: Yes/no feedback from participants – Percentage responses of participants

Question Posed to Participants				
	Yes	**No**	**Yes**	**No**
Did you experience any technical errors when testing the device?	X	X	50	50
Do you think the start button can be easily accessed? / Was the start button easy to access?	100	0	100	0
Could you or your student use this device without the help of a teacher or parent?	100	0	100	0
Do you think that the device could be fun to use? / Did you have fun trying the device?	100	0	100	0
Could you understand what the device was asking you to do?	X	X	100	0
Do you think this device could be an effective braille learning tool?	100	0	100	0
Would you use this device to help you (or your students) learn braille?	100	0	100	0

Results presented in Table 11 show that half of the participants who physically tested the device experienced technical errors. All participants who provided feedback on the remaining questions responded unanimously that the start button could be easily accessed; users could use the device without the help of a teacher or parent; the device could be fun to use; users could understand what the device was telling them to do; the device could be an effective braille learning tool and that they would use the device or give the device to their students to help them learn braille.

Participants were asked how much they would be willing to spend on a similar device to P2 if it was further developed. Figure 15 displays the average price that the participants would be willing to spend. These prices reflect responses from five participants in the Philippines and 14 participants in Canada. Prices given in Philippine pesos were converted to Canadian dollars. Both prices are in Canadian dollars.

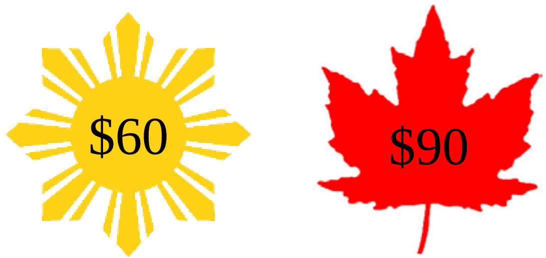


Figure 15: Average prices willing to pay if BraillePad was further developed

Figure 15 shows that participants in Canada would be willing to pay approximately $30 more than the participants from the Philippines for a device similar to P2.

Participants were asked for suggestions on how to improve P2. Table 12 shows the improvements recommended by the participants from the second questionnaire in the categories accessibility, portability, durability, usability, function and aesthetics.

Table 12: Suggested device improvements by participants

Suggestions	Number of Responses
Accessibility	
Suggestions for accessibility were primarily defined by how much participants were willing to spend on a commercially available version of the device (Figure 15)	
Portability	
• Drawer for pegs	2
• Lighter	1
• Have a case	1
Durability	1
• Plastic shell (Wipeable)	1
• Microswitches should be more durable	1
Usability	
• Headphone port	5
• Shorter pegs	5
• Pegs with smaller diameters	4
• Black frame, while holes or vice versa	4
• Spell out word	3
• Say “M as in mother”	3
• Line between cells	3
• Volume wheel	2
• Male voice	1
• Say word in a sentence	1
• Have words sequenced alphabetically	1
• ON/OFF switch	1
• Evenly weighted pegs	1
• Closer holes	1
• Add small dot numbers beside each dot	1
• Big size for seniors	1
• Small size for children/adults	1
Function	
• Different modes/levels	6
o Contracted braille (Grade 2)	4
o Timer	3
o Make sentences	2
o Different languages	2
o Punctuation	1
o Nemeth code	1
o Capital vs. Lower-case letters	1
o Connect to other BraillePads – competitive game	1
o Use phonics instead of random	1
o Include numbers	1
• Add extra cells	4
• Sound effects	2
• Solar-powered/Wind-up	1
• Spellcheck	1
Aesthetics	
• Sleek frame	4

Although many unique recommendations were given by the participants, some suggestions were provided multiple times. Specifically, various participants recommended that the device have a headphone port for users who might be using the device in a noisy environment such as a classroom. As well, many participants identified that they believed the pegs were too long and large in diameter. Another suggestion was to have contrasting colours between the device's surface and the holes for users with visual impairment. As stated by four participants, the contrasting colours would enable users with VI to locate the holes more easily. Recommended by many participants was for the device to have various levels or modes for users of varying skill levels. Some of the modes suggested included adding a Grade 2 (contracted) braille level, a timed mode and a sentence mode (if extra cells were added to the device). There were also multiple requests for the device to be sleek and look "cool".

Table 13 displays the best and worst features of P2 as indicated by participants in both the Philippines and Canada.

Table 13: Best and worst features of Prototype 2

Best features		**Worst features**	
Easy to use	1	• Sticks are too long	3
• Simple	3	• Too few cells	2
• Minimal buttons	2	• Takes too long to write	1
• Large size	1	• Too big	1
• Dots are easy to feel	1	• No tactile reading option (Alphabet on the front)	1
Interactive	1	• Pegs do not always go all the way down	1
• Audio	2	• Dots are too far apart	1
• Positive feedback (Reward)	1	• Too many tries	1
• Lets you know which letter is correct/incorrect	1	• Weight of pegs are unevenly distributed	1
• User does not need help of parent/teacher	1	• Too heavy	1
• It is fun	1	• Sound could be clearer	1

Overall, participants liked that the device was simple and easy to use and that it was interactive. Participants did not like that the pegs were too long, and that the device only had spaces for four letters at once. One participant commented that he or she did not like that the weight of the pegs were unevenly distributed. To ensure the wooden pegs were heavy enough to activate the switches in the device, washers were added to one end of each peg. Therefore, the end of the peg with the washers was heavier than the opposite side. An interesting observation is that while one participant liked the large size of the device, another believed that it was too big.

Table 14 provides a visual representation of whether P2 met (green), did not meet (red) or marginally met (yellow) the user needs identified from the initial questionnaire. Scores were determined by the study investigator and influenced by usability testing results.

Table 14: Extent to which user needs were met

Accessibility	**Met?**	**Usability (Easy to use)**	**Met?**
• Affordable	🔴	• Easy to navigate/good layout	🟢
• Available in the country	🟡	• Adjustable letter size/zoom feature	🔴
Portability		• Adjustable font	🔴
• Not bulky	🔴	• Adjustable colour contrast	🔴
• Lightweight	🔴	• Convenient to use/handy	🟢
• Does not need to be plugged in	🟢	• Anti-glare	🔴
• Good battery life	🟡	**Function**	
Durability		• Feedback	🟢
• Hardware	🔴	o Can communicate in Tagalog	🟢
o Not fragile	🟡	o Good pronunciation	🟢
• Software	🟢	• Effective learning tool	🟢
o No technical errors/malfunctions	🟢	o Tactile learning feature	🟡
o No viruses	🟢	o Has pictures	🔴
o No upgrades required	🟢	• Multifunctional	🔴

Although P2 met many needs identified from the initial questionnaire such as having a good layout, being able to provide feedback to the user, and its ability to teach braille in both English and Tagalog, there were many user needs that were not satisfied. Some of these needs included affordability, small size, lightweight and adjustability (e.g. text size, font, colour, etc.).

P2 was also assessed against the technical specifications from the initial QFD matrices. The results are summarized in Table 15 where specifications were either met (green), not met (red) or close to being met (yellow). Scores were again determined by the study investigator and influenced by results from usability testing.

Table 15: Extent to which technical specifications were met

Technical Specification from QFD	Initial Projected Target Value	Value from P2 Results	Met?
Volume (Size)	< 26x20x5 cm	29x16x6 cm	🟡
Weight	< 2kg	2.3 kg	🟡
Cost	< $100 CAD	$258.25 CAD	🔴
Material Strength	TBD	Not tested	
No Viruses/ Glitches/Malfunctions	0	2 Causes (Both related to switches not being fully pressed)	🔴
Adjustable Font Size	Minimum 18 pt.	No	🔴
Adjustable Font	Roman or sans serif	No	🔴
Adjustable Font Colour	Dark blues, greens	No	🔴
Adjustable Colour Contrast	White or yellow on dark	No	🔴
Glare	TBD	Some	🔴
Battery Life	>10 hours	~ 4 hours	🔴
Intuitive Use	<30 minutes to learn how to use	< 5 minutes	🟢
Teaches Reading in Multiple Languages	English and Tagalog (minimum)	English and Tagalog	🟢
Engaging	Could use for at least 1 hour	Average 68.8 mins	🟢
Maintenance	No maintenance/replacements for at least 5 years	Not tested	
Assembly Time	< 15 minutes	< 1 minute	🟢
Volume (Sound)	TBD	Not tested	
Brightness	TBD	Not tested	

P2 did not meet many of the technical specifications initially identified from the QFD matrices. In the future, additional tests to determine the durability, ability to be maintained, volume and brightness of the device must be performed.

5.4 Discussion

Results from usability testing of P2 highlighted its strengths and areas for future work. Responses from the second questionnaire revealed that most participants agreed that the device was very easy to use, had a good layout and had clear instructions. Upon being introduced to the different features of BraillePad and given an explanation on how to use the device, users required less than 5 minutes to start effectively interacting with the device. Furthermore, feedback revealed that participants thought BraillePad was fun to use. Since BraillePad provided auditory feedback, users were keen to provide correct answers to hear a congratulatory message and move onto another letter or word. Additionally, users believed the device could be an effective braille learning tool and could be used to teach or learn braille. Since BraillePad provided feedback on whether the user's responses were correct, incorrect or how to correct a wrong answer, testing results showed that BraillePad could allow a student to use the device independently. As well, the concept of BraillePad is similar to the egg carton tool that is currently used to teach braille, which has been said to already be an effective method of learning the dot positions of the braille alphabet.

On the other hand, most participants also agreed that the device was too heavy and large. P2 was 2.3kg and 29x16x6 cm. If another prototype is created, it is recommended that the weight and size of the device be reduced. When physically tested, it was also found that half of the participants experienced technical errors. The reasons for these technical errors were all related to the switch mechanism. Specifically, the microswitches at the bottom of each hole were sometimes not activated if a peg hit a switch at an incorrect angle or did not go fully into a hole. Occasionally, pegs got stuck on the edge of layers of MDF if sliding between the layers had occurred. These technical errors show that in the future, to improve usability, the switch mechanism and/or design of the pegs should be altered. Some other suggestions for improvement include having shorter and skinnier pegs, having a headphone port, having additional learning modes and adding extra braille cells.

In relation to findings from Chapter 2, the device met many end-user needs including: no need to be plugged in, did not exhibit software malfunctions, was easy to use and had a good layout, was interactive and gave users feedback in both English and Tagalog, had good pronunciation and could be an effective learning tool. BraillePad did not meet many of the user needs identified in Chapter 2. Specifically, the device was not affordable, bulky, too heavy, not adjustable and not multi-functional. These findings highlight the importance of involving end-users throughout the design process, understanding user needs and designing to satisfy those needs. Unfortunately, during the design process of BraillePad, it was not possible to involve end-users in the brainstorming stage of the device and the physical creation of the device. During these stages, it would have been beneficial for end-users to provide feedback on what kind of device they wanted and whether various features and components of BraillePad were satisfactory. Since end-users were not engaged in these stages, BraillePad failed to improve upon some of the user needs that were identified from the initial questionnaire. Therefore, although it is unlikely that all stakeholders will be completely satisfied by a completed product because of contrasting perspectives, it is still important to address as many stakeholder needs possible by involving them throughout the design process to increase stakeholder satisfaction.

Participants from the Philippines expressed that they would be willing to spend approximately \$60 on a further developed version of P2, while Canadian participants were willing to spend approximately \$90 on the device. These differences in expected prices were not surprising considering there is a difference in average salary between the Philippines and Canada. As mentioned in Chapter 3, in Manila, the average salary is 383 226 PHP [40], which is equivalent to approximately \$9 400 CAD. In comparison, the average salary of a worker in Toronto is $58 618 CAD [41]. Considering the average salary of workers in Manila is approximately one sixth of those in Toronto, it is not surprising that the participants in the Philippines would be willing to spend less on the device. When designing devices for the people of the Philippines, it is important to understand that if an individual is unable to afford the device, it is likely that they will not be able to acquire and use the device. Thus, efforts to reduce the costs of product development and manufacturing must be made so that all children, regardless of financial constraints, can have access to effective educational tools.

From observing Table 14, it was evident that P2 did not meet several device needs defined by the initial questionnaire and QFD matrices such as adjustability and multifunctional capabilities (different modes). Though it would be helpful for future iterations to include adjustability and multifunctional capabilities, it is important to understand that these added features would likely increase cost as well. As a designer, the prioritization of device needs must be established and the pros and cons of changing various design features must be thoroughly analyzed before making design alterations.

When working with multiple stakeholders, it was found that different perspectives sometimes elicited opposing views. For example, from Chapter 4, a modification made between P1 and P2 was to change in audio output from headphones in P1 to a speaker in P2 as a result of feedback from the partner in the Philippines. From P2 testing, however, users said that they would want to use headphones. Also, there were conflicting views on the size of the device. While some liked its large size, others found the large size to be BraillePad’s worst feature. These observations highlighted a negative aspect of working with various stakeholders. With contrasting views, it is nearly impossible to satisfy the desires of all stakeholders. Thus, it is necessary to carefully analyze user input before implementing changes.

5.5 Limitations

A limitation from usability testing of P2 was that only one child tested the device (the rest were adults) although this device is intended to primarily be used by children. Therefore, it is recommended that the device be tested with more children. In addition, although a video (with descriptive audio for participants with visual impairments) was sent to participants in the Philippines to assess the usability of the device, it is difficult to fully understand all components of the device unless it is being physically used. Thus, it is also recommended that the device be sent to the Philippines to be tested by participants to obtain more informed usability feedback. Additionally, for both participants in the Philippines and Canada, it would be useful to allow users to test the device for extended periods of time in their regular learning/teaching settings to acquire more meaningful user feedback.

5.6 Conclusions

Results from usability testing showed that P2 improved upon some features of P1. Specifically, P2 was more durable than P1, could be used by participants to test various features of the device and included a correction algorithm for more effective braille learning. Participants liked that the device was easy to use and interactive. P2 testing also revealed several areas of improvement. For future iterations, development should be focused on improving the peg-switch mechanism as well as reducing the cost, size and weight of the device. Other ways that the device could be improved include having a headphone port, having more learning modes (e.g. contracted braille mode and a timed mode) and having additional braille cells.

Chapter 6

Conclusions and Future Steps

6.1 Conclusions

This thesis presented the iterative design process to create a device to help children in the Philippines and Canada with VI learn braille. Based on device needs identified by end-users, two prototypes of a device that aimed to be accessible, portable, durable, easy to use and have good functional capabilities were created. Feedback from participants who tested the second prototype revealed that the device was easy to use and interactive. Some suggestions for improvement included that the device be smaller, lighter, have a headphone port and have various modes for learning braille. User feedback to date shows potential for BraillePad to be an effective braille learning tool for children with VI in the Philippines and Canada.

This study showed the importance of understanding end-user needs and incorporating end-users in the design process when creating a device. By engaging in the co-design process, designer bias is likely to decrease, leading to more usable products and greater end-user satisfaction.

Although, as a designer, it is tempting to make every change to a prototype to make it better, a thorough analysis of the pros and cons of each change should be taken into account before adjustments are implemented. Specifically, when addressing the accessibility of a device, especially for end-users with monetary restrictions, designers must find a balance between the function and cost of the device to ensure that the device is effective at its purpose, while still accessible to its users.

6.2 Future Steps

Although BraillePad shows promise in being an effective braille learning tool for children with VI in both the Philippines and Canada, before that can occur, many adjustments to its design and more testing must be performed. Specific areas of improvement to the design of BraillePad that should be prioritized include implementing a more reliable peg-switch mechanism and adding different learning modes, while reducing the size, weight and cost of the device.

Additional usability testing of the device by children in the Philippines and Canada for extended periods of time would be helpful in determining to what extent the device is able to help children with VI in the Philippines and Canada learn braille. Future designers working on this device should continue engaging in the co-design process with end-users and other stakeholders throughout the development of BraillePad to ensure user satisfaction.

References

[1] “WHO | World Health Organization,” *WHO*, 2017.

[2] CNIB, “Fast Facts about Vision Loss,” 2015. [Online]. Available: http://www.cnib.ca/en/about/media/vision-loss/pages/default.aspx. [Accessed: 13-Sep-2017].

[3] World Health Organization, “Socio economic aspects of blindness and visual impairment,” *WHO*, 2017.

[4] M. D. Naraine, P. H. Lindsay, and F. Cdso, “Social inclusion of employees who are blind or low vision,” *Disabil. Soc.*, vol. 26, no. 4, pp. 389–403, 2011.

[5] World Health Organization, “GLOBAL INITIATIVE FOR THE ELIMINATION OF AVOIDABLE BLINDNESS,” 2007.

[6] Resources for the Blind, “Blindness in the Philippines,” 2017. [Online]. Available: http://blind.org.ph/blind_phil.html. [Accessed: 06-Sep-2017].

[7] “All Children Reading: A Grand Challenge for Development.” [Online]. Available: https://docs.google.com/forms/d/e/1FAIpQLSfSzC9Q-N4AFWb9NSIBAVSK0Vvh4FeprFHmVNSQqcbBP4397g/viewform.

[8] Resources for the Blind, “Rehabilitation | Training and Rehabilitation,” 2017. [Online]. Available: http://blind.org.ph/projprog/projprog_tr_r.html. [Accessed: 06-Sep-2017].

[9] B. Phillips and H. Zhao, “Predictors of Assistive Technology Abandonment,” *Appl. Res. Assist T echn ol*, vol. 5, pp. 36–4, 1993.

[10] R. Verza, M. Lopes Carvalho, M. Battaglia, and M. M. Uccelli, “An interdisciplinary approach to evaluating the need for assistive technology reduces equipment abandonment,” 2006.

[11] Y. M. Choi, “Utilizing end user input in early product development,” *Procedia Manuf.*, vol. 3, pp. 2244–2250, 2015.

[12] C. R. da Costa, F. M. R. M. Ferreira, M. V. Bortolus, and M. G. R. Carvalho, “Dispositivos de tecnologia assistiva: fatores relacionados ao abandono,” *Cad. Ter. Ocup. da UFSCar*, vol. 23, no.

3, pp. 611–624, Sep. 2015.

[13] P. Bradwell and S. Marr, "making the most of collaboration an international survey of public service co-design making the most of collaboration: an international survey of public service co-design," 2008.

[14] L. D. W. D. J. D. R. G. Couvreur, "The Role of Subjective Well-Being in Co-Designing Open-Design Assistive Devices," *Int. J. Des. suppl. Spec. Issue*, vol. 7, no. 3, 2013.

[15] J. Borg, R. Berman-Bieler, C. Khasnabis, G. Mitra, W. N. Myhill, D. Samant Raja, A. Burlyaeva-Norman, S. Chadha, C. Cormency, A. Cote, A. Farkas, S. Mariotti, Z. Mirza, S. Mitra, H. Moller, M. Alarcos Cieza Moreno, A. K. Mukherjee, S. Mullally, B. O. Olusanya, A. Pupulin, L. Sabbe, A. Shankar, M. Steenbeek, and M. Tucker, "Assistive Technology for Children with Disabilities Assistive Technology for Children with Disabilities: Creating Opportunities for Education, Inclusion and Participation A discussion paper Assistive Technology for Children with Disabilities Assistive Technology for Children with Disabilities."

[16] ICF, "Chapter 1 Products and Technology." [Online]. Available: http://apps.who.int/classifications/icfbrowser/. [Accessed: 07-Sep-2017].

[17] A. Bhowmick, S. M. Hazarika, and B. A. Bhowmick, "An insight into assistive technology for the visually impaired and blind people: state-of-the-art and future trends," *J. Multimodal User Interfaces*, vol. 11, pp. 149–172, 2017.

[18] P. Chakraborti, H. A. K. Toprakci, P. Yang, N. Di Spigna, P. Franzon, and T. Ghosh, "A compact dielectric elastomer tubular actuator for refreshable Braille displays," *Sensors Actuators A Phys.*, vol. 179, pp. 151–157, Jun. 2012.

[19] Humanware, "BrailleNote Apex BT 32 Braille Notetaker," 2016. [Online]. Available: http://store.humanware.com/hus/braillenote-apex-bt-32-braille-notetaker.html.

[20] maudelynn, "Braille edition of The Little Prince by Antoine de Saint-Exupery." [Online]. Available: https://www.pinterest.ca/pin/550565123178410413/. [Accessed: 15-Sep-2017].

[21] M. Kingswood, “How to Use A Screen Reader with Skype,” 2013. [Online]. Available: http://www.supertintin.com/blog/skype-recorder/how-to-use-a-screen-reader-with-skype. [Accessed: 15-Sep-2017].

[22] E. Hall, “How assistive technology can improve your quality of life,” 2014. [Online]. Available: http://www.perkins.org/stories/how-assistive-technology-can-improve-your-quality-of-life. [Accessed: 15-Sep-2017].

[23] How Products are Made, “How braille publication is made,” 2017. [Online]. Available: http://www.madehow.com/Volume-4/Braille-Publication.html. [Accessed: 15-Sep-2017].

[24] American Foundation for the Blind, “Screen Readers and Screen Magnifiers: An Introduction to Computer Accessibility Software,” 2017. [Online]. Available: http://www.afb.org/info/living-with-vision-loss/using-technology/using-a-computer/part-ii-for-the-experienced-computer-user-with-a-new-visual-impairment/screen-readers-and-screen-magnifiers/12345. [Accessed: 06-Nov-2017].

[25] American Foundation for the Blind, “CCTVs/Video Magnifiers - Browse Results - American Foundation for the Blind,” 2017. [Online]. Available: http://www.afb.org/prodBrowseCatResults.aspx?CatID=53. [Accessed: 15-Sep-2017].

[26] “What Is Braille? - American Foundation for the Blind,” 2017. [Online]. Available: http://www.afb.org/info/living-with-vision-loss/braille/what-is-braille/123. [Accessed: 30-Aug-2017].

[27] “CNIB - About the Braille System,” 2017. [Online]. Available: http://www.cnib.ca/en/living/braille/braille-system/Pages/default.aspx. [Accessed: 30-Aug-2017].

[28] A. Mulholland, “Few blind Canadians reading braille | CTV News,” 2010. [Online]. Available: http://www.ctvnews.ca/with-new-technology-few-blind-canadians-read-braille-1.503149. [Accessed: 15-Sep-2017].

[29] S. Rogers, “Learning braille and print together - the mainstream issues,” *Br. J. Vis. Impair.*, 2012.

[30] All Children Reading, “The Problem of Literacy,” 2018. [Online]. Available: https://allchildrenreading.org/about-us/problem/. [Accessed: 07-Sep-2017].

[31] R. Ryles, “The impact of braille reading skills on employment, income, education, and habuts,” *J. Vis. Impair. Blind.*, vol. 90, no. 3, p. 219, 1996.

[32] A. Russomanno, S. O ’modhrain, R. B. Gillespie, and M. W. M. Rodger, “Refreshing Refreshable Braille Displays.”

[33] G. J. Varao-Sousa, Trish L.; Kingston, Alan; Solman, “Re-Reading After Mind Wandering,” *Can. J. Exp. Psychol.*, vol. 71, no. 3, 2017.

[34] T. L. Varao Sousa, J. S. A. Carriere, and D. Smilek, “The way we encounter reading material influences how frequently we mind wander,” *Front. Psychol.*, vol. 4, p. 892, Nov. 2013.

[35] World Health Organization, “Visual impairment and blindness,” *WHO*, 2017.

[36] Resources for the Blind, “All Children Reading: A Grand Challenge for Development,” 2018. [Online]. Available: http://allchildrenreading.org/innovators/resources-for-the-blind-inc/.

[37] “Kano Model Tutorial - ASQ.” [Online]. Available: http://asq.org/learn-about-quality/qfd-quality-function-deployment/overview/kano-model.html. [Accessed: 02-Aug-2017].

[38] “The Complete Guide to the Kano Model - Folding Burritos.” [Online]. Available: https://foldingburritos.com/kano-model/. [Accessed: 02-Aug-2017].

[39] J. Nielsen and J. Faber, “Improving System Usability Through Parallel Design,” *Computer (Long. Beach. Calif).*, vol. 29, no. 2, pp. 29–35, 1996.

[40] PayScale, “Manila Salary, Average Salaries | PayScale Philippines,” 2017. [Online]. Available: https://www.payscale.com/research/PH/Location=Manila/Salary. [Accessed: 17-Oct-2017].

[41] PayScale, “Toronto, Ontario Salary, Average Salaries | PayScale Canada,” 2017. [Online]. Available: https://www.payscale.com/research/CA/Location=Toronto-Ontario/Salary. [Accessed: 17-Oct-2017].

[42] S. Kujala, “User involvement: a review of the bene®ts and challenges.”

[43] T. Lowdermilk, *User-Centered Design: A Developer's Guide to Building User-Friendly Applications*. Sebastopol: O'Reilly Media, Inc., 2013.

[44] Braille Authority, "Size and Spacing of Braille Characters Standards for Braille Embossed on Paper," 2008.

[45] Arduino, "Frequently Asked Questions," 2017. [Online]. Available: https://www.arduino.cc/en/Main/FAQ. [Accessed: 09-Dec-2017].

[46] "Kindergarten Spelling Words Lists & Resources | Time4Learning." [Online]. Available: https://www.time4learning.com/spellingwords/kindergarten-spelling-words.shtml#words. [Accessed: 11-Jan-2018].

[47] S. R. Enriquez, *Abakada, unang hakbang sa pagbasa*. Manila, Philippines: Philippine Book Co., 1987.

[48] "5 Simple Button and Led Projects With Arduino: 5 Steps (with Pictures)." [Online]. Available: http://www.instructables.com/id/5-Simple-Button-and-Led-Projects-with-Arduino/. [Accessed: 11-Jan-2018].

[49] M. Thurlings, M. Vermeulen, T. Bastiaens, and S. Stijnen, "Understanding feedback: A learning theory perspective," 2013.

[50] R. S. Alsawaier, "The effect of gamification on motivation and engagement," *Int. J. Inf. Learn. Technol.*, vol. 35, no. 1, pp. 56–79, 2018.

[51] O. Simko, "Gamification – creating engaging learning communities," *Adult Educ. Dev.*, no. 81, 2014.

[52] J. M. Keller, "Development and Use of the ARCS Model of Instructional Design," *J. Instr. Dev.*, vol. 10, no. 3, pp. 2–10, 1989.

Appendix

6.3 GMECH-040-16 GREB Clearance

November 18, 2016

Ms. Rhianne Lopez
Master's Student
Department of Mechanical and Materials Engineering
Queen's University
Kingston, ON, K7L 3N6

GREB Ref #: GMECH-040-16; TRAQ # 6019797
Title: "GMECH-040-16 Technology-enabled innovations to assist children with visual impairments in the Philippines"

Dear Ms. Lopez:

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposal entitled **"GMECH-040-16 Technology-enabled innovations to assist children with visual impairments in the Philippines"** for ethical compliance with the Tri-Council Guidelines (TCPS 2 (2014)) and Queen's ethics policies. In accordance with the Tri-Council Guidelines (Article 6.14) and Standard Operating Procedures (405.001), your project has been cleared for one year. You are reminded of your obligation to submit an annual renewal form prior to the annual renewal due date (access this form at http://www.queensu.ca/traq/signon.html/; click on "Events"; under "Create New Event" click on "General Research Ethics Board Annual Renewal/Closure Form for Cleared Studies"). Please note that when your research project is completed, you need to submit an Annual Renewal/Closure Form in Romeo/traq indicating that the project is 'completed' so that the file can be closed. This should be submitted at the time of completion; there is no need to wait until the annual renewal due date.

You are reminded of your obligation to advise the GREB of any adverse event(s) that occur during this one year period (access this form at http://www.queensu.ca/traq/signon.html/; click on "Events"; under "Create New Event" click on "General Research Ethics Board Adverse Event Form"). An adverse event includes, but is not limited to, a complaint, a change or unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that all adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be cleared by the GREB. For example, you must report changes to the level of risk, applicant characteristics, and implementation of new procedures. To submit an amendment form, access the application by at http://www.queensu.ca/traq/signon.html; click on "Events"; under "Create New Event" click on "General Research Ethics Board Request for the Amendment of Approved Studies". Once submitted, these changes will automatically be sent to the Ethics Coordinator, Ms. Gail Irving, at the Office of Research Services for further review and clearance by the GREB or GREB Chair.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Sincerely,

John D. Freeman

John Freeman, Ph.D.
Chair
General Research Ethics Board

c: Dr. Claire Davies, Supervisor

6.4 Questionnaire 1 List of Questions – For Teachers

General Information

1. **What is your level of visual function?**
   A. Normal vision
   B. Moderate visual impairment
   C. Severe visual impairment
   D. Blindness
2. **Do you read without Braille?** Yes No
   a. **If yes, at what age did you start learning how to read without Braille?**
3. **Do you read in Braille?** Yes No
   a. **If yes, at what age did you start learning how to read in Braille?**
4. **Did you learn to read without Braille before learning Braille** Yes No
5. **In what language(s) are you learning how to read? Please specify whether or not you are learning in Braille for each language.**
6. **Why do you want to learn how to read?**

Specialized Schools or Programs

7. **Do you attend any specialized schools or programs for persons with VI?** Yes No
   a. **If yes, which one(s)?**
8. **How often do you attend?**
9. **What do you read when you attend?**:
   A. Novels
   B. Magazines
   C. Worksheets
   D. Textbooks
   E. The Bible
   F. Webpages
   G. Other: ____

Reading Environment

10. **Where do you read most often?**
11. **What do you read most often?**:
    H. Novels
    I. Magazines
    J. Worksheets
    K. Textbooks
    L. The Bible
    M. Webpages
    N. Other: ____

Assistive Devices/Technology

12. **What devices/technologies do you use to help you learn to read?**
    Device #1: ____
13. **Please circle a number based on to what extent the device/technology meets the following criteria.**

Cost:

	Very cheap								Very expensive	
N/A	1	2	3	4	5	6	7	8	9	10

Ease of use:

	Very easy to use									Very difficult to use
N/A	1	2	3	4	5	6	7	8	9	10

Durability:

	Never breaks/rips/malfunctions							Always breaks/rips/malfunctions		
N/A	1	2	3	4	5	6	7	8	9	10

Level of engagement:

	Could use for several hours								Would prefer not to use	
N/A	1	2	3	4	5	6	7	8	9	10

14. **What is the best feature of this device/technology?**
15. **What is the most annoying feature of this device/technology?**
16. **Are there any devices/technologies that you have heard about that could help you read, but do not have access to?:** Yes No
    a. **If yes, what are the devices/technologies and what are their attractive features?**
17. **What is preventing you from gaining access to these devices/technologies?**
18. **If you were to create a new device/technology to help you read, what features should it include?**
19. **Additional Comments:**

6.5 GMECH-043-17 GREB Clearance

May 30, 2017

Ms. Rhianne Lopez
Master's Student
Mechanical and Materials Engineering
Queen's University
Kingston, ON, K7L 3N6

GREB Ref #: GMECH-043-17; TRAQ # 6020836
Title: "GMECH-043-17 Matuto, Magbasa, Maglaro: Learning to read in braille through play"

Dear Ms. Lopez:

The General Research Ethics Board (GREB), by means of a delegated board review, has cleared your proposal entitled **"GMECH-043-17 Matuto, Magbasa, Maglaro: Learning to read in braille through play"** for ethical compliance with the Tri-Council Guidelines (TCPS 2 (2014)) and Queen's ethics policies. In accordance with the Tri-Council Guidelines (Article 6.14) and Standard Operating Procedures (405.001), your project has been cleared for one year. You are reminded of your obligation to submit an annual renewal form prior to the annual renewal due date (access this form at http://www.queensu.ca/traq/signon.html/; click on "Events"; under "Create New Event" click on "General Research Ethics Board Annual Renewal/Closure Form for Cleared Studies"). Please note that when your research project is completed, you need to submit an Annual Renewal/Closure Form in Romeo/traq indicating that the project is 'completed' so that the file can be closed. This should be submitted at the time of completion; there is no need to wait until the annual renewal due date.

You are reminded of your obligation to advise the GREB of any adverse event(s) that occur during this one year period (access this form at http://www.queensu.ca/traq/signon.html/; click on "Events"; under "Create New Event" click on "General Research Ethics Board Adverse Event Form"). An adverse event includes, but is not limited to, a complaint, a change or unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that all adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be cleared by the GREB. For example, you must report changes to the level of risk, applicant characteristics, and implementation of new procedures. To submit an amendment form, access the application by at http://www.queensu.ca/traq/signon.html; click on "Events"; under "Create New Event" click on "General Research Ethics Board Request for the Amendment of Approved Studies". Once submitted, these changes will automatically be sent to the Ethics Coordinator, Ms. Gail Irving, at the Office of Research Services for further review and clearance by the GREB or GREB Chair.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Sincerely,

John D. Freeman

John Freeman, Ph.D.
Chair
General Research Ethics Board

c: Dr. Clarie Davies, Supervisor

6.6 List of Reasons to Read

Participants Learning to Read

- To enhance my skills
- So that if I ever become blind, I already know how to read Braille
- So that I can be a fast reader
- So that if I ever become blind, I can already
- To improve myself
- Because it is so important. It will help for my studies, work and socialization
- So I Can read whatever I want and/or need to read
- To do task in school
- Because it is important to read. If you cannot read it is difficult to communicate
- It is helpful to our daily living
- To understand the words and sentences written on the book
- Because reading is necessary to gather information in our daily lives
- Wants to know the current events around the world and have a better understanding
- Educational purposes
- Because I want to read stories
- to learn and be literate
- I want to explore the world through reading
- I want to be a teacher and teach other people with VI
- Because I believe that reading is one of the most important skills needed in order to be successful in life
- I want to go to school. I want to read more books

Participants who had Already Learned to Read

- Learn more about things
- Key of a door - unlocks wisdom or knowledge which can help you in many ways - eg. Helps me to know the real truth
- Gives new knowledge, wisdom, etc. Reading is like a teacher, because it develops my personality and it brings me from nothing to something
- Need to know where I'm going when travelling
- You can learn a lot, and you will not be deceived, and it is also the road toward success
- To gain knowledge
- Reading is important to me because through reading we can go to the place that we cannot go through imagination
- To increase and widen my knowledge
- Wants to learn a lot of things
- To get more knowledge

Participants who Taught Reading

- Because reading is the key to advance in any form of literacy.
- To prepare them for higher aptitude of learning
- It is important for inclusion purposes
- So they will not be left behind
- Reading is essential for understanding and discovering new things
- It is also a way to communicate and a source of information
- Yes it is, because reading can help them in the betterment of their ideas and they can use it for future reference
- It develops the mind, and discover new things

- Reading is a means of language acquisition and communication visually impaired or not
- It is important for them how to read so they can study and understand lessons

6.7 Current Devices Used by Participants in the Philippines to Help Learn to Read or to Read

Table A 1: Reading devices used by participants from the Philippines

Reading Device	Learning	Learned	Teaching	Total
Books	10	5	2	17
Computers	6	4	1	11
Cellphones	7	2		9
Magnifiers	1	1	2	4
Tablets	1		1	2
Braille Scanners	1			1
Screen Readers		4	1	5
Multi-Players		2	1	3
Embosser			3	3
Slate and Styluses			1	1
Braillers			2	2

6.8 QFD Matrices

QFD matrices can be found in Figures A2, A3 and A4. The legend for these Figures can be seen in Figure A 1.

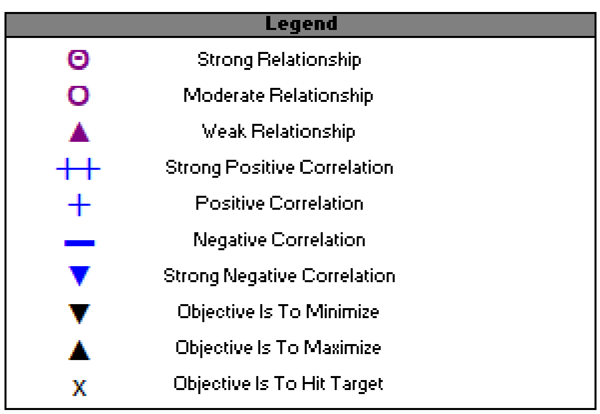


Figure A 1: Legend for QFD matrices

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	▼	▲	▼	x	x	x	x		▲	x	▲	▲	▼	▼	x	x
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Volume	Weight	Cost	Material Strength	No Viruses/Glitches/Malfunctions	Adjustable font size	Adjustable font	Adjustable font colour	Adjustable contrast	Glare	Battery life	Intuitive use	Teaches how to read in multiple languages	Engaging	Maintenance	Assembly time	Volume	Brightness
1	9	10.6	7.0	Affordable	O	O	Θ	Θ	▲						Θ		O		▲	O		
2	9	10.6	7.0	Not bulky	Θ	Θ	O															
3	3	4.5	3.0	Lightweight	▲	▲	O								▲							
4	9	6.1	4.0	Good battery life	O		O		O						Θ			O	O			O
5	9	10.6	7.0	Not fragile		▲	Θ	Θ	Θ							▲			Θ	▲		
6	9	10.6	7.0	Adjustable letter size / Zoom feature			▲			Θ						▲		▲				
7	9	12.1	8.0	Adjustable font			▲				Θ					▲		▲				
8	9	7.6	5.0	Adjustable colour contrast			▲					Θ	Θ			▲		▲				O
9	9	3.0	2.0	Convenient / Handy to use	O	O			▲						▲	Θ		▲			▲	
10	9	1.5	1.0	Talks back (eg. Text to Braille)			▲									Θ	O	▲			Θ	
11	9	3.0	2.0	Has pictures			▲						▲	▲				Θ				
12	9	10.6	7.0	Multifunctional			Θ									O	O	Θ				
13	9	7.6	5.0	Has screen reader / Reads content													▲	O			Θ	
14	9	1.5	1.0	Reliable			O	O	Θ						O	Θ	O	O	Θ			
				Target or Limit Value	26x20x5 cm	< 2kg	<100 CAN	TBD	0	Minimum 18 pt.	Roman or sans seri (Arial)	Dark blues, greens	White or yellow on dark	TBD	> 10 hours	<30 mins to learn how to use	English and Tagalog (minimum)	Could use for at least 1 hour	no maintenance / replacements for at least 5 years	<15 minutes	TBD	TBD
				Difficulty (0=Easy to Accomplish, 10=Extremely																		
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	1	9	9	3	9	9	3	9	3
				Weight / Importance	159.1	151.5	389.4	195.5	140.9	95.5	109.1	68.2	71.2	3.0	162.1	127.3	80.3	203.0	137.9	42.4	84.8	40.9
				Relative Weight	7.0	6.7	17.2	8.6	6.2	4.2	4.8	3.0	3.1	0.1	7.2	5.6	3.5	9.0	6.1	1.9	3.8	1.8

Figure A 2: QFD matrix for participants learning how to read

				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	▼	▲	x	x	x	x	x		▲	x	▲	▲	▼	▼	x	x
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Volume (Size)	Weight	Cost	Material Strength	No Viruses/Glitches/Malfunctions	Adjustable font size	Adjustable font	Adjustable font colour	Adjustable contrast	Glare	Battery life	Intuitive use	Teaches how to read in multiple languages	Engaging	Maintenance	Assembly time	Volume	Brightness
1	9	14.7	6.5	Affordable	Ο	Ο	Θ	Θ	▲						Θ		Ο		▲	Ο		
2	9	7.9	3.5	Available in the country			Θ										▲		▲			
3	3	3.4	1.5	Lightweight	▲	▲	Ο								▲							
4	9	3.4	1.5	Good battery life	Ο		Ο		Ο						Θ			Ο	Ο			Ο
5	9	2.3	1.0	Doesn't rip easily		▲	▲	Θ								▲			Θ			
6	9	2.3	1.0	Not fragile		▲	Θ	Θ	Θ							▲			Θ	▲		
7	9	2.3	1.0	No technical errors			Ο		Θ						Ο	Θ			Θ	▲		
8	9	6.8	3.0	No viruses			▲		Θ									Ο	Θ			
9	9	2.3	1.0	No upgrades required			▲		Θ							▲		▲	Θ			
10	9	2.3	1.0	Easy to navigate/Good layout	▲											Θ		Θ				
11	9	6.8	3.0	Adjustable letter size/Zoom feature			▲			Θ						▲		▲				
12	9	4.5	2.0	Convenient to use/Handy	Ο	Ο			▲						▲	Θ		▲			▲	
13	9	2.3	1.0	Anti-Glare			▲							Θ				▲				Ο
14	9	5.2	2.3	Can read any language (especially Tagalog)			Ο										Θ	Ο			Ο	
15	9	5.2	2.3	Good pronunciation												▲	Θ	Ο			Ο	
16	9	5.2	2.3	Talks back			▲									Θ	Ο	▲			Θ	
17	9	2.9	1.3	Descriptive/Emotive speech			▲									Θ	▲	Θ			Ο	
18	9	9.0	4.0	Multifunctional			Θ									Ο	Ο	Θ				
19	9	9.0	4.0	Has screen reader / Reads content													▲	Ο			Θ	
20	9	2.3	1.0	Reliable			Ο	Ο	Θ						Ο	Θ	Ο	Ο	Θ			
				Target or Limit Value	26x20x5 cm	< 2kg	<100 CAN	TBD	0	Minimum 18 pt.	Roman or sans serif (Arial)	Dark blues, greens	White or yellow on dark	TBD	> 10 hours	<30 mins to learn how to use	English and Tagalog (minimum)	Could use for at least 1 hour	no maintenance / replacements for at least 5 years	<15 minutes	TBD	TBD
				Difficulty (0-Easy to Accomplish, 10-Extremely Difficult)																		
				Max Relationship Value in Column	3	3	9	9	9	9				9	9	9	9	9	9	3	9	3
				Weight / Importance	73.5	65.6	383.5	179.9	171.9	61.1				20.4	184.4	221.0	207.2	245.0	195.7	48.6	172.9	17.0
				Relative Weight	3.3	2.9	17.1	8.0	7.6	2.7				0.9	8.2	9.8	9.2	10.9	8.7	2.2	7.7	0.8

Figure A 3: QFD matrix for participants who had already learned how to read

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Volume	Weight	Cost	Material Strength	Viruses/Glitches/Malfunctions	Adjustable font size	Adjustable font	Adjustable font colour	Adjustable contrast	Glare	Battery life	Intuitive use	Teaches how to read in multiple languages	Engaging	Maintenance	Assembly time	Volume	Brightness
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	▼	▲	▼	x	x	x	x		▲	x	▲	▲	▼	▼	x	x
1	9	22.5	14.0	Affordable	Θ	O	Θ	Θ	▲						Θ		O		▲	O		
2	9	11.3	7.0	Available in the country			Θ										▲		▲			
3	9	6.1	3.8	Not bulky	Θ	Θ	O															
4	3	6.1	3.8	Lightweight	▲	▲	O								▲							
5	9	2.9	1.8	Doesn't need to be plugged in											Θ							
6	9	4.5	2.8	Good battery life	O		O		O						Θ			O	O			O
7	9	6.4	4.0	No technical errors			O		Θ						O	Θ			Θ	▲		
8	9	4.8	3.0	Adjustable letter size / Zoom feature			▲			Θ						▲		▲				
9	9	6.4	4.0	Can get work done easily						▲	▲	▲	▲	▲		Θ					▲	▲
10	9	4.8	3.0	Convenient to use / Handy	O	O			▲						▲	Θ		▲			▲	
11	9	8.0	5.0	Provides feedback (eg. Through speech)												O	▲	▲			Θ	
12	9	4.8	3.0	Tactile learning feature	▲	▲	O	O								Θ	O	O	▲			
13	9	6.4	4.0	Multifunctional			Θ									O	O	Θ				
14	9	4.8	3.0	Has screen reader / Reads content													▲	O			Θ	
				Target or Limit Value	26x20x5 cm	< 2kg	<100 CAN	TBD	0	Minimum 18 pt.	Roman or sans serif (Arial)	Dark blues, greens	White or yellow on dark	TBD	> 10 hours	<30 mins to learn how to use	English and Tagalog (minimum)	Could use for at least 1 hour	no maintenance / replacements for at least 5 years	<15 minutes	TBD	TBD
				Difficulty (0=Easy to Accomplish, 10=Extremely																		
				Max Relationship Value in Column	9	9	9	9	9	9	1	1	1	1	9	9	3	9	9	3	9	3
				Weight / Importance	296.5	147.9	450.5	217.0	98.7	49.8	6.4	6.4	6.4	6.4	299.4	250.8	125.4	118.0	110.0	74.0	127.0	19.9
				Relative Weight	12.3	6.1	18.7	9.0	4.1	2.1	0.3	0.3	0.3	0.3	12.4	10.4	5.2	4.9	4.6	3.1	5.3	0.8

Figure A 4: QFD matrix for participants teaching reading

6.9 Preliminary Device Ideas

Table A 2: Results from initial brainstorming session

Device #	Description
PD1	Hooks up to Brailler Speaks/reads to you Reads the braille that is printed out
PD2	Braille blocks Connect together to form words Has something to read the words
PD3	LeapFrog that can give haptic feedback using a shock
PD4	Braille kobo with refreshable braille
PD5	Stickers on keyboard (Dymo)
PD6	Refreshable braille (bed of nails)
PD7	Braille Lego that speaks
PD8	LeapFrog that allows you to swap out braille letters (similar to LeapFrog's Fridge Phonics)
PD9	Piano keyboard with braille letters
PD10	Braille glove with pins
PD11	Refreshable braille display that uses inflation to push up the pins
PD12	Braille computer keyboard (either polymer keyboard cover or stickers on top of existing keyboard) Computer/tablet/cellphone tells you which key is pressed Once a word is written, it tell you what word you spelled Can incorporate a game to go with it Connects to multiple device using Bluetooth
PD13	Lego brick touch pad Pad tells you a word or sentence to write The pad says the word once the letters are in place and the full word is down Can connect to other boards/devices (race against friends)
PD14	Keyboard with braille stickers Keyboard connects to a microprocessor with USB memory USB memory has dictionary and audio storage along with performance tracking data
PD15	Braille buttons (bigger than standard braille) that can print the braille if needed Once the appropriate buttons are pressed, recites the letter By pressing braille buttons, paper underneath keyboard is embossed
PD16	Comprises of a board with six holes and six slightly weighted cylinders Student puts the weights in the holes depending on the letter that the device says Can have lights and/or vibration to indicate where to put the weights for students who just started learning how to read Mostly focuses on spatial awareness
PD17	Octo-blocks with eight letters on them Can attach octo-blocks to each other to form words Says the word once it is formed

6.10 Merged Device Ideas

Table A 3: Device ideas after merging best features of preliminary device ideas

Device #	Preliminary Device Ideas Used	Description
M1	**PD2, PD7, PD8, P1D3**	**Lego brick touch board** o Pad tells you a word or sentence to write o The pad says the word once the letters are in place and the full word is down o Uses pin recognition to detect which block is in the board o Can connect to other boards/devices (race against friends) o Can have word blocks as well that students have to read o Device asks you what it says and gives you options to choose from
M2	**PD5, PD12, PD14**	**Keyboard with braille stickers** • Keyboard connects to a microprocessor with USB memory • USB memory has dictionary and audio storage along with performance tracking data • Computer/tablet/cellphone tells you which key is pressed • Once a word is written, it tell you what word you spelled • Can incorporate a game to go with it • Connects to multiple device using Bluetooth or cords • *would they know which key to press just from muscle memory?
M3	**PD3, PD5, PD8**	**LeapFrog's Fridge Phonics – use existing pin system** • Instead of having large Latin letters, replace with braille letters
M4	**PD2, PD13, PD17**	**Blocks (6 sides) can be inserted into slots to spell words** • Pad tells you a word or sentence to write • The pad says the word once the letters are in place and the full word is down • Can connect to other boards/devices (race against friends) • Can have word blocks as well that students have to read • Device asks you what it says and gives you options to choose from
M5	**PD4,PD6, PD11**	**Braille kobo with refreshable braille** • Uses inflation to form dots
M6	**PD6, PD10**	**Braille glove with pins** • Uses bed of nails to poke out pins
M7	**PD5, PD9, PD12, PD14**	**Piano keyboard with braille stickers** • Once a word is written, it tells you what word you spelled • Can incorporate a game to go with it • Connects to multiple device using Bluetooth or cords • MIDI to USB
M8	**PD1, PD15, PD16**	**Braille buttons (bigger than standard braille) that can print the braille if needed** • Once the appropriate buttons are pressed, recites the letter • By pressing braille buttons, paper underneath keyboard is embossed
M9	**PD1, PD16**	**Comprises of a board with six holes and six slightly weighted cylinders** • Student puts the weights in the holes depending on the letter that the device says • Can have lights and/or vibration to indicate where to put the weights for students who just started learning how to read • Mostly focuses on spatial awareness • Press button to print letter (not necessary)

6.11 Questionnaire 2 List of Questions – Participants from Canada

General Participant Information

1. **What is your level of visual function?**
   A. Normal vision
   B. Moderate visual impairment
   C. Severe visual impairment
   D. Blindness
2. **You are an individual _______:**
   A. below the age of 18 who has visual impairment and has just started to learn braille
   B. who has visual impairment and has already learned braille
   C. who teaches braille to persons with visual impairments (eg. teacher, parent of child with visual impairment, etc.)
      a. **You are a ____:**
         i. Parent
         ii. Teacher
         iii. Caregiver
         iv. Other – Please specify

3. **What is your gender?** Male Female Prefer not to answer
4. **How old are you? _______**
5. **Which country are you from?** Philippines Canada
6. **In which city do you live?**
7. **In what language(s) are you learning braille?**

Accessibility

8. **If commercially available, for how much would you buy a product similar to this device?**

Portability

9. **Do you think this device is too big?** Yes No
   a. **If yes, how small would you prefer it to be?**
      i. Size of a smart phone
      ii. Size of an iPad
      iii. Size of a computer keyboard
10. **For how long would you play with the device before it needs to be plugged in to be charged?**

Durability

11. **Did you encounter any technical errors when testing the device?** Yes No
    a. **If yes, what happened?**

Usability

12. **Were any of the buttons difficult to access?** Yes No
a. **If yes, which one(s) and where would you prefer to have the button(s)?**
13. **On a scale from 1 to 10, how clear were the instructions on how to use the device?**

Very unclear									Very clear
1	2	3	4	5	6	7	8	9	10

14. **How could the instructions be clearer?**

15. **On a scale from 1 to 10, how easy was it to use the device?**

    Very difficult to use — Very easy to use

1	2	3	4	5	6	7	8	9	10

16. **What device features would you change to make it easier to use?**

17. **On a scale from 1 to 10, how useful is the screen?**

    Not useful — Very useful

1	2	3	4	5	6	7	8	9	10

18. **Could you use this device without the help of a teacher or parent?** Yes No

Function

19. **Did you have fun trying this device?** Yes No
20. **For how long do you think you could use this device in one sitting?**
21. **Could you understand what the device was asking you to do?** Yes No
22. **Do you think this device could be an effective braille learning tool?** Yes No
    a. **Please explain.**
23. **Would you use this device to help you (or your students) learn braille?** Yes No
    a. **Please explain.**
24. **What features would you add to the device?**

General Device Questions

25. **What is the best feature of this device?**
26. **What is the worst feature of this device?**
27. **Additional comments:**