DEVELOPMENT AND DESIGN OF BRAILLEBUNNY: A DEVICE FOR BRAILLE LITERACY EDUCATION

by

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Abstract

Braille is crucial for social and economic opportunity and has been linked to higher rates of employment, education, financial self-sufficiency, and self-esteem. Braille literacy is decreasing, and the National Federation of the Blind has declared a braille literacy crisis. One area of the world particularly impacted by braille illiteracy is the Philippines. In 2016, Digital Learning for Development and All Children Reading released a “Grand Challenge for Development” that challenged researchers to address the need for assistive technologies to help children with sensory disabilities learn to read in the Philippines.

The work of this thesis aimed to address the need for a device that helps children in the Philippines learn to read braille. A comprehensive set of ideal design criteria for a device for braille literacy education in the Philippines was developed. A parallel, iterative, and co-design process was undertaken to develop a prototypical device, BrailleBunny. The extent to which the device fulfilled the design criteria developed, and directions for future development were determined through a series of case studies with end-users.

The results of this thesis highlight that a device for braille literacy education in the Philippines should promote transferable braille literacy skills including writing with a slate and stylus, provide real time auditory and tactile feedback, be accessible, durable and reliable, safe, easily and independently operable, and enable co-play and cooperative learning. To entice students to use the device, it should be engaging, motivational, and portable. The device achieved all criteria with the exception of being accessible, durable and reliable, and enabling co-play or cooperative learning. Directions for future development to further meet all criteria are presented.
The design criteria developed, and suggestions for improvement provide important insight for designers developing devices for braille literacy education.
Co-Authorship

This thesis contains the original work of Elizabeth Hoskin under the supervision of Dr. T. Claire Davies and Dr. Shane Pinder. The systematic review was completed by Elizabeth Hoskin and co-authors Dr. Morag Coyne, Dr. Michael White, Dr. T. Claire Davies, and Dr. Shane Pinder. The work contained expands on the initial pilot project undertaken by Rhianne Lopez as outlined in Chapter Two.
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### List of Abbreviations

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<th>Description</th>
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<tbody>
<tr>
<td>3D</td>
<td>Three Dimensional</td>
</tr>
<tr>
<td>dB</td>
<td>Decibels</td>
</tr>
<tr>
<td>NA</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>PRISMA</td>
<td>Preferred Reporting Items for Systematic Reviews and Meta-Analyses</td>
</tr>
<tr>
<td>VI</td>
<td>Visual Impairment</td>
</tr>
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Chapter 1

Introduction

1.1 Context and motivation

Braille is a tactile alphabet system that enables people who are blind or visually impaired to read through touch [1]. Braille is crucial for social and economic opportunity and has been linked to higher rates of employment, education, financial self-sufficiency, and self-esteem [2][3][4]. It is estimated that 180 million people worldwide are blind or visually impaired, 90 percent of whom live in developing countries [5]. Braille literacy is decreasing and the National Federation of the Blind has declared a braille literacy crisis [6].

One area of the world particularly impacted by braille illiteracy is the Philippines. In the Philippines, up to four percent of people are blind or visually impaired [7]. In 2016, Digital Learning for Development and All Children Reading released a “Grand Challenge for Development” that challenged researchers to address the need for assistive technologies to help children with sensory disabilities learn to read in the Philippines [8].

A systematic review examining the effectiveness of technologies for braille literacy education was completed (Chapter Four). Despite the fact that 90 percent of people who are blind or visually impaired live in developing countries [5], less than a third of the studies captured by the systematic review evaluated technologies in developing countries. Furthermore, many studies detailed technologies that were still in the prototype phase and not commercially available. Additionally, the high cost of many commercially available technologies makes them inaccessible, especially to users in developing countries [9][10][11].
The factors identified in the systematic review, paired with the Grand Challenge, and the high cost of commercially available technologies, indicate that the assistive technology needs of students in developing countries including the Philippines may not currently be met.

To address the need for assistive technologies to help children with sensory disabilities learn to read in the Philippines, a prototypical device, BrailleBunny, was developed through the work of this thesis. A parallel, iterative, and co-design process was followed. Parallel design is a process where multiple designers independently create designs or design concepts to address a specific problem. Features of each individual design are then merged to create a final design. The majority of design features can be identified with 6 – 8 designers [12]. Advantages of using a parallel design process include decreased time-to-market, and better usability [13]. Iterative design involves a single design that is adapted or a repeated design process to create an improved design. Co-design is an umbrella term which includes the collaborative processes of ‘community design’ and ‘participatory design’. 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” [14]. Including end-users in this way has shown to reduce device abandonment rates [15][16][17].

1.2 Research objectives
The objectives of this research were to:

1. Summarize the state of existing technology for braille literacy education and examine the effectiveness of these technologies.
2. Develop a comprehensive set of ideal design criteria for a device for braille literacy education in the Philippines.

3. Engage in a parallel, iterative, and co-design process to create a device for braille literacy education in the Philippines.

4. Determine the extent to which the device developed in goal four was able to fulfill the needs identified in goal three.

5. Using feedback from goal five, develop directions of future development for the device.

1.3 Thesis layout

To meet these goals, we undertook literature reviews complemented by a systematic review, engaged in a parallel, iterative, and co-design process, and completed a series of case studies. The chapters following the introduction include:

Chapter 2: The key outcomes from the pilot study of BraillePad, a device developed by Lopez to meet the Grand Challenge requirements, are summarized [15][18][19] (Objectives 1 and 2).

Chapter 3: Literature reviews were used to identify educational strategies that should be incorporated into a braille education device, understand how students write braille in the Philippines, and evaluate evidence-based practices (Objective 2).

Chapter 4: To examine the effectiveness of technology applied within braille literacy education and identify design criteria, a systematic review was conducted (Objectives 1 and 2).

Chapter 5: To thoroughly summarize the state of existing braille education technology not captured by the systematic review and identify design criteria, a cross-section of
existing technology and characteristics of this technology were compiled (Objectives 1 and 2).

Chapter 6: To formulate a design concept, design criteria were determined, and a parallel and co-design process was followed (Objectives 2 and 3).

Chapter 7: A prototype was built to act as proof of concept. A description of the prototype and manufacturing methods is presented (Objective 3 and 4).

Chapter 8: To assess the prototype, an internal assessment and series of case studies were conducted. An evaluation of the prototype and directions for future development are presented (Objectives 4 and 5).

Chapter 9: The conclusions, implications, and future work relating to this thesis is discussed.
Chapter 2

BraillePad Pilot Study

2.1 Overview

In September 2016, Digital Learning for Development and All Children Reading released a “Grand Challenge for Development” to address the need for assistive technologies to help children with sensory impairments learn to read [8]. This challenge sparked the BraillePad pilot study, completed by Rhianne Lopez [18]. Lopez (2018) examined user needs and developed a prototype of a device for braille literacy education in the Philippines, BraillePad. This section summarizes the key aspects of the BraillePad project that informed the design of the current system, BrailleBunny. For complete details of the BraillePad project, refer to the thesis by Lopez, Matuto, Magbasa, Maglaro: Learning To Read Braille Through Play [18] and associated papers [15][19].

The BraillePad project consisted of three phases and associated outcomes: user needs assessment, device creation, and device assessment.

2.1.1 User needs assessment

To determine user needs for a device that would help people learn to read braille, a questionnaire was completed in the Philippines with participants who were: 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 visual impairment, etc.).

The most prevalent user needs responses were grouped into four categories: accessible (affordable and available in the Philippines), portable (good battery life, lightweight, not bulky), durable/reliable (no technical errors/malfunctions, robust), and
functional (easy to use, effective learning tool, engaging, multifunctional, provides auditory feedback).

2.1.2 Device creation

Using design goals identified from the user needs assessment, a device was ideated through the processes of parallel design and co-design, and prototyped as BraillePad.

BraillePad is an interactive device with which users can quiz their spelling and knowledge of the braille alphabet. BraillePad has four series of holes that each represent a braille cell (Figure 1). BraillePad interacts with the user through auditory cues and an LCD screen. It directs the user to spell out a single letter or four-letter word by placing pegs in the holes that represent a braille dot. When the user places a peg in a hole, BraillePad notifies the user whether the answer is correct. If the answer is incorrect, it gives the user two more chances, then tells them which cells are incorrect, and where the pegs should be placed. BraillePad can interact with the user in English or Tagalog.

![Figure 1: Top view (left) and isometric view (right) of BraillePad](image)

2.1.3 Device assessment

To assess the usability of BraillePad, participants who fit the same criteria as the user needs survey completed a usability questionnaire based on the earlier criteria of accessibility, portability, durability, and function. Participants in Canada physically tested
the device, while Participants in the Philippines watched or listened to a descriptive video about BraillePad before responding to the questionnaire.

A total of seven participants from the Philippines and 14 participants from Canada completed the device assessment questionnaire. The most prevalent responses of device strengths included clarity of instructions, ability to be used independently, and the potential to be an effective braille learning tool. Challenges were identified as lack of affordability ($258.25 CAD), weight and size created issues with portability, durability affected by technical errors and difficulty in cleaning, and function issues including the lack of a headphone port, enabled only one activity, and used random generation of words rather than an educational phonetics approach.

2.2 Discussion

The BraillePad pilot study demonstrated that developing a braille education device for use in the Philippines is feasible and that such a device is desirable to users. Key design criteria that should be prioritized are device accessibility, portability, durability/reliability, and functional requirements including ease of use, audio feedback, user engagement, multifunctionality, and efficacy as a braille learning tool. Financial accessibility was identified as an especially challenging criteria to meet, as the cost of BraillePad ($258.25 CAD) is prohibitive for many users considering that the average family income in the Philippines is 264 000 PHP, or about 6 600 CAD per year [20].

BrailleBunny was designed to capitalize on the benefits of the BraillePad while simultaneously addressing the aforementioned challenges.
Chapter 3

The Learning Process

3.1 Overview

Literacy is the set of tangible cognitive skills related to reading and writing, where reading and writing skills go hand in hand [21]. To identify educational strategies that should be incorporated into a braille literacy education device, evidence-based practices with respect to reading braille are summarized. A description of learning to write braille in the Philippines and developing countries is then compared to techniques used in Canada.

The importance of braille literacy is well documented. A 2018 study found that blind adults who used braille at least once a week have higher employment rates (65% versus 45%) [3]. Braille usage has also been shown to contribute to self-esteem, life-satisfaction, and job satisfaction for people who have learned braille at any stage through childhood, adolescence, or adulthood [22]. Compared to auditory methods, braille leads to better comprehension, less mind wandering [23], and the development of grammar and spelling skills [24].

Despite the well-documented importance of braille, braille literacy is decreasing. The National Federation of the Blind has declared a braille literacy crisis [6]. It is thought that braille instruction is not being provided to some students for whom it may be appropriate [25]. This may be due to the misconception that braille is isolating or stigmatizing, or due to a lack of qualified braille teachers [6].
3.2 Evidence-based practice

Beginning braille learners must develop tactile discrimination skills [26]. A lack of tactile discrimination skills often leads to difficulty discerning the small dots in a standard braille cell. In these cases, over-sized, large scale versions of braille that enable beginning braille learners to discern the braille patterns more easily can be used. Examples of these include braille peg boards [27], or plastic eggs in egg cartons [28]. Once the user has learned tactile discrimination skills, they can move on to reading.

Strategies for braille literacy education vary [29][28][30]; however, researchers agree that early exposure to braille concepts is crucial not only for the development of literacy skills [24][28][31], but also for opportunities to participate in the classroom with sighted peers [30]. To master braille successfully, students need ample, daily practice of 30 minutes to two hours per day [32][31][33][34] and individual feedback and attention [35]. For any student working on literacy concepts, not just braille learners, feedback that is immediate, specific, positive, encouraging, and guides the student to discover the correct answer independently is the most effective [36].

Reading instruction should not be based on a single tactic or principle [37]. Recommended practices include direct instruction in phonics and decoding morphemes and graphemes, repeated readings, and exposure to a wide variety of reading genres [34][26]. When students learn braille, they must learn to discriminate tactile patterns while concurrently associating them with spoken language. Therefore, progress occurs gradually and new letters or concepts should only be introduced once previous concepts are thoroughly acquired [26]. Structured drill and practice instruction has been shown to result in increased reading achievement and greater reading comprehension [34][32]. When self-instructional material is used, it should incorporate small steps, active
participation, self-pacing, immediate feedback, gradual withdrawal of instructional prompts, and student testing [38].

For students who are struggling to learn braille, skills-based approaches are not always successful [30]. Although it is effective for many students, breaking up reading into letters and words through a skills-based approach without context offers students the most complex elements first [39]. Children with additional disabilities in particular may have gaps in concepts including basic directions or location, or have a limited vocabulary, making it difficult for them to succeed with a skills-based approach [30]. Instead, whole-language, functional, or meaning-centred approaches that focus on words that are meaningful to students, or emphasize context using stories may improve literacy outcomes, motivation, and engagement [40][30][39].

There are two major forms of braille, uncontracted braille sometimes referred to as alphabetic braille or Grade 1 braille, and contracted braille sometimes referred to as standard braille or Grade 2 braille. Uncontracted braille consists of the letters a through z and punctuation, while contracted braille is a more complicated shorthand. There are 63 possible dot combinations using one or more of the six dots in a braille cell. However, there are 180 letter contractions used in contracted braille, including short form words [41]. There is debate on when it is best to introduce students to contracted braille. Contracted braille is more complicated, and has disadvantages when it comes to developing spelling skills [30]. Uncontracted braille can increase the amount of braille in a student’s environment, a crucial step for improving literacy outcomes [39], as it is easier for a sighted family member to learn [30]. Conversely, introduction to contractions early in a student’s literacy development has been correlated with higher literacy
performance [34][37], contracted braille can enable students to read faster, and is a standard for braille signage in many countries [30].

3.3 Learning to write braille

Braille can be written using a variety of technologies including electronic braille notetakers, braillers, and a slate and stylus. Figure 2 shows a brailler. Using a brailler, braille is typed from left to write across the page, unmirrored. To type a braille cell, the user pushes keys that represent the braille dots. The braille cell is comprised of six possible dots, two columns wide by three rows tall. The left-most column has dots referred to as one, two, and three starting from the top, and the right-most column has dots four, five, and six starting from the top. However, on a brailler, the keys are placed in one row, instead of columns like a typical braille cell. The user places their index, middle, and ring finger of their left hand on buttons that represent dots one, two, and three. The user places their index, middle, and ring finger of their right hand on buttons that represent dots four, five, and six respectively. To type a cell, the user presses each of buttons that represent the desired dots down simultaneously. In these scenarios, braille is written in the same direction it is read, from left to right [42]. Using a slate and stylus, braille is written mirrored from right to left by punching individual holes into cardstock (Figure 3) [43]. An example of mirrored and unmirrored text is provided in Figure 4. Learning to write with a slate and stylus can be challenging because students must learn mirror images of the braille characters, and feedback is delayed until the paper is removed from the slate [44]. However, a slate and stylus is commonly used in developing countries due to the minimal cost. A slate and stylus is available for approximately $15 CAD, whereas other technologies such as braillers or braille notetakers typically cost
$1000 - $5000 CAD [45][46][47]. In addition to cost, advantages of the slate and stylus are that it is portable, quiet, and does not require a power source [31].

Figure 2: Perkins next generation brailler

Figure 3: Slate and stylus in use (i – dimpling the cardstock, ii – paper removal, iii – reading braille)

Figure 4: Example of unmirrored and unmirrored braille, shown with the word “Elizabeth” in uncontracted braille

3.4 Recommendations when developing technological learning tools

All students must develop basic literacy concepts that include phonological awareness, knowledge of letter names, language skills [48] and these can be achieved through either contracted or uncontracted braille strategies. However, reading braille in
printed medium (in English or Tagalog) occurs from left to right. In addition to the basic literacy concepts, students learning to write with a slate and stylus must learn how to read from left to right while simultaneously learning to write from right to left. While learning mirror images of the braille code, they must also perform while receiving significantly delayed feedback. Although learning to write with a slate and stylus poses unique challenges, it is crucial for literacy in developing countries due to its financial accessibility.

A tool to assist teaching writing with a slate and stylus would be beneficial to students learning braille. The research presented in this thesis will describe the development of a device that aids in the teaching of literacy concepts that are transferable to a slate and stylus, and eases the process of learning to write with a slate and stylus. In the development of such a device, a variety of evidence-based practices should be employed. Considering that reading and writing skills are very closely related, an educational tool should build and combine both reading and writing skills. To ensure that students who are in the early stages of developing tactile discrimination skills are able to access the device, it should provide braille at a larger scale. The device should provide and enable early exposure to braille concepts, ample daily practice, and individualized and immediate feedback. Students should be exposed to a wide variety of reading genres, be instructed through active learning, and be given small steps in instruction while prompts are removed gradually. Skills-based approaches that should be incorporated include repeated readings, direct instruction in phonics and decoding morphemes and graphemes, structured drill and practice instruction, and student testing. Furthermore, skills-based approaches should be complemented with functional, meaning-centred, and
whole-language methods, particularly by introducing context through stories. Feedback should be immediate, specific, positive, encouraging, and guide the student to discover the correct answer independently. To accommodate varying opinions on contracted braille, the device should have options for instruction with both contracted and uncontracted braille. In addition, tactile feedback should be prioritized.
Chapter 4

A Systematic Review Investigating the Effectiveness of Technology for Braille Literacy Education for Children and Youth

To date, there are few studies that explore educational methods for braille literacy [32][49], and even fewer that explore the effectiveness of technology for facilitating braille literacy education [50]. In fact, intervention studies that seek to identify the most effective instructional strategies even without considering technology are sparse [51]. There is a need for evaluations of the impact of using assistive devices on academics for children and youth who are blind or visually impaired [52]. This systematic review aimed to synthesize the evidence available to address the aforementioned issues, as suggested by Valentine and Cooper [53].

4.1 Objective

The objective of this systematic review was to examine the effectiveness of technology applied within braille literacy education for children and youth. The findings of this review can help inform the engineering design and selection of technology for braille literacy education.

4.2 Method

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [54]. This review assessed (i) study characteristics, (ii) participant characteristics, (iii) methodological quality, and (iv) technology characteristics.
4.2.1 Eligibility criteria

The objectives were framed using the PICO model of population, intervention, comparison, and outcome [54]. Only peer-reviewed, English-language articles addressing technologies used for braille literacy education for children and youth were included in the review. Studies were excluded if they (i) were systematic or literature reviews, (ii) did not report literacy outcomes, or (iii) did not meet the eligibility criteria defined for each PICO category.

4.2.1.1 Population

The population of interest was defined as children and youth aged 0-21 years who were blind or visually impaired, learning literacy through braille as their primary medium, and had not previously learned to read through sighted methods. Studies that specifically targeted participants who had additional disabilities (for example, people who are deafblind) were excluded. If the inclusion criteria of the study being evaluated enabled students with co-existing disabilities to participate, and the data could not be separated, these articles were included within this review. Similarly, participants who were dual-media learners, or had previously learned braille through sighted methods were included when the data could not be separated.

4.2.1.2 Intervention

The intervention was defined as any form of technology applied to braille literacy education. For this review, technology was defined as any physical or software device or application that enhanced braille literacy education. Literacy was defined as reading and writing. Studies were excluded if their focus was (i) tactile languages other than braille, (ii) applications other than literacy, or (iii) sighted or partially sighted education methods.
4.2.1.3 Comparison

The comparison was defined as the relative positive differences in the measured literacy outcomes among different technologies.

4.2.1.4 Outcome

The outcome was defined as gains in braille literacy outcomes such as spelling ability, knowledge of contractions, and quality of writing composition.

4.2.2 Information sources

In June 2018, 16 academic education, health sciences, multidisciplinary, rehabilitation, and engineering databases were searched. These included Allied and Complementary Medicine Database (AMED), Excerpta Medica Database (Embase), HealthStar, MEDLINE and PsycINFO via OvidSP, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Education Resources Information Center (ERIC), Education Source via EBSCOhost, Compendex and Inspec via Engineering Village, Physical Education Index via ProQuest, Cochrane via Wiley Online Library, PsycArticles via APA PsycNet, Association for Computing Machinery Digital Library (ACM), REHABData, and Web of Science Core Collection. In addition, cited references from prior systematic and literature reviews and articles included in the review were examined.

4.2.3 Search

Each database was searched using a combination of three search categories paired with Boolean operators: (braille) AND (child OR youth) AND (education OR technology). No date limit was specified, and wherever possible, keywords were mapped to subject headings or thesaurus terms, and search results were limited to English articles and age ranges from 0-21. When a database search resulted in a limited number of articles using only the search term ‘braille’, no other search terms were included. Some
databases did not allow for complex search structuring with multiple Boolean operators. In these cases, the child and youth search terms were omitted. The complete MEDLINE search is provided as an example in Table 1.

4.2.4 Study selection
Duplicate results were removed, and relevant studies were selected after two-stages of independent review by at least two researchers. During the first stage, titles and abstracts were assessed for eligibility. During the second stage, the full text of studies identified from the previous stage were assessed for eligibility. At each stage, studies were sorted into ‘Yes’, ‘No’, and ‘Maybe’ categories by each reviewer. Studies in the ‘Maybe’ category were discussed in detail to evaluate whether all reviewers agreed that the eligibility criteria were met.

4.2.5 Data items
Data items including (i) study characteristics, (ii) participant characteristics, (iii) methodological quality, and (iv) technology characteristics were collected from each study. Study characteristics included the total intervention time, study design, and number of participants (Table 2). Participant characteristics included age, education level, and braille proficiency before the technology intervention (Table 2). Methodological quality was assessed using Oxford Levels of Evidence [55], GRADE [56], and Evidence Alert Traffic Light [57], as demonstrated by Novak et al. [58], as well as risk of bias for each study based on guidelines by Law et al. [59] (Table 3). Oxford Levels of Evidence is a hierarchy of the likely best evidence, based on study design and researcher question [55][60]. To determine if a form of technology was effective, the “Does this intervention help?” question from the Oxford Levels of Evidence was used [55]. The GRADE system
rates the quality of evidence based on study design, and strength of the recommendation based on trade-offs between the benefits and harms of using the intervention [56][59]. The Evidence Alert Traffic Light provides a common, easily readable recommendation that is linked to the quality and strength summarized by GRADE. A Traffic Light action of green represents “Go” where the intervention is effective, yellow represents “Measure”, where the effect is uncertain, therefore outcomes must be measured, and red represents “Stop” where the intervention is ineffective [57][59]. Technology characteristics, including a description of the technology, positive literacy outcomes observed with technology use, the number of participants who experienced positive literacy outcomes, and strengths and weaknesses of the technology (Table 4) were also collected.

4.2.6 Synthesis of results
The data items relevant to this review were independently assessed and recorded by two reviewers using The McMaster Quantitative Critical Review Form [61] and corresponding guidelines [59], as well as a custom form for collecting Oxford Levels of Evidence [55], GRADE [56], and Evidence Alert Traffic Light data [57].

4.3 Results
Each study included in this systematic review was assigned a roman numeral. This numeral was used to refer to the appropriate study in the results and discussion sections (Table 2, Table 3, Table 4). In total, nine articles were included in this review.

4.3.1 Study selection
Combined, all database searches yielded 3828 results, of which 2222 were unduplicated. In total 121 records appeared to meet the eligibility criteria and full texts
were screened. Nine articles met the inclusion criteria based on their full text review. No records were identified through other sources. The PRISMA flow chart is shown in Figure 5.

![PRISMA flow chart](image)

**Figure 5: PRISMA flow chart**

### 4.3.2 Study characteristics

Detailed study characteristics are provided in Table 2. Two studies were cohort design (Studies III and VI), three were single-case design (Studies I, II, and VIII), and four were case studies (Studies IV, V, VII, and IX). Studies V and VI considered different iterations of the same device and tested the device with different participants, using different study designs. The total intervention time varied between studies, ranging from 37 minutes to two years of regular classroom use. A total of 113 participants were
assessed, and sample sizes ranged from two to 40 individuals. Two studies (Studies III and VI) included control groups consisting of 28 and nine participants respectively.

4.3.3 Participant characteristics

Detailed participant characteristics are provided in Table 2. The education level of participants ranged from pre-kindergarten to the eighth grade, with the exception of one participant who was in ninth grade. The youngest participants were four years old, the oldest was 15 years old, and the average age was nine. The braille proficiency of the students before the technology intervention was described in varying levels of detail. Most students, however, were at least partially proficient in uncontracted braille.

All participants had no additional disabilities, with the exception of Studies IV, V, and VIII. In Study IV, one participant had cerebral palsy, one had language delays, and one had concurrent motor and language delays. The participants with cerebral palsy and language delays had no difficulties using the technology. On the other hand, the participant with concurrent motor and language delays could not manipulate the technology independently. Additionally, one participant in Study IV was not fluent in English and had difficulties using the technology as they could not understand the verbal cues. These participants were included in the review since the participant limitations were addressed by the authors of the studies in the assessment of the technology, and delays in development do not necessarily indicate the presence of a disability. In Study V, one participant had not yet developed necessary pre-braille skills, and at least one participant had an intellectual disability. The technology efficacy discussion was not assigned to specific participants. Therefore, all participants from Study V were included. In Study VIII, at least three participants had mild learning disabilities or attention deficit
hyperactivity disorder (ADHD). These participants were included since they did not have any challenges using the technology. Furthermore, due to the prevalence of these conditions in children and youth, it is likely that their experiences are relevant to the design and selection of devices for braille literacy education [62][63].

In one study, Study II, several participants were dual-media learners who used print as their primary literacy medium. This study did not attribute the results to specific participants and could not be separated, resulting in the inclusion of all Study II participants. In Study VII, one participant had previously learned to read using sighted methods. The efficacy discussion could be separated by participant and this participant was excluded.

4.3.4 Methodological quality

The methodological quality of the included studies is summarized in Table 3. All studies had an Oxford Level of Evidence of four, one of the poorest levels, out of five. Two studies (III and VI) were cohort studies, typically cited as Oxford Level of Evidence of three, however the quality included significant bias with limited results reducing the level to four. While the outcomes of each study were favourable, the moderate and poorer quality rankings resulted in a GRADE recommendation of weak+ for all studies, meaning “Probably do it”, and a ‘Yellow’ Traffic Light action indicating an uncertain effect [58].

Each study included in this review was subject to at least five types of bias: attention, volunteer/referral, lack of masked or independent evaluation, timing of intervention, and site. In addition, four studies were at risk for recall/memory bias (Studies I, IV, VIII, and IX). Due to lack of information provided, the risk of co-intervention and seasonal bias could not be determined.
4.3.5 Main summary measures

Detailed technology characteristics are provided in Table 4. Of the nine studies, one study considered a smart phone app for practicing braille character recognition (Study IV), two studies considered a slate and stylus tool for practicing writing braille (Studies V and VI), three studies considered braille readers/braille note takers (Studies VII, VIII, and IX), and three studies considered technologies that used a combination of mechanical and electrical components to facilitate reading practice (Studies I, II, and III).

Although all studies indicated learning outcomes, there was no consensus on how these were assessed. Methods included qualitative reporting from parents or teachers, standardized measures, or custom measures. Of the nine studies, three indicated that all students experienced positive learning outcomes (Studies I, VII, VII), five indicated that some students experienced positive literacy outcomes (Studies IV, V, VI, VIII, IX), and two did not specify how many students experienced positive learning outcomes (Studies II and III). Some studies noted that participants may not have met positive literacy outcomes because they had already met the outcomes prior to the intervention, or they may not have been at the appropriate developmental level to benefit from the intervention.

Across the nine studies, 15 technology strengths and 12 technology weaknesses were reported (Table 4). The most prevalent strength amongst technologies was the ability to provide real-time auditory feedback to the user, noted in all studies. The strengths ‘easy to use’, ‘provided tactile braille feedback’, ‘motivational’, and ‘engaging’ were each reported in six studies. The strengths ‘enabled independent study/practice’ and ‘enabled students to edit/interact with their work’ were each reported in four studies. Other strengths and weaknesses were each noted in only one or two studies.
4.4 Discussion

Four different technologies were identified in this review including: a smartphone app for practicing braille character recognition (Study IV), a slate and stylus tool for practicing writing braille (Studies V and VI), braillers/braille note takers (Studies VII, VIII, and IX), and three studies that used a combination of mechanical and electrical components to facilitate reading practice (Studies I, II, and III). Under-represented areas of technologies were smartphone applications and concepts using a slate and stylus. The studies that considered a slate and stylus tool were different iterations of the same technology concept. Although there was no consensus in the area of application, it is clear that braillers/braille note takers are represented well in the research.

Of the 113 participants considered, the participants ranged from four to fifteen years old with an average age of nine. Although this is a significant range, no participants above ninth grade were considered. Likewise, there was limited research with students in pre-kindergarten or kindergarten (Studies II and IX). It is unclear if this is due to technology need or logistical barriers of doing research with certain age groups.

The methodological quality of all studies included in this review yielded low reliability and uncertain effect, as demonstrated by their Oxford Level of Evidence of four and Traffic Light action of “Yellow” [58][55]. Despite the importance of accurate literacy performance for implications on teaching, there was no consensus on procedures employed and literacy outcomes measured by the studies included in the review [50]. With educational games and technologies, it is difficult to evaluate and show learning [64][50][65]. Due to the low incidence of visual impairment, conducting research with sufficient sample sizes to produce statistical significance is challenging [32]. As seen through this review, research in visual impairment is commonly characterized by single
case studies, small sample sizes, or anecdotal evidence [32]. These challenges are compounded by underfunding in visual impairment research [66]. Wherever possible, there is a need for the quality of research employed within technology for braille literacy to be improved by expanding the duration of studies, improving outcome measurements, and employing more sophisticated research designs and analyses. A standard of evaluation should be developed to improve the measurability of literacy outcomes, and the reliability of efficacy analyses.

The identified strengths from the research studies suggest that technologies designed and selected for applications in braille literacy education for children and youth should provide real-time auditory and tactile feedback, and enable independent study/practice and editing of work. Additionally, technologies should be easy to use, motivational, and engaging. Since there is no evidence in the literature that technology has an adverse effect on the development of literacy through braille, it is expected these factors are at least neutral to literacy outcome development if not facilitators of positive literacy outcomes [50]. Only one technology, the Mountbatten Pro Brailler, met all of these criteria (Study IX).

4.5 Limitations

Systematic reviews are instrumental for synthesizing research findings to improve decision making and professional practice [67]. Although systematic reviews are commonly regarded as the highest level of evidence [55], they are at risk for database bias, source-selection bias, and publication bias [68]. It is possible that not all relevant articles were captured, despite a thorough search strategy. Additionally, only nine studies were included in this review, meaning that only nine technologies and a small number of
participants were considered. Two studies were different iterations of the same concept, further reducing the range of technologies considered. These results may not be representative of the entirety of braille literacy technology users. Each study included in this review was subject to at least five types of bias, had an Oxford Level of Evidence of four, and yielded ‘Yellow’ Traffic Light actions. Although low levels of evidence are common for this subject, an Oxford Level of Evidence of three or lower presents a risk of low reliability and ‘Yellow’ Traffic Light actions indicate an uncertain effect.

Furthermore, the results of this review were limited by the inclusion criteria. The results were limited to children and youth who use braille as their primary literacy medium, have not previously learned to read using sighted methods, and do not have additional disabilities that may have significantly impeded their ability to learn or use braille. In addition, this review captured only peer-reviewed articles in attempt to preserve methodological quality.

4.6 Conclusions
The methodological quality of all studies included in this review yielded low reliability and uncertain effect, as demonstrated by their Oxford Level of Evidence of four and Traffic Light action of “Yellow” [58]. There was no consensus on the methods employed, the literacy outcomes, or strengths and weaknesses of the technologies reported. It is clear that there is no accepted standard for technology evaluation in braille literacy education. There are several implications of this review for the practice of special education. There is a need for a standard of technology evaluation to be developed. Technologies for braille literacy education for children and youth should provide real-
time auditory and tactile feedback, enable independent study/practice and editing of work, and be easy to use, motivational, and engaging.
Table 1: MEDLINE database search terms

<table>
<thead>
<tr>
<th>Braille Search Term</th>
<th>Child and Youth Search Terms</th>
<th>Education or Technology Search Terms</th>
</tr>
</thead>
</table>
| ‘braille’           | (‘child*’ OR ‘youth*’ OR ‘boy*’ OR ‘girl*’ OR ‘juvenile*’ OR ‘kid*’ OR ‘teen*’ OR ‘young adult*’ OR ‘school age*’ OR ‘young person*’ OR ‘young people*’ OR ‘adolescent*’ OR ‘pediatric*’ OR ‘paediatric*’ OR ‘student*’ OR ‘pupil*’ OR ‘preschool*’ OR ‘kindergarten*’ OR ‘kindergarden*’ OR ‘toddler*’) | (‘educat*’ OR ‘teach*’ OR ‘instruct*’ OR ‘teaching strateg*’ OR ‘coach*’ OR ‘teaching method*’ OR ‘pedagog*’ OR ‘train*’ OR ‘develop*’ OR ‘learn*’ OR ‘attain*’ OR ‘comprehend*’ OR ‘understand*’ OR ‘achiev*’ OR ‘cultivat*’ OR ‘method*’ OR ‘strateg*’ OR ‘curricul*’ OR ‘milestone*’ OR ‘school*’ OR ‘memor*’ OR ‘motivat*’)
| OR                  | (‘child development/’ OR ‘infant/’ OR ‘educational measurement/’ OR ‘teaching/’ OR ‘student dropouts/’ OR ‘curriculum/’)) | OR (‘physical education and training/’ OR ‘memory/’ OR ‘educational measurement/’ OR ‘child development/’ OR ‘cognition/’ OR ‘mental recall/’ ‘equipment and supplies/’ OR ‘equipment design/’ OR ‘equipment and supplies, hospital/’ OR ‘computer simulation/’ ‘program development/’ OR ‘software design/’ or ‘user-computer interface/’ OR ‘*mechanical/’)


<table>
<thead>
<tr>
<th>Study #</th>
<th>Citation</th>
<th>Study Description</th>
<th>Study Design</th>
<th># of Participants</th>
<th>Total Intervention Time</th>
<th>Participant Age (Years)</th>
<th>Education Level</th>
<th>Braille Proficiency Before Technology Intervention</th>
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<tr>
<td>I</td>
<td>[38]</td>
<td>Creation and evaluation of self-instructional material and technology to teach braille to children.</td>
<td>Single case</td>
<td>n = 3</td>
<td>Unspecified</td>
<td>6 – 9</td>
<td>Unspecified</td>
<td>Grade 1 braille with some Grade 2 braille</td>
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<tr>
<td>II</td>
<td>[35]</td>
<td>Evaluation of the impact of an artificial intelligence tutor on the learning of braille contractions in children.</td>
<td>Single case</td>
<td>n = 10</td>
<td>75 minutes – 3.5 hours</td>
<td>4 – 14</td>
<td>Kindergarten – Grade 9</td>
<td>Grade 1 braille with some Grade 2 braille</td>
</tr>
<tr>
<td>III</td>
<td>[69]</td>
<td>Comparison of the efficiency of an electronic teaching system to a braille book program.</td>
<td>Cohort</td>
<td>n = 40 experimental, n = 28 control</td>
<td>4.5 – 6 hours</td>
<td>12 – 15</td>
<td>Grades 7 – 8</td>
<td>Grade 1 braille</td>
</tr>
<tr>
<td>IV</td>
<td>[65]</td>
<td>Evaluation of the design and effectiveness of a suite of educational smartphone games for blind children.</td>
<td>Case study</td>
<td>n = 8</td>
<td>37 minutes – 5 hours and 12 minutes</td>
<td>5 – 8</td>
<td>Unspecified</td>
<td>Ranged from knowledge of some letters to Grade 1 braille</td>
</tr>
<tr>
<td>V</td>
<td>[44]</td>
<td>Evaluation of the E-Slate with typical end-user students and teachers in India.</td>
<td>Case study</td>
<td>n = 12</td>
<td>24 hours</td>
<td>Unspecified</td>
<td>Grades 2 – 3</td>
<td>Ranged from no proficiency to Grade 1 braille</td>
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<td>[70]</td>
<td>To ascertain the effectiveness of the braille Writing Tutor in helping younger students to grasp the</td>
<td>Cohort</td>
<td>n = 9 experimental, n = 9 control</td>
<td>30 hours</td>
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<td></td>
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<td>Study investigating if using a Perkins Braille Writer versus a Braille Note Taker would affect students’ engagement during the writing process, the quality of their writing samples, and their attitudes toward writing.</td>
<td>Case study</td>
<td>n = 2</td>
<td>1.5 hours – 2 hours and 15 minutes per device</td>
<td>13 – 14</td>
<td>8</td>
<td>Grade 1 braille</td>
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<tr>
<td>VII</td>
<td>[71]</td>
<td></td>
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<td></td>
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<td>VIII</td>
<td>[72]</td>
<td>Study evaluating whether there was a difference in students’ outcomes for braille fluency with instruction in traditional braille media or refreshable braille.</td>
<td>Single case</td>
<td>n = 9</td>
<td>67.5 hours</td>
<td>6 – 8</td>
<td></td>
<td>Unspecified Some Grade 1 braille</td>
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<tr>
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<td>[73]</td>
<td>Study outlining the Early Braille Readers Project and the outcomes.</td>
<td>Case study</td>
<td>n = 20</td>
<td>One or two years of regular use.</td>
<td>4 – 7</td>
<td></td>
<td>Pre-K to Grade 2</td>
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Table 3: Methodological quality

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<th>Study #</th>
<th>Citation</th>
<th>Oxford Level of Evidence</th>
<th>Quality</th>
<th>Recommendation</th>
<th>Traffic Light Action</th>
<th>Bias</th>
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<td>[38]</td>
<td>4</td>
<td>Moderate</td>
<td>Weak +</td>
<td>Yellow</td>
<td>Attention, volunteer/referral, lack of masked or independent evaluation, timing of intervention, site, recall/memory</td>
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<td>III</td>
<td>[69]</td>
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<td>Moderate</td>
<td>Weak +</td>
<td>Yellow</td>
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<td>[65]</td>
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<td>Low</td>
<td>Weak +</td>
<td>Yellow</td>
<td>Attention, volunteer/referral, lack of masked or independent evaluation, timing of intervention, site, recall/memory</td>
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<tr>
<td>V</td>
<td>[44]</td>
<td>4</td>
<td>Moderate</td>
<td>Weak +</td>
<td>Yellow</td>
<td>Attention, volunteer/referral, lack of masked or independent evaluation, timing of intervention, site</td>
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<td>[70]</td>
<td>4</td>
<td>Very Low</td>
<td>Weak +</td>
<td>Yellow</td>
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<td>[71]</td>
<td>4</td>
<td>Moderate</td>
<td>Weak +</td>
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<td>Attention, volunteer/referral, lack of masked or independent evaluation, timing of intervention, site</td>
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<td>VIII</td>
<td>[72]</td>
<td>4</td>
<td>Moderate</td>
<td>Weak +</td>
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<td>4</td>
<td>Moderate</td>
<td>Weak +</td>
<td>Yellow</td>
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Table 4: Main summary measures

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<th>Citation</th>
<th>Description of Technology</th>
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<th>Weaknesses</th>
</tr>
</thead>
</table>
| I       | [38]     | The wand, a small, hand-held, fiber optic scanner, "reads" and decodes ‘Talking Tracks’ as it passes over bar codes. Code is interpreted and sent to a speech synthesizer. Student can complete self-instructional tasks. | Improved cumulative number of braille endings correctly identified. | 3/3 | • Easy to use  
• Portable  
• Real-time auditory feedback | • Unspecified |
| II      | [35]     | Braille Tutor is an Internet based tool that requires a computer, a screen reader, a refreshable display, and a braille or QWERTY keyboard that permits six-key entry. The user logs into the website and can complete units of braille contractions. | Students reached 100% accuracy quicker, and saw a quicker initial jump in accuracy of braille contractions. Students who used the Tutor more learned more contractions. | Unspecified | • Enabled independent practice/study  
• Motivational  
• Real-time auditory feedback | • Insufficiently engaging  
• Language usage was too advanced |
| III     | [69]     | Braillephon display consists of a mechanical printer and paper belts. Instructions are provided through braille display or auditory feedback. Answers are entered through a braille keyboard or commands for | Learning gain. | Unspecified | • Enabled independent practice/study  
• Real-time auditory feedback | • Took longer to use than non-technical methods |
| IV  | [65] | BraillePlay is a suite of educational smartphone games for children. The user taps and swipes on the screen to submit braille characters to the game, and the game provides auditory feedback. | Improved knowledge of braille. | 3/8 | • Easy to use  
• Enabled independent practice/study  
• Motivational (although only for short periods of time)  
• Real-time auditory feedback  
• Real-time haptic feedback (not braille)  
• Insufficiently engaging |
|-----|-----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|-----|---------------------------------------------------------------------------------|
| V   | [44] | An electronic slate and stylus that interacts with a software program. The program has three levels geared towards different abilities.                                                                                               | Faster braille writing with fewer mistakes.                                                       | 5/12 | • Aided teachers to diagnose knowledge gaps  
• Easy to use  
• Enabled independent practice/study  
• Engaging  
• Real-time auditory feedback  
• Could not be assembled and installed by blind teachers |
| VI  | [70] | An intelligent tutor system that provides guided practice using audio feedback. It consists of an electronic slate (E-slate) and  
|     |     | Improved understanding of braille concept.                                                                                    | 6/9 experimental  
4/9 control                                                                                   | 6/9 | • Aided teachers to diagnose knowledge gaps  
• Motivational  
• Buttons were too hard and uncomfortable                                                 |
<p>| VII | [71] | Comparison of the BrailleNote M-Power (BNT), a word processor with a braille display that provides auditory feedback, to a conventional, mechanical Perkins Brailler (PBW). | Students engaged in sustained writing for longer periods of time. Improved quality of writing when using the BNT as compared with the PBW. | 2/2 | BrailleNote M-Power • Real-time auditory feedback • Easy to use • Enabled students to edit/interact with their work • Engaging • Motivational • Real-time auditory feedback • Real-time tactile feedback (braille output) | BrailleNote M-Power • Insufficient tactile feedback (only one line of braille) |
| VIII | [72] | Comparison of the PAC Mate, an electronic notetaker to the Perkins Brailler (PBW). PAC mate was shown to foster oral reading and word-writing fluency however, there was no clear differences in outcomes between the two devices. | 8/8 (oral reading) 9/9 (writing) | PAC Mate • Easy to use • Enabled students to edit/interact with their work • Engaging • Motivational • No need to load paper • Real-time auditory feedback • Real-time tactile feedback (braille display was easy to read) | PAC Mate • Keys were too easy to press, resulting in frequent mistakes • Insufficient tactile feedback (only one line of braille output. Requires a braille embosser to make a full copy of braille work) | Perkins Brailler • Required user to load paper and sometimes the paper jammed |</p>
<table>
<thead>
<tr>
<th>IX</th>
<th>[73]</th>
<th>The Mountbatten Pro Brailler enables reading tasks such as learning motor aspects of tracking, locating information on a page, and formatting writing.</th>
<th>Improved Texas Primary Reading Inventory score.</th>
<th>7/10 (10 participants completed a standardized test)</th>
<th>Mountbatten</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Perkins Brailler</td>
<td>Mountbatten</td>
<td>Mountbatten</td>
<td>Mountbatten</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Could teach spatial skills</td>
<td>- No finger strength required</td>
<td>- Poor battery life</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Easy to use</td>
<td>- Easy to use</td>
<td>- Technical errors</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Real-time tactile feedback (full page of braille)</td>
<td>- Enabled independent practice/study</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Enabled students to edit/interact with their work</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Enabled the development of listening skills</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Engaging</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Motivational</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Programmable by teacher</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Real-time auditory feedback</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Real-time tactile feedback (full page of braille)</td>
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</tbody>
</table>
Chapter 5

Cross-Section of Existing Technologies for Braille Literacy Education

5.1 Overview

While the systematic review (Chapter Four) identified many of the studies that have assessed technology when teaching and learning braille, there are many technologies that have not been assessed as learning tools, but are used when teaching and learning braille. To thoroughly summarize the state of existing technology for braille literacy education and identify additional design criteria, a cross-section of existing technologies not captured by the systematic review are summarized.

5.2 Methods

Examples of existing technology were sought through books intended for teachers of people who are blind or visually impaired, service provider websites such as the CNIB Foundation [74] or American Printing House for the Blind [75], a generic Google search for “braille education device”, and academic literature that was not eligible for inclusion in the systematic review (Chapter Four). Characteristics of the technology including purpose, functional characteristics, and cost were noted.

5.3 Results

Due to the number of technologies on the market and in literature, it would not be prudent to summarize all in detail. Therefore, a cross-section of six technologies were selected and are expanded upon in Table 5.
<table>
<thead>
<tr>
<th>Name</th>
<th>Picture</th>
<th>Purpose</th>
<th>Functional Characteristics</th>
<th>Cost (CAD)</th>
<th>Citation</th>
</tr>
</thead>
</table>
| Annie        | ![Annie](image1.png) | Teach braille to children with varying degrees of braille knowledge | • Audio and tactile feedback  
• Teaches reading and writing  
• Jumbo and standard braille  
• Enables self-study (independent use)  
• Allows teacher to program lessons | $1000 +170/year | [9]       |
| BecDot       | ![BecDot](image2.png) | Expose young children to braille | • Teaches spelling, letters, and numbers  
• Jumbo braille  
• Programmable by teacher  
• Enables self-study (independent use) | Unlisted        | [76]      |
| brailleBuzz  | ![brailleBuzz](image3.png) | Encourage practice with braille characters and phonics | • Audio and tactile feedback  
• Enables self-study (independent use)  
• Three modes of play: phonics, keyboard, and letters. | $130            | [77]      |
| Read Read    | ![Read Read](image4.png) | Teach braille to young, beginning braille learners | • Audio and tactile feedback  
• Announces letter, position of dots, sound the letter makes to help students learn to decode words  
• Enables self-study (independent use) | $700-865        | [10]      |
| Slate Master | ![Slate Master](image5.png) | Teach beginning braille learners (child or adult) to use a slate and stylus | • Audio feedback  
• Plastic slate that enables user to interact with smart phone learning app  
• Structured programming based on users learning patterns  
• Enables self-study (independent use) | Unlisted + cost of smartphone | [78]      |
| Taptilo      | ![Taptilo](image6.png) | Teach braille to young, beginning braille learners | • Audio and tactile feedback  
• Durable  
• Jumbo braille  
• Self-study (independent use) and structured instruction  
• Connects to an app for teacher to program lessons and track learning | $1,600         | [11]      |
5.4 Discussion

Of the six technologies, four listed costs. These ranged from $130-$1,600 CAD, not including any annual membership fees. This is well outside of a feasible cost for developing countries considering that the average family income in the Philippines is 264,000 PHP, or about 6,600 CAD per year [20]. This not only indicates that there is a need for cost effective technologies for braille literacy education, but that cost may be a challenging design criterion to meet.

The majority of technologies focus on brailler or exploratory toy concepts, and not a slate and stylus. Although this may be due to the under-use of the slate and stylus in developed countries, it does little to support learners in areas where braille users are not financially accessible. Furthermore, Slate Master, the example of technology geared towards writing with a slate and stylus does not enable the user to read what they have written in braille and relies on the user having access to a smartphone.

Common technology characteristics were auditory feedback (6/6), tactile feedback (5/6), jumbo braille feedback (4/6), enabling self-study (6/6), and enabling a teacher to program instruction through an app (3/6). Although these characteristics are not evidence-based since there are no studies testing these technologies, they may represent the needs of a user from a sample of the market determined by the technology developers. Therefore, they were considered as design criteria in the development of BrailleBunny.
Chapter 6

Design Ideation

6.1 Overview
To address the need for a device for braille literacy education in the Philippines, a prototype was developed. This section summarizes the development of design criteria, design ideation, and creation of the prototype concept.

6.2 Methods
The concept realization was achieved after the design criteria including the target user group were selected, and device concepts were ideated on through a combination of parallel, iterative, and co-design processes.

6.2.1 Identifying the target user group
The target user group was selected based on the “Grand Challenge for Development” [8], an Early Grade Reading Skills Spectrum released by All Children Reading and Digital Learning for development [79], a user needs survey completed in the BraillePad pilot study (Chapter Two) [15][18][19], and semi structured interviews with a community partner in the Philippines. The community partner was a special education teacher working with children who are blind or visually impaired advised on the demographic of students who are blind or visually impaired in the Philippines.

6.2.2 Design criteria
A comprehensive set of ideal design criteria for a device for braille literacy education in the Philippines was developed, by combining criteria from educational strategies, collected data, and review criteria. Educational strategies included evidence-based practices (Chapter 3) and the Early Grade Reading Skills Spectrum [79]. Collected
The data included the user needs survey and device assessment completed in the BraillePad pilot study (Chapter Two) [15][18][19], and a semi-structured interview with the community partner. Review criteria included the systematic review examining the effectiveness of technologies for braille literacy education (Chapter Four), and the cross-section of existing technologies for braille literacy education (Chapter Five), and two studies developing and evaluating devices for braille literacy education [44][65].

6.2.3 **Parallel, iterative, and co-design processes**

A combination of parallel [13], iterative [13], and co-design [14] processes were used. Parallel design was achieved with members of the study investigator’s lab group, iterative design was achieved by the study investigator, and co-design was achieved between the study investigator and community partner. A flow chart of the process annotating the type of design process followed in each step is provided in Figure 6.

![Flow chart of design process, annotating the type of design process followed in each step](image_url)

**Figure 6:** Flow chart of design process, annotating the type of design process followed in each step
6.3 Results

The selected design criteria, details of the ideation phases, and final prototype device are summarized below.

6.3.1 Target user group

The Grand Challenge tasked researchers with addressing the need for assistive technologies to help children with sensory disabilities who live in the Philippines learn to read. The pilot study of BraillePad [15][18][19] reinforced the need for a device for braille literacy education in the Philippines. To address this need, the target group was selected as children who are blind or visually impaired and learning to read using braille in the Philippines. Considering the importance of mother-tongue instruction [79], it is important to note that early braille intervention in the Philippines is completed in Tagalog.

The target group was better defined after a conversation with the community partner. The target user group should include beginning braille learners, as young as five years old. The device should be suitable for children with or without a variety of disabilities including but not limited to autism, learning disabilities, behavioral problems, motor impairments, and any type of vision impairment ranging from completely blind to low vision. The device should be able to be used every day to aid in learning when teachers cannot give 1:1 attention (class sizes can be up to 12 students for one teacher) and help with spelling and writing with a slate and stylus since these are topics that students commonly struggle with. Finally, the device should be affordable to families in the Philippines where the average family income is 264 000 PHP, or about 6 600 CAD per year [20].
6.3.2 Design criteria

The design criteria are summarized in Table 6 and are derived from the source references.
<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Sub-Criteria</th>
<th>Source</th>
</tr>
</thead>
</table>
| **Accessible**  | Low cost     | • Similar study [44]  
|                 |              | • User needs survey [15][18][19] |
|                 | Low power    | • Similar study [44]  |
|                 | Available in the Philippines and other low resource areas | • User needs survey [15][18][19]  
|                 |              | • Community partner |
|                 | Usable by children who are learning to read using braille | • Grand challenge |
|                 | Usable by children who are blind or visually impaired | • User needs survey [15][18][19]  
|                 |              | • Community partner |
|                 | Usable by children who are as young as 5 years old | • Community partner |
|                 | Usable by children who have poor motor skills | • User needs survey [15][18][19]  
|                 |              | • Community partner  
|                 |              | • Similar study [65] |
|                 | Usable by children who have poor tactile discrimination skills | • Community partner  
|                 |              | • Existing technologies (Chapter Five)  
|                 |              | • Evidence-based practices (Chapter Three) |
|                 | Usable by children who have additional disabilities | • User needs survey [15][18][19]  
|                 |              | • Community partner |
|                 | Usable in a variety of languages including English or Tagalog | • Early Grade Reading Skills Spectrum [79]  
|                 |              | • Community partner |
| **Durable/Reliable** | Robust / not fragile | • User needs survey [15][18][19] |
|                   | No technical errors / malfunctions | • User needs survey [15][18][19]  
|                   | Usable in multiple ways | • User needs survey [15][18][19] |
|                   | Locally maintainable | • Similar study [44]  
| **Easily and Independently Operable** | Not applicable | • Systematic review  
|                                |              | • Similar study [44]  
<p>|                                |              | • User needs survey [15][18][19] |</p>
<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engaging</strong></td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>• Cross-section of existing technologies (Chapter Five)</td>
</tr>
<tr>
<td><strong>Motivational</strong></td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>• Systematic review (Chapter Four)</td>
</tr>
<tr>
<td></td>
<td>• Similar study [65]</td>
</tr>
<tr>
<td><strong>Enable Co-play and Cooperative Learning Among Students</strong></td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>• Systematic review (Chapter Four)</td>
</tr>
<tr>
<td></td>
<td>• Similar study [65]</td>
</tr>
<tr>
<td><strong>Portable</strong></td>
<td>Not bulky</td>
</tr>
<tr>
<td></td>
<td>• User needs survey [15][18][19]</td>
</tr>
<tr>
<td></td>
<td>Lightweight</td>
</tr>
<tr>
<td></td>
<td>• User needs survey [15][18][19]</td>
</tr>
<tr>
<td></td>
<td>Good battery life</td>
</tr>
<tr>
<td></td>
<td>• User needs survey [15][18][19]</td>
</tr>
<tr>
<td><strong>Provide Real Time Auditory and Tactile Feedback</strong></td>
<td>In general</td>
</tr>
<tr>
<td></td>
<td>• Systematic review</td>
</tr>
<tr>
<td></td>
<td>• User needs survey [15][18][19]</td>
</tr>
<tr>
<td></td>
<td>Immediate</td>
</tr>
<tr>
<td></td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td></td>
<td>Specific</td>
</tr>
<tr>
<td></td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td></td>
<td>Encouraging</td>
</tr>
<tr>
<td></td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td></td>
<td>Guides the student to discover the correct answer independently</td>
</tr>
<tr>
<td></td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td></td>
<td>In mother-tongue language</td>
</tr>
<tr>
<td></td>
<td>• Early Grade Reading Skills Spectrum [79]</td>
</tr>
<tr>
<td><strong>Safe</strong></td>
<td>No choking hazards</td>
</tr>
<tr>
<td></td>
<td>• Industry standard</td>
</tr>
<tr>
<td></td>
<td>No shock/electrocution risk</td>
</tr>
<tr>
<td></td>
<td>• Industry standard</td>
</tr>
<tr>
<td></td>
<td>No pinch points</td>
</tr>
<tr>
<td></td>
<td>• Industry standard</td>
</tr>
<tr>
<td><strong>Transferable Learning to Reading and Writing</strong></td>
<td>In general</td>
</tr>
<tr>
<td></td>
<td>• Similar study [44]</td>
</tr>
<tr>
<td></td>
<td>• Similar study [44]</td>
</tr>
<tr>
<td></td>
<td>• User needs survey [15][18][19]</td>
</tr>
<tr>
<td></td>
<td>Build and combine both reading and writing skills</td>
</tr>
<tr>
<td></td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td>Challenge/Goal</td>
<td>Practice Details</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Reduce challenges of learning to write with a slate and stylus</td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td>• Writing from right to left</td>
<td>• Community partner</td>
</tr>
<tr>
<td>• Learning mirror images of braille code</td>
<td></td>
</tr>
<tr>
<td>• Learning with delayed feedback</td>
<td></td>
</tr>
<tr>
<td>Develop basic literacy skills</td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td>• Phonological awareness</td>
<td>• Early Grade Reading Skills Spectrum [79]</td>
</tr>
<tr>
<td>• Knowledge of letter names</td>
<td></td>
</tr>
<tr>
<td>• Language skills</td>
<td></td>
</tr>
<tr>
<td>Develop of tactile discrimination skills</td>
<td>• Community partner</td>
</tr>
<tr>
<td></td>
<td>• Existing technologies (Chapter Five)</td>
</tr>
<tr>
<td></td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td>Early exposure to braille</td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td>Instruction in/employ:</td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td>• Active learning</td>
<td></td>
</tr>
<tr>
<td>• Ample daily practice</td>
<td></td>
</tr>
<tr>
<td>• Both contracted and uncontracted braille</td>
<td></td>
</tr>
<tr>
<td>• Drill and practice</td>
<td></td>
</tr>
<tr>
<td>• Exposure to a wide variety of reading genres</td>
<td></td>
</tr>
<tr>
<td>• Functional, meaning-centered, and whole-language methods,</td>
<td></td>
</tr>
<tr>
<td>particularly by introducing context through stories</td>
<td></td>
</tr>
<tr>
<td>• Gradual withdrawal of instructional prompts</td>
<td></td>
</tr>
<tr>
<td>• Repeated readings</td>
<td></td>
</tr>
<tr>
<td>• Small steps in instruction</td>
<td></td>
</tr>
<tr>
<td>• Student testing</td>
<td></td>
</tr>
<tr>
<td>Instruction in/employ</td>
<td>• Evidence-based practices (Chapter Three)</td>
</tr>
<tr>
<td>• Phonics and decoding</td>
<td>• Early Grade Reading Skills Spectrum [79]</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.3.3 Parallel, iterative, and co-design processes

The designs created by each participant of the parallel design process are shown in Table 7. Each individual designer who participated in the process produced an independent design. The best aspects of each design were selected and merged together to create iteration one, shown in Figure 7. The key concept of iteration one is that it functions similar to a slate and stylus. The student can push braille dots through the board to make them protrude on the other side, leaving an empty space in place of the dot on the side the dot was pushed from (position two, as shown in Figure 7). Then, the student can flip the board and read the mirror image as they would when writing with a slate and stylus. This design also enables the student to push a dot down with a peg, leaving a raised peg in place of the hole so that the braille dot protrudes without needing to flip the device (position three, as shown in Figure 7). This device is intended to interact with the user to help them practice spelling, writing, and other basic lessons.

The next stage of the design process was to engage in the co-design process by receiving feedback and suggestions about this merged design from the community partner. The partner indicated the following. The number of braille cells (four) was plenty as most basic words in Filipino and English curriculum for beginning learners are usually three or four letters. Positioning the buttons (help, mode, ready) on the side of the device would aid students in orienting themselves to which position the device is oriented in. Portability is very important, and a good example of appropriate sizing and weight is a handheld device such as an iPad or Leapfrog product [80]. The use of speakers instead of headphones would help students who have sensory sensitivities and don’t like headphones while/and speakers enable a helper to work with the student. There is no
practical use for a refreshable braille display interface as braille displays are extremely expensive and hard to come by in developing countries.

Feedback from the community partner, and further iterative design led to iteration two (Figure 8). The buttons were placed on the side of the device and the braille display interface was excluded. Iteration two does not use pegs, thus minimizing the number of parts, increasing portability, and making interaction more intuitive. The braille dot concept was adapted so that a ‘braille dot’ can be pushed through the device to protrude on one side, and be flush on the other. The device has two sides, a ‘read’ (unmirrored), and ‘write’ (mirrored) side. When the ‘read’ side is facing upwards, a protruding dot indicates that the braille dot is selected, and a flush dot indicates the dot is unselected. When the write side is facing upwards, the opposite is true. Finally, the shape of the frame that supports the device was altered to enable braille dots to protrude through the other side. The new frame acts as a stand, allowing the device to sit on top. This enables the user to choose if they would like to use the frame or hold the device in their hands, and interact with the surfaces of the device more easily.

Iterations one and two informed the creation of iteration three, the final design concept before physical prototyping, shown in Figure 9. This iteration functions much the same as the other iterations, with slight adjustments. The number of buttons was reduced from three to two by introducing a rocker switch as one of the buttons. This enables the user to scroll through and select a level from a menu, and ask for a hint by holding down the other button (a push button). The speaker location was adjusted to be in the corner of the device on the top surface to increase sound quality. Additionally, an option for a headphone jack was included to improve the flexibility of use.
<table>
<thead>
<tr>
<th>Parallel Design #</th>
<th>Concept Sketch</th>
<th>Description and Key Characteristics</th>
<th>Best characteristics as identified by the study investigator to be used in merged design</th>
</tr>
</thead>
</table>
| P1               | ![Peg Board Sketch](image) | **Reversible Peg Board**  
- Peg board with pegs small enough that you can feel a letter with one or two fingers at a time  
- Reversible to allow larger and smaller pegs  
- Interacts with user to teach them a lesson  
- Magnetize pegs to snap in place to prevent falling out or rolling away  
- Only read mode  
- High colour contrast between braille dots and board |  
- Interacts with user to teach them a lesson  
- High colour contrast between braille dots and board |
| P2               | ![Button Board Sketch](image) | **Push Button Board A**  
- Read and write modes  
- ‘Push buttons’ that push through board for tactile feedback  
- Distinct shape and raised outline around braille cells to help with orientation  
- switches/buttons: power, mode, ready  
- Device interacts with user to teach them a lesson |  
- Read and write modes  
- ‘Push buttons’ that push through board for tactile feedback  
- Distinct shape and raised outline around braille cells to help student orientation  
- Switches/buttons: power, mode, ready  
- Interacts with user to teach them a lesson |
| P3               | ![Button Board Sketch](image) | **Push Button Board B**  
- ‘Push buttons’ don’t push through the device as in Push Button Board A  
- Battery compartment inside  
- Raised outline around braille cells to help student orientation |  
- Battery compartment inside  
- Raised outline around braille cells to help student orientation |
<table>
<thead>
<tr>
<th>P4</th>
<th>Mirrored Image Peg Board</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peg board in which pegs are input in top row from left to right, and mirrored image is practiced below from right to left</td>
</tr>
<tr>
<td></td>
<td>Textured top of board to help student orientation</td>
</tr>
<tr>
<td></td>
<td>Start button and LCD screen in between two cell rows, each of four cells</td>
</tr>
<tr>
<td></td>
<td>Weighted pegs with textured top</td>
</tr>
<tr>
<td></td>
<td>Pegs snap in place with magnet</td>
</tr>
<tr>
<td></td>
<td>Interacts with user to teach them a lesson</td>
</tr>
<tr>
<td></td>
<td>Can be programmed to update lessons</td>
</tr>
<tr>
<td></td>
<td>Can track progress</td>
</tr>
<tr>
<td></td>
<td>Battery inside</td>
</tr>
<tr>
<td></td>
<td>Waterproof</td>
</tr>
<tr>
<td></td>
<td>Can track progress</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P5</th>
<th>Standard Peg Board</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Able to be sanitized</td>
</tr>
<tr>
<td></td>
<td>Read and write modes</td>
</tr>
<tr>
<td></td>
<td>Interacts with user to teach them a lesson</td>
</tr>
<tr>
<td></td>
<td>Encourages user with cheering sounds</td>
</tr>
<tr>
<td></td>
<td>Weighted pegs</td>
</tr>
<tr>
<td></td>
<td>Built in storage for pegs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P6</th>
<th>Button and track board</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>User tracks a ‘stylus’ underneath the board to push braille dots up</td>
</tr>
<tr>
<td></td>
<td>Reset button for all pegs to fall down</td>
</tr>
<tr>
<td></td>
<td>Only read mode</td>
</tr>
</tbody>
</table>

<table>
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</tr>
</thead>
<tbody>
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</tr>
<tr>
<td></td>
<td>Textured top of board to help student orientation</td>
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<td></td>
<td>Start button and LCD screen in between two cell rows, each of four cells</td>
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<td></td>
<td>Weighted pegs with textured top</td>
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<td></td>
<td>Pegs snap in place with magnet</td>
</tr>
<tr>
<td></td>
<td>Interacts with user to teach them a lesson</td>
</tr>
<tr>
<td></td>
<td>Can be programmed to update lessons</td>
</tr>
<tr>
<td></td>
<td>Can track progress</td>
</tr>
<tr>
<td></td>
<td>Battery inside</td>
</tr>
<tr>
<td></td>
<td>Waterproof</td>
</tr>
<tr>
<td></td>
<td>Can track progress</td>
</tr>
</tbody>
</table>

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<th>Standard Peg Board</th>
</tr>
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</tr>
<tr>
<td></td>
<td>Read and write modes</td>
</tr>
<tr>
<td></td>
<td>Interacts with user to teach them a lesson</td>
</tr>
<tr>
<td></td>
<td>Encourages user with cheering sounds</td>
</tr>
</tbody>
</table>

<table>
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<tr>
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<td>User tracks a ‘stylus’ underneath the board to push braille dots up</td>
</tr>
<tr>
<td></td>
<td>Reset button for all pegs to fall down</td>
</tr>
<tr>
<td></td>
<td>Only read mode</td>
</tr>
<tr>
<td>P7</td>
<td>Flip Slate Board or Peg Board</td>
</tr>
<tr>
<td>----</td>
<td>--------------------------------</td>
</tr>
</tbody>
</table>
| ![Image](image1.png) | - Push buttons through board and flip to read, or insert pegs to read without flipping  
- Use a stylus or fingers to push buttons through  
- Read and write modes  
- Interacts with user to teach them a lesson  
- Option for attaching a standard sized braille display  
- Battery compartment inside device  
- Help button for students to get help from the program | ![Image](image2.png) | - Interacts with user to teach them a lesson  
- Push buttons down on one row, and mirrored image pops up on other row  
- Only write mode  
- Battery compartment inside device  
- Help button for students to get help from the program |

- Read and write modes  
- Interacts with user to teach them a lesson  
- Buttons that can push through, and then you can flip the board like you are using a slate  
- Battery compartment inside device  
- Help button for students to get help from the program  
- Option for attaching a standard sized braille display  
- Help button for students to get help from the program
Figure 7: Sketch of iteration one

Figure 8: Sketch of iteration two
6.4 Discussion

Design criteria were established under advisement of the community partner, as part of the co-design process. These criteria included: accessible, durable/reliable, independently operable, enable co-play/cooperative learning, engaging, motivational, safe, provide auditory/tactile feedback, and provide transferable learning. Eight parallel designs were independently created, the best features of which were merged to create the first iteration. The co-design process was continued with feedback about this iteration being sought from the community partner. The investigator independently created two further iterations considering the feedback. To enable the concept to be assessed, a prototype was created, as outlined in Chapter 7.
Chapter 7

Prototype Creation

7.1 Overview
To evaluate the design ideation demonstrated in Chapter 6, a prototype was constructed. The prototype of BrailleBunny is shown in Figure 10. The main body of BrailleBunny is shaped like a rectangular prism 18 cm wide, by 10.5 cm tall, and 3 cm deep. At the top of BrailleBunny, speakers are housed in rounded structures that resemble a bunny’s ears. Along the bottom of BrailleBunny, there are four cells of large scale braille where each dot of braille is represented by circular buttons, each one centimeter in diameter. At the base of one of the ears, there is a small slide switch that turns the device on and off. On the opposite side along the body of the device, there is a toggle switch and push button that are used to control the menu and enter an answer. There is a stand that raises BrailleBunny about 2.5 centimeters from a surface it is set on. BrailleBunny sits in the stand, and the user can take BrailleBunny out of the stand, flip it over and return it to the stand if they wish. This section details the hardware selection, manufacturing methods, software design, and adaptations made to the design during the prototyping stages.
Figure 10: Front view of the mirrored (writing) side of BrailleBunny (left), front view of the unmirrored (reading side) of BrailleBunny (centre), and side view of BrailleBunny sitting in its stand with the unmirrored side facing upwards.

7.2 Hardware

BrailleBunny was constructed using a printed circuit board (PCB), a variety of switches, a microcontroller board, speakers, an accelerometer, and various 3D printed components to create the device casing, buttons, and stand. The prototype of BrailleBunny cost 429.08 CAD to manufacture. The bill of materials with expenses is provided in Table 8.
### Table 8: Bill of materials including source and cost

<table>
<thead>
<tr>
<th>Part #</th>
<th>Part</th>
<th>Distributor</th>
<th>Quantity</th>
<th>Per Quantity</th>
<th>Cost (CAD)</th>
<th>Per Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Purchased</td>
<td>Used</td>
<td>Purchased</td>
<td>Used</td>
</tr>
<tr>
<td>1</td>
<td>Printed Circuit Board</td>
<td>General Circuits Co.</td>
<td>5</td>
<td>1</td>
<td>71.75</td>
<td>14.35</td>
</tr>
<tr>
<td>2</td>
<td>Arduino Mega</td>
<td>Amazon</td>
<td>1</td>
<td>1</td>
<td>49.95</td>
<td>49.95</td>
</tr>
<tr>
<td>3</td>
<td>MP3 Shield</td>
<td>Digi-Key</td>
<td>1</td>
<td>1</td>
<td>38.21</td>
<td>38.21</td>
</tr>
<tr>
<td>4</td>
<td>64 GB Micro SD Card</td>
<td>Amazon</td>
<td>1</td>
<td>1</td>
<td>14.99</td>
<td>14.99</td>
</tr>
<tr>
<td>5</td>
<td>Accelerometer</td>
<td>Digi-Key</td>
<td>1</td>
<td>1</td>
<td>14.11</td>
<td>14.11</td>
</tr>
<tr>
<td>6</td>
<td>Slide Switch (Braille Dots)</td>
<td>Digi-Key</td>
<td>25</td>
<td>24</td>
<td>132.63</td>
<td>127.33</td>
</tr>
<tr>
<td>7</td>
<td>Slide Switch (Power)</td>
<td>Digi-Key</td>
<td>1</td>
<td>1</td>
<td>5.79</td>
<td>5.79</td>
</tr>
<tr>
<td>8</td>
<td>Push Button (Menu Control)</td>
<td>Digi-Key</td>
<td>1</td>
<td>1</td>
<td>6.69</td>
<td>6.69</td>
</tr>
<tr>
<td>9</td>
<td>Rocker Switch (Menu Control)</td>
<td>Digi-Key</td>
<td>1</td>
<td>1</td>
<td>4.33</td>
<td>4.33</td>
</tr>
<tr>
<td>10</td>
<td>Bussed Resistor Network (7 Pin)</td>
<td>Digi-Key</td>
<td>4</td>
<td>4</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>11</td>
<td>Bussed Resistor Network (5 Pin)</td>
<td>Digi-Key</td>
<td>1</td>
<td>1</td>
<td>0.63</td>
<td>0.63</td>
</tr>
<tr>
<td>12</td>
<td>Battery</td>
<td>Amazon</td>
<td>2</td>
<td>1</td>
<td>10.99</td>
<td>5.495</td>
</tr>
<tr>
<td>13</td>
<td>Battery Snap</td>
<td>Qkits</td>
<td>1</td>
<td>1</td>
<td>0.52</td>
<td>0.52</td>
</tr>
<tr>
<td>14</td>
<td>Speaker</td>
<td>Qkits</td>
<td>2</td>
<td>2</td>
<td>5.9</td>
<td>5.9</td>
</tr>
<tr>
<td>15</td>
<td>Nut</td>
<td>Rona</td>
<td>24</td>
<td>24</td>
<td>2.88</td>
<td>2.88</td>
</tr>
<tr>
<td>16</td>
<td>Bolt</td>
<td>Rona</td>
<td>24</td>
<td>24</td>
<td>4.56</td>
<td>4.56</td>
</tr>
<tr>
<td>17</td>
<td>Print Filament and Operation Charge (Fortus 380)</td>
<td>McLaughlin Hall Machine Shop</td>
<td>1</td>
<td>1</td>
<td>113.75</td>
<td>113.75</td>
</tr>
<tr>
<td>18</td>
<td>Print Filament (Ultimaker)</td>
<td>Shop3D</td>
<td>750 grams</td>
<td>87 grams</td>
<td>54.95</td>
<td>6.37</td>
</tr>
<tr>
<td>19</td>
<td>Solder</td>
<td>Home Depot</td>
<td>86 grams</td>
<td>10 grams</td>
<td>7.49</td>
<td>0.87</td>
</tr>
<tr>
<td>20</td>
<td>Wires</td>
<td>Qkits</td>
<td>25 feet</td>
<td>1 foot</td>
<td>14.2</td>
<td>0.568</td>
</tr>
<tr>
<td>21</td>
<td>Super Glue</td>
<td>Rona</td>
<td>1 tube</td>
<td>1 tube</td>
<td>7.99</td>
<td>7.99</td>
</tr>
</tbody>
</table>

**Total**: 429.08 CAD
7.2.1 **Printed circuit board interface**

The PCB acted as a key structural element when building the prototype. It supports the switches and acts as a shoulder for the braille dot buttons on one side. The PCB with key elements labelled is shown in Figure 11.

![PCB with key components labelled](image)

**Figure 11: PCB with key components labelled**

7.2.2 **Microcontroller board**

An Arduino MEGA was selected as the microcontroller for BrailleBunny. This board was selected specifically due to the large number of pins it provided, enabling the state at the braille dot button, push button, toggle switch, and accelerometer to be read and the speakers to be controlled.

7.2.3 **Sound output**

A SparkFun MP3 shield was used to interface between the Arduino and the speakers. This shield enabled MP3 files to be played from a micro SD card controlled by the Arduino code. Two 8 ohm, 0.5 Watt speakers were installed in each ‘ear’ structure, with one facing each of the ‘read’ and ‘write’ surfaces so that sound output could be controlled to be in the upwards direction, away from the surface the device is held on.
7.2.4 Accelerometer

An accelerometer was installed to allow for identification of orientation and to inform the task executed by the device accordingly.

7.2.5 Switches

The braille dot buttons are actuated using vertical on-off slide switches. This enabled the position of the dots to be easily read as written or erased while concurrently providing a mechanism for writing or erasing a dot. A push button and toggle switch were chosen to control the menu and an on-off switch was installed to preserve battery life. To make a selection from the menu or enter their answer, the user presses the push button for one second. To scroll through options in a menu level, the user presses the toggle switch in either direction.

7.2.6 Battery

BrailleBunny is powered by a 9 volt battery. This type of battery is available in the Philippines, however, the cost of replacing the battery may be prohibitive (approximately 5 CAD).

7.2.7 3D printed components

The housing, braille dots, and stand were constructed using 3D printers. Prototyping and the final stand construction was completed using an Ultimaker 2+ [81], and final housing and buttons were completed using a Fortus 380 [82].

7.2.7.1 Stand

A stand with a rim that runs along the outer edges of the device can be used to support the device. This allows the user to rest the device about 2.5 centimeters above the table, and feel underneath to raise a dot, or feel which dots are selected or protruding. The stand is shown in Figure 12.
Figure 12: Overhead (top) and front view (bottom) of the stand

7.2.7.2 Housing

A 3D printed housing enclosed the PCB, shown in Figure 13. Standoffs, locating pegs, support for speakers, and a shoulder for the buttons were incorporated within the housing. To aid the student’s orientation to the device, an arrow that points to the mirrored side was embossed on each side, and notches were placed between each cell.
Figure 13: Interior view of the mirrored side of the housing (left) and exterior view of the unmirrored side of the housing (right) with key components labelled.

7.2.7.3 Buttons

The braille dot buttons are actuated using vertical on-off slide switches. The button sandwiches the slide switch, so the slide switch is actuated when the button is pushed from either direction. This was achieved using an assembly of 3D printed components, a nut, and bolt. An assembly of the model, and the 3D printed buttons are shown in Figure 14 and Figure 15 respectively.

Figure 14: Cross section of button assembly model

Figure 15: 3D printed button components
7.2.7.4 Ear covers

The left surface of each ear has a removable, exchangeable cover attached with Velcro. Velcro was selected so the cover could be easily removed and replaced. On the unmirrored side, the ear cover has BrailleBunny embossed in print and braille, as well as the braille alphabet. To access the battery, this cover is removed. On the mirrored side, BrailleBunny is embossed in mirrored print and braille, as well as the mirrored braille alphabet. The cover on the unmirrored side is shown in Figure 16.

![Ear cover from unmirrored side](image)

**Figure 16: Ear cover from unmirrored side**

7.3 Overall assembly

To assemble BrailleBunny, the PCB is placed in the housing from the unmirrored side of the housing, and the unmirrored side of the buttons are placed through the holes. The shaft of the mirrored button is placed over the bolt, and the top of the button is secured into place using a nut. The other half of the housing is then put in place by snapping it onto the unmirrored housing side. This is demonstrated in Figure 17 and Figure 18.
Figure 17: Full assembly of button system. (i – portion of system assembled around the nut, ii – cap assembled to the bolt, iii – combined system)

Figure 18: Buttons being assembled around casing (i – button assembly around PCB, ii – button assembly around housing)

7.4 Software

BrailleBunny functions in both English and Tagalog, has four advanced settings that can be toggled on and off, and four levels from which to choose. Each element of the software is described in detail below. The software was programmed using Arduino integrated development environment. The software was designed by the investigator, a native English speaker. The software was translated by a professional Tagalog translator.

7.4.1 Overall menu flow

A flowchart of the menu interaction is shown in Figure 19. Upon start-up, BrailleBunny automatically prompts the user to choose a language. The user selects their language of choice and navigates through the settings and activity selection. To select, the user presses the push button for one second (shown by the bold arrow). To scroll through options in a menu level, the user presses the toggle switch in either direction (shown by the thin double arrow). To return to the previous menu level, the user holds the
push button for four seconds (shown by the dashed arrow). Menu flows that happen automatically without user direction are shown by the red line with a ball end.

![Diagram of menu structure flowchart]

Figure 19: Menu structure flowchart

### 7.4.2 Volume settings

Four volume setting options are programmed: off, quiet, medium, and loud. Loud is the loudest setting possible for the selected speakers, about 63 dB. The quiet setting was set to about 50 dB. The user scrolls through the options using the toggle switch. For each option, a “pop” sound plays at that volume. To select an option, the user presses the push button, which allows a return to the previous menu level. A flowchart of the volume menu is shown in Figure 20.
7.4.3 Advanced settings

There are four advanced settings options. The user may select none, all, or any combination of these settings. A description of each setting is given in Table 9. To toggle a setting on or off, the user presses the push button on that setting. A flowchart of the advanced settings menu is shown in Figure 21.

Table 9: Advanced setting options and descriptions

<table>
<thead>
<tr>
<th>Advanced Setting</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Announce dot written or erased</td>
<td>Each dot has a “written” or “erased” position. When a dot is raised on the unmirrored side and flush with the mirrored side, it is written. When the opposite is true, it is erased. To aid a student in learning the positions of dots in a cell, BrailleBunny continually checks if there is a change in a dot position, and will announce a change by saying “Cell X, Dot X, erased” or “Cell X, Dot X, Selected”. To avoid unnecessary verbosity,</td>
</tr>
<tr>
<td></td>
<td>BrailleBunny will only announce a change, and does not announce the dot position when the level begins.</td>
</tr>
<tr>
<td>---</td>
<td>----------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2</td>
<td>Announce letter written</td>
</tr>
<tr>
<td>3</td>
<td>Announce if in read or write mode when flipped</td>
</tr>
<tr>
<td>4</td>
<td>Always help the student with spelling</td>
</tr>
</tbody>
</table>
Figure 21: Flowchart of the advanced settings menu

7.4.4 Activities

BrailleBunny has four level options, described in detail in Table 10. The activity menu flow is shown in Figure 22. To enter an answer, the user presses the push button for one second. An example activity flow is given in Figure 23 and Figure 24.
### Table 10: Activity names and descriptions

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration</td>
<td>Announces the dot written or erased, letter written, or orientation flipped to depending on what advanced settings the user has selected. No specific task is given.</td>
</tr>
<tr>
<td>Letter</td>
<td>Quizzes the user on how to write a letter in braille. The letter must be written in cell one. It starts by generating a random letter, telling the user what sound it makes, and asking them what it is in braille. The user is given three attempts, and prompted with audio feedback when they get it wrong or right. If they get it wrong, they are coached through writing the letter until they get it right. Once they get it right, a new letter is generated. If a user doesn’t enter any dots, it repeats the question.</td>
</tr>
<tr>
<td>Word</td>
<td>Quizzes the user on how to spell a randomly generated word in braille. It follows the same flow as the letter level, with the exception that it tells the user which cells are right or wrong after each attempt.</td>
</tr>
<tr>
<td>Story</td>
<td>Same as the word level except clip of a story is recited between tasks, and a request to spell a word occurs after each story clip.</td>
</tr>
</tbody>
</table>
Figure 22: Flow chart of activity menu
Figure 23: Flow chart of letter level
Figure 24: Flowchart of BrailleBunny taking answer up with user in the letter level
7.5 Adaptations to the design concept

The design of BrailleBunny was adapted as compared to the paper ideation stage to enable feasibility in the prototyping stage. A list of changes is summarized below:

- Speakers were accommodated using ear-shaped structures in the device housing. This enabled larger and louder speakers to be selected, while adding another cue to the user about how to orient the device.

- The headphone jack was not included. The output from the mp3 shield was configured to split sound output between speakers and headphones when both were installed, resulting in insufficient circuitry to direct sound output directly to headphones.

- The battery compartment was moved to the top surface of the read side to enable easier access.

- Functionality that enabled students to request a hint was not included. The investigator weighed the time cost required to program this feature over the expected benefit. Although the investigator expects it could be a useful feature for some students, it was not crucial for this evaluation stage since the feature would overlap with the “announce letter” advanced setting, and when the question is taken up after three wrong attempts.

7.6 Discussion

3D printing enabled the design to be iterated throughout the prototyping stage. Although the concept remained, small changes and additions such as a snap mechanism to hold the case together, and locating pegs/standoffs were required. 3D printing also enabled the housing and braille dot buttons to be constructed without relying on outside manufacturers. However, the cost of 3D printing, and time required to print and assemble
BrailleBunny makes this method unfeasible for larger scale production. Other manufacturing methods will need to be explored if BrailleBunny is to be produced at a larger scale in the future.

The cost of the BrailleBunny prototype is not accessible for developing countries. However, since the prototype is a proof of concept and not a final proposal, this does not rule out the possibility of reducing the cost of manufacturing through other methods that include prepopulated circuit boards, injection-molded housing and braille dot buttons, and assembly style manufacturing of the braille dot buttons.

There is much greater potential for the software than what was achieved in this prototype. There is potential for adding many more features with further software development with minimal additional cost. Examples include: additional levels, games, hints, and tracking student progress.

The prototyping process produced a device that was usable, and enabled testing by the investigator and end-users, as detailed in Chapter 8.
Chapter 8

Prototype Assessment

8.1 Overview
To evaluate the prototype device, it was necessary to provide it to end-users and assess how effective they were at using BrailleBunny to navigate menu structures, and the activities with different combinations of advanced settings. Furthermore, it was necessary to discuss their experiences using BrailleBunny to further evaluate BrailleBunny’s usability and gain recommendations for future work. Included in this chapter are the assessment methods, results, and directions for future development.

8.2 Assessment methods
Both an internal assessment by the investigator and case studies with end-users were conducted.

8.2.1 Internal assessment
The study investigator trialed the prototype, assessed how well each design criteria was met and by what factors, and noted areas for future development. The study investigator is sighted therefore, the assessment came from a sighted lens.

8.2.2 Case studies
The device was tested in Canada and the Philippines. In the Philippines, the community partner assisted the study investigator with data collection. We recruited through schools and organizations that provide services to people who are blind or visually impaired. Participants were invited to participate in the usability study if they: (1) were blind or visually impaired and at any stage of braille education, (2) were blind or
visually impaired and had not learned braille, or (3) were or had ever been a teacher, caregiver, parent/guardian, or intervenor to someone who is blind or visually impaired.

8.2.2.1 Canada

In Canada, BrailleBunny was tested in-person facilitated by the investigator. All testing sessions in Canada were audio recorded. At the beginning of each testing session, a background information questionnaire was administered (Appendix B). Next, the BrailleBunny’s functionality and features were explained as the participant explored and manipulated the device. The participant was allowed to ask questions about how to use BrailleBunny as the features were explained. Participants were asked to trial a specific activity or advanced setting combination when the background questionnaire indicated that their feedback would be especially applicable to that activity or setting. Otherwise, the setting(s) and activity were selected based on participant preference. Participants were given 15-30 minutes to trial BrailleBunny. The study investigator observed the participant as they interacted with the device. Throughout the trial, participants were allowed to ask the study investigator for prompts on how to interact with the device if needed. When a participant appeared to be struggling, the investigator offered guidance and suggestions on how to use the device. Prompts given and questions asked by participants were considered in the assessment of BrailleBunny, as described in Analysis methods (Section 8.2.2.3).

After the testing session, a semi-structured interview was conducted. For participants who were over the age of 21, the full list of interview prompts was used (Appendix C) while a shortened list was used for participants under the age of 21 (Appendix C). In cases where the participant played a specific role (teacher,
parent/guardian, caregiver, intervenor, etc.) to someone who is blind or visually impaired, and were blind or visually impaired themselves, they were asked questions based on their own experience and their perspective based on their role. In some cases, not all prompts were asked due to time limitations.

8.2.2.2 Philippines

A prototype of BrailleBunny was shipped to the Philippines. Participants in the Philippines were invited to test BrailleBunny and give feedback through the same semi-structured interview as in Canada through video conference. The background questionnaire was also completed over video conference. However, it was not possible to observe the participant using BrailleBunny due to challenges capturing the interaction on camera in detail. Participants in the Philippines who were not available for an interview were invited to test the device in person with the community partner and complete an online questionnaire. The questionnaire took participants approximately 20-30 minutes to complete. The questionnaire was delivered through Qualtrics [84], and combined the background questionnaire and device assessment/feedback.

8.2.2.3 Analysis methods

Interviews were transcribed verbatim. Interviews, observation notes, and questionnaire responses were manually coded by the investigator using an evaluation coding method [85]. Observation notes were embedded into the transcriptions, at times corresponding with audio at the time of observation. Areas that BrailleBunny did well, and areas for improvement were assessed using suggestions from participants, and were coded as continue, stop, or start. Specific questions of interest were coded using the question as a code, and a magnitude of yes or no for the response where applicable.
Design criteria were assessed by assigning each criteria a code of meets or doesn’t meet. An example of where a response from P2 was coded as the design criteria of motivational being met is provided.

“Investigator: do you think that this device would be motivating for students?
P2: I think so yeah. Anything that adds some variety right. Especially if they are using a slate and stylus, that is just so low tech. Anything that offers some variety to that I think is positive.”

8.3 Results
The results of the prototype assessment are summarized below.

8.3.1 Internal assessment
The extent to which BrailleBunny fulfilled the design criteria was assessed by the study investigator. Factors contributing to design criteria being met or unmet and suggestions for improvement are given in Table 11.

Overall, the prototype of BrailleBunny clearly demonstrated the design concept. The investigator could successfully navigate the menu using the push button to select an answer, holding the push button for four seconds to exit a menu level, and scroll through menu options using the toggle button. The investigator could navigate the menu to select the language, control the volume, select the settings, and activities. Each advanced setting could be independently turned on or off, and each activity and setting worked as expected. The braille dot buttons were easily pushed up or down from either surface, and stayed in position if BrailleBunny was flipped. The investigator was able to feel the position of the dots from each surface without unintentionally pushing a dot up or down.
The investigator noted areas for improvement based on the interaction. The push button and power switch are quite small. Furthermore, holding the push button for four seconds requires the user to be able to successfully count to four, at an appropriate pace. The investigator was able to use these functions effectively however, a user with larger fingers, poorer motor control, or an inability to count to four may have difficulty. While audio is playing, the button state is not sensed by the system. Therefore, it is not possible to scroll through menu options, enter an answer, or exit a menu level while audio is playing. Although this requires the user to listen to the prompts which may be useful in an educational setting, users may become frustrated. The device lacks a case which presents risk of damage during transportation. Otherwise, it is small, lightweight and easily portable.

Each advanced setting worked as intended individually (as described in Chapter Six). However, settings one and two do not always interact smoothly with each other (announce which dot is written or erased, or the letter written, as described in Table 9) do not always interact smoothly with each other. As a user is pushing dots up or down, the code checks each dot and letter to notice and announce any changes. Sometimes, BrailleBunny will recognize some of the dot changes, then the letter change, and then the remaining dot changes. Since the order of recognition is not always consistent, this may be confusing for some users. Additionally, because the change in each individual dot is announced, the dot changes announced by BrailleBunny can extend long beyond the time of the actual change when a user pushes many dots up or down quickly. This setting was intended for users who are just beginning to learn braille, therefore, the investigator expected their interaction with the device to be slow. However, if they push dots down
quickly, the audio feedback may be confusing and will delay their ability to enter their answer until all dot changes are announced.

Each activity worked as expected, as described in Chapter Six. Although a variety of activity concepts were demonstrated, the investigator expects that additional activities and variation of the existing activities will be required in future iterations to ensure student engagement and motivation. Furthermore, gamification aspects should be included. Additionally, the activities can be modified to follow existing strategies for teaching emerging literacy. For example, the word level randomly assigns a word for the user to spell. Instead, the words assigned could follow phonetic structures, increase difficulty over time, and repeat words with which the student has difficulty.

A user with cognitive impairment may find the menu structure difficult to navigate. To aid this, the previous setting and activity selection should be saved instead of resetting upon device start-up.

Portability, and financial accessibility is diminished by poor battery life. The battery lasts only 1-4 hours and cannot be recharged. The short battery life greatly increases the maintenance cost of the device and limits its portability since multiple batteries would be required for a full day’s use. A rechargeable battery with a built-in charging port should be installed.

In addition to the cost of batteries, the prototype of BrailleBunny cost 429.08 CAD to manufacture. This is financially out of reach of many families in the Philippines. Alternative manufacturing methods that are more cost effective should be explored.

The prototype of BrailleBunny is safe for supervised use but could be improved for independent use. The housing is not watertight and leaves the user open for the risk of
a small shock and damaging the device if device gets wet. Additionally, the braille dot buttons are assembled from small parts that could be a choking hazard if they become disassembled. However, the study investigator is not aware of any additional risks.

Transferable skills to reading and writing are achieved by BrailleBunny as it is centered around the slate and stylus concept of a mirrored and unmirrored mode. Essentially, BrailleBunny represents the paper in a slate where one side the dots are pressed through the page, and on the other they are raised. Phonological awareness is promoted through the letter activity which makes the user aware of the sound a letter is associated with. BrailleBunny is designed to be accessible to young users enabling it to provide early exposure to braille literacy. The letter, word, and story activities are centered around drill and practice and student testing. A variety of prompts are available to the user through advanced settings however, they are not automatic and rely on the instructor, parent, or user to withdraw the prompts as the student becomes ready.

BrailleBunny’s instruction is currently provided in only uncontracted braille. Conventional sized braille is located over the ear cover, however, the braille dot buttons on BrailleBunny are significantly scaled up. Although the investigator expects that these dots can enable the development of tactile discrimination skills, the investigator recognizes that the tactile feedback is not the same as what occurs with conventional braille. Every activity and setting aim to provide the user with immediate auditory and tactile feedback when they perceive which dots are raised. Greater variety in the stories and activities can increase the range of reading genres and meaning-centered tasks to which a student is exposed.
Table 11: Results of internal analysis

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Assessment</th>
<th>Suggestion for Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accessible</strong></td>
<td>Negative</td>
<td>• Reduce cost&lt;br&gt;• Chargeable battery with charging port&lt;br&gt;• Save setting and activity selection without resetting after power off&lt;br&gt;• Increase size of push and power switches</td>
</tr>
<tr>
<td></td>
<td>• Not affordable for many families in the Philippines&lt;br&gt;• Requires batteries to be replaced every 1-4 hours&lt;br&gt;• Unable to be maintained without a technical person who is skilled in soldering and 3D printing&lt;br&gt;• A user with cognitive impairment may find it difficult to navigate the menu structure&lt;br&gt;• Power switch is quite small</td>
<td></td>
</tr>
<tr>
<td><strong>Durable/Reliable</strong></td>
<td>Positive&lt;br&gt;• Maintains ‘peg board’ function without audio cues&lt;br&gt;• Minimal technical errors&lt;br&gt;• Many parts replaceable by 3D printing</td>
<td>• Waterproof casing&lt;br&gt;• Design buttons so that they cannot come apart&lt;br&gt;• Build case to cushion if dropped, or build out of more durable plastic</td>
</tr>
<tr>
<td></td>
<td>Negative&lt;br&gt;• Unable to be maintained without a technical person who is skilled in soldering and 3D printing&lt;br&gt;• Not waterproof&lt;br&gt;• Small parts that could come disassembled&lt;br&gt;• Not able to withstand being dropped</td>
<td></td>
</tr>
<tr>
<td><strong>Easily and Independently Operable</strong></td>
<td>Positive&lt;br&gt;• Braille dot buttons are easy to press&lt;br&gt;• Toggle switch is easy to press and control&lt;br&gt;• Power switch is located in a position it won’t be accidentally hit&lt;br&gt;• Few buttons to memorize&lt;br&gt;• Audio takes up answer with student if they get it wrong</td>
<td>• Make push button and power switch larger and more prominent&lt;br&gt;• Re-design exiting mechanism, perhaps with another button</td>
</tr>
<tr>
<td></td>
<td>Negative&lt;br&gt;• Push button and power switch are small</td>
<td></td>
</tr>
<tr>
<td>Enable Co-Play and Cooperative Learning Among Students</td>
<td><strong>Exit ing menu level may be difficult for some users</strong></td>
<td><strong>Exiting menu level may be difficult for some users</strong></td>
</tr>
<tr>
<td>-------------------------------------------------------</td>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td><strong>Engaging</strong></td>
<td><strong>Positive</strong></td>
<td><strong>Positive</strong></td>
</tr>
<tr>
<td></td>
<td>• Increasing difficulty of activities to work through</td>
<td>• Increasing difficulty of activities to work through</td>
</tr>
<tr>
<td></td>
<td>• Variety of words and letters as tasks</td>
<td>• Variety of words and letters as tasks</td>
</tr>
<tr>
<td></td>
<td>• Cheer or trumpet sound to recognize right answer</td>
<td>• Cheer or trumpet sound to recognize right answer</td>
</tr>
<tr>
<td></td>
<td>• Advanced settings which provide immediate feedback</td>
<td>• Advanced settings which provide immediate feedback</td>
</tr>
<tr>
<td></td>
<td><strong>Negative</strong></td>
<td><strong>Negative</strong></td>
</tr>
<tr>
<td></td>
<td>• Only one story option</td>
<td>• Only one story option</td>
</tr>
<tr>
<td><strong>Motivational</strong></td>
<td><strong>Positive</strong></td>
<td><strong>Positive</strong></td>
</tr>
<tr>
<td></td>
<td>• Increasing difficulty of activities to work through</td>
<td>• Increasing difficulty of activities to work through</td>
</tr>
<tr>
<td></td>
<td>• Cheer or trumpet sound to recognize right answer</td>
<td>• Cheer or trumpet sound to recognize right answer</td>
</tr>
<tr>
<td></td>
<td>• Advanced settings which provide immediate feedback</td>
<td>• Advanced settings which provide immediate feedback</td>
</tr>
<tr>
<td></td>
<td>• Story Activity: Must enter answer to hear rest of story</td>
<td>• Story Activity: Must enter answer to hear rest of story</td>
</tr>
<tr>
<td></td>
<td><strong>Negative</strong></td>
<td><strong>Negative</strong></td>
</tr>
<tr>
<td></td>
<td>• Only one story option</td>
<td>• Only one story option</td>
</tr>
<tr>
<td><strong>Portable</strong></td>
<td><strong>Positive</strong></td>
<td><strong>Positive</strong></td>
</tr>
<tr>
<td></td>
<td>• Small and lightweight, easily fits in any backpack, and easily carried by hand</td>
<td>• Small and lightweight, easily fits in any backpack, and easily carried by hand</td>
</tr>
<tr>
<td></td>
<td><strong>Negative</strong></td>
<td><strong>Negative</strong></td>
</tr>
<tr>
<td></td>
<td>• Battery life is only 1-4 hours depending on how audio-heavy the setting/activity selected is, meaning that multiple batteries must be kept on hand for one day’s use.</td>
<td>• Battery life is only 1-4 hours depending on how audio-heavy the setting/activity selected is, meaning that multiple batteries must be kept on hand for one day’s use.</td>
</tr>
<tr>
<td></td>
<td>• Battery cannot be charged, and requires replacing when it runs out</td>
<td>• Battery cannot be charged, and requires replacing when it runs out</td>
</tr>
<tr>
<td><strong>Provide Real Time Auditory and Tactile Feedback</strong></td>
<td><strong>Positive</strong></td>
<td><strong>Feedback could be geared more to the student’s response. Instead of saying which cells/dots are incorrect and giving solution, could tell them what they wrote instead, or if they made a common mistake such as a reversal.</strong></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>• No case to prevent dust or dirt accumulation, or buttons being pressed during travel</td>
<td>• Advanced settings respond immediately</td>
<td></td>
</tr>
<tr>
<td>• Stand is separate piece</td>
<td>• Student is corrected immediately</td>
<td></td>
</tr>
<tr>
<td>• Feedback such as “nice try”, “great job”, etc. is positive and encouraging</td>
<td>• Student is required to try three times, before answer is taken up. Student must correctly enter answer when it is taken up to continue.</td>
<td></td>
</tr>
<tr>
<td>• Tagalog and English options</td>
<td>• Raised braille dots in “read” or unmirrored mode represent a large scale braille cell. Dots can be felt to give the concept of which dots are raised and un-raised in each letter.</td>
<td></td>
</tr>
<tr>
<td><strong>Safe</strong></td>
<td><strong>Positive</strong></td>
<td><strong>Waterproof casing</strong></td>
</tr>
<tr>
<td>• No pinch points</td>
<td>• Immediate audio feedback and tactile feedback</td>
<td><strong>Design buttons so that they cannot come apart</strong></td>
</tr>
<tr>
<td>• Minimal shock risk (9V battery)</td>
<td>• Phonological awareness promoted through letter level teaching letter sounds</td>
<td></td>
</tr>
<tr>
<td><strong>Negative</strong></td>
<td>• Knowledge of letter names promoted through all activities</td>
<td></td>
</tr>
<tr>
<td>• Housing is not water proof</td>
<td>• Listening skills promoted through story level</td>
<td></td>
</tr>
<tr>
<td>• Buttons are assembled from small parts, that could come apart</td>
<td>• Tactile discrimination skills promoted through braille dot buttons</td>
<td></td>
</tr>
<tr>
<td><strong>Transferable Learning to Reading and Writing</strong></td>
<td><strong>Positive</strong></td>
<td><strong>Increase variety of stories in story level</strong></td>
</tr>
<tr>
<td>• Immediate audio feedback and tactile feedback</td>
<td>• Mirror and unmirrored modes for reading and writing to replicate a slate and stylus.</td>
<td><strong>Add additional words or options to program words that are meaningful to students</strong></td>
</tr>
<tr>
<td>• Phonological awareness promoted through letter level teaching letter sounds</td>
<td>• Geared towards young children enables early braille exposure</td>
<td><strong>Program automatic withdrawal of prompts based on student progress</strong></td>
</tr>
<tr>
<td>• Knowledge of letter names promoted through all activities</td>
<td>• Letter, word, and story levels are centered around student testing</td>
<td><strong>Program activities in contracted braille in addition to uncontracted</strong></td>
</tr>
<tr>
<td>• Listening skills promoted through story level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Not true ‘reading’ since braille dot buttons are not real sized</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• No real-size braille display</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• At this time, only one story is programmed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• At this time, only one meaning centred approach is programmed, the story level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Withdrawal of prompts is not automatic, relies on instructor selecting settings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Only uncontracted braille is programmed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8.3.2 Case studies

8.3.2.1 Participant demographics

The background questionnaire was used to assess participant demographics and each participant was asked about their experience with a slate and stylus in the semi-structured interview. Teachers were asked questions about the population of students with whom they worked. However, the variability of these populations made it difficult to generalize responses. In these cases, a response of “varies” was given. A summary of the demographic information is provided in Table 14 (Appendix A). In total, data from 25 participants was collected, where 22 participants tried the device in Canada, and three in the Philippines. In the Philippines, one participant was interviewed, and two completed the questionnaire.

As shown in Figure 25, the majority of participants were blind or visually impaired (n = 18, 72%). Of this, three self-identified their level of vision as moderate visual impairment, three identified their level of vision as severe visual impairment, and 12 identified as blind.

Figure 25: Level of visual function of participants
As shown in Figure 26, about half the participants were only users themselves and thus did not play a role to someone who is blind or visually impaired (n = 13, 52%). Ten participants were a teacher to student(s) who were blind or visually impaired, one participant was a parent/guardian, and one participant identified as “other”, which they specified as an assistive technology specialist.

Figure 26: Participants’ role to someone who is blind or visually impaired

Figure 27 shows that all participants knew braille in some capacity. Most were proficient in braille (n = 21, 84%).

Figure 27: Participants' braille knowledge
As shown in Figure 30, the participants’ ages ranged significantly. For participants who were blind or visually impaired, the maximum age was 75, the minimum age was 10, and the median age was 18.5. Similarly, the overall maximum participant age was 75, the minimum participant age was 10, and the median age was 23.5. Box plots of the participant ages at the time of study and when they learned braille are shown in Figure 28 for all participants, Figure 29 for participants who were sighted, and Figure 30 for participants who were blind or visually impaired.

**Figure 28: Box plot of all participant ages at time of study and when they learned braille**

**Figure 29: Box plot of sighted participant ages at time of study and when they learned braille**
Figure 30: Box plot of participants who are blind or visually impaired ages at time of study and when they learned braille

All participants used braille in English. Ten participants also used braille in French, and three used braille in Filipino/Tagalog. Each of the participants who used braille in Filipino/Tagalog live in the Philippines. Other languages used by one or two participants were Mandarin/Japanese, Spanish, Arabic, Dutch, and German.

Participants had varying levels of experience with a slate and stylus. Eighteen participants (72%) were aware of the slate and stylus and how it is used in some capacity. Four participants (16%) were unaware of the slate and stylus and how it is used. Details of participant experiences are shown in Figure 31 below, and Table 13 (Appendix A).

Figure 31: Participant slate and stylus experience
8.3.2.2 Areas trialed

Participants 24 and 25 completed the online questionnaire, therefore, the details of what features they tested were not collected. Many participants trialled multiple features, and some trialled activities without any advanced settings selected. Twenty-five trials by 21 participants were completed in the unmirrored mode and 18 trials by 12 participants were completed in the mirrored mode. As shown in Figure 32, the word activity was the most trialled with 11 (34%) participants. As shown in Figure 33, of the advanced settings, the announce letter and dot settings were the most trialled with 14 participants (33%) each. Full details of the settings, levels, and mirrored/unmirrored modes trialed by each participant are shown in Table 15 (Appendix A).

![Figure 32: Pie chart of activities trialled](image-url)
8.3.2.3 Qualitative results

The overall attitudes towards BrailleBunny were very positive. Participants were asked if they would use the device, either in their current practice as an educator, or when they were learning braille. The parent/guardian was asked if their child would use BrailleBunny. Twenty participants said that they or their child/student(s) would use or would have used BrailleBunny. Two were unsure if they would/would have (P2 and P14), and three said they wouldn’t (P7, P17, P21). P23, a teacher in the Philippines, noted that she expected her students would use it for up to two hours at a time and may not want to give it back at the end of the school day.

“Investigator: how long do you think they would use it for in one sitting?

P23: I think the whole class, I mean the whole period for about 2 hours. They might refuse to give it to me to go home.”

Participants valued BrailleBunny as a reasonable investment as well. Adult participants were asked an expected price for BrailleBunny, or how much they would pay
for it if it was commercially available. Younger students were not asked about cost, as the investigator didn’t expect they would have the context to inform the research.

Participants in the Philippines said they would expect to pay 1500-2000 PHP, or 40-55 CAD. In Canada, participants said they would pay 100-1000 CAD. The average expected cost in Canada was 393 CAD, with the average across all participants being 300 CAD. A box plot of the participants’ expected cost is shown in Figure 34.

![Box plot of participants’ expected cost](image)

**Figure 34: Box plot of participants’ expected costs**

The target user group included young children learning literacy through braille. However, participants suggested that the application of BrailleBunny could be more diverse. P12 lost his sight in early adulthood and learned to write braille with a slate and stylus before he was able to get funding for a brailler. He said that he would have used BrailleBunny to help teach himself braille.
“Investigator: But I do kind of wonder, you know, if you were learning braille as an adult, if something like this could have been a tool for you to practice independently. So maybe we do need to design it for people with bigger hands.

P12: Absolutely. I guarantee this would have been helpful actually, and I love the audio feedback on it ... when I was practicing with ping pong balls and an egg carton there is a sighted assistant there telling you if you got it right or wrong. [You’re] right there is really nothing [available].”

P3 is a retired special education teacher and also teaches braille to blind adults in the Bahamas. She said that she would have used BrailleBunny with her young students in Canada, as well as with her older adult students in the Bahamas. In Canada, she would have liked to use BrailleBunny as a skill to promote independence in her students.

“P3: Kid can self-initiate with this. Kid can go to his little corner. You might want a headset on it. And play, just play, not be asked questions, not be told to do anything. They are directed to do everything. Often they don’t get a chance to just play like the other [sighted] kids do.”

In the Bahamas, she expects that BrailleBunny would be useful since many of her students have numbness in their fingers due to diabetes.

“Investigator: Do you think anything like this would also be useful when you’re teaching the older population?

P3: You know, I would like to use it with some of my older ones in the Bahamas. The reason they were blind is diabetes which also causes numbness in extremities which really screws up the braille scene. And so, they just want something. You know they just want something back ... but this would be something I could work with on orientation and my hope would be that he could feel, feel this.”
P18, a 13 year old student who started learning braille five months prior to the study, thought that she would have liked to use BrailleBunny to learn braille because it would be more fun than how she had been learning previously.

“Investigator: So, since you just started learning braille five months ago, is this something you wish you had five months ago? Just from first impressions.

P18: Probably yeah because instead of just getting frustrated and trying to read it, actually you could make it fun, and like a game and stuff”

BrailleBunny currently provides instruction in uncontracted braille only. The investigator expected that when a student was learning contracted braille, they would have developed braille skills and would only benefit from conventional sized braille and not derive benefit from a device such as BrailleBunny. However, 11 participants requested that contracted braille be included in future iterations, and only one did not see a benefit. P19 suggested that since contractions are particularly difficult to learn, there should be an activity that would enable students to practice them.

“P19: And would this go into contracted braille as well?

Investigator: It doesn’t right now but if you think it should, it could.

P19: Well because that’s the big one. Learning the 26 letters of the alphabet is one thing and I have had pretty much 100% success with that. It’s when you get into contracted braille, it becomes a struggle because kids don’t remember. But that might be like, there could be a mode for contracted braille.”

Other areas of potential development that were suggested were math/numbers (n = 3), spatial and directional skills, full cell, and empty cell (n = 2), and music (n = 1), as shown in Figure 35.
Through hypothesis coding, each design criteria was coded as “meets” or “doesn’t meet”. There were 447 instances of design criteria being met, and 162 instances of design criteria being unmet, as shown in Figure 36.
As shown by Figure 36, all design criteria with the exception of accessible, and durable/reliable had higher instances of being met as compared to not being met. However, there were only two instances of the code for enabling co-play and cooperative learning, indicating that this design criteria may have also been unmet. Due to time limitations, most participants were not asked specifically about if they thought BrailleBunny could enable co-play/cooperative learning. Participants did not suggest independently that BrailleBunny could be used for this application. Engaging, motivational, and transferable learning had the highest prevalence of being met, each with about 95% of the criteria instances being “meets” as opposed to “doesn’t meet”. All participants with the exception of P21 had higher instances of “meets” as compared to “doesn’t meet”. P21 expressed his dislike of the orientation of the braille dot buttons. P21 is skilled at using a brailler, and this is his main method of braille production. Since the brailler is his literacy method, he thought it would not be beneficial for him to learn braille in a slate and stylus orientation.

“P21: ... or maybe even make them look more like actual braille dots. Like the buttons on a braille cell. So, you know how braillers work, right? Make them look like the button on the brailler, a more realistic feel. Now, on the brailler there is a space bar too and the two sides, so I guess this is more like a slate and stylus.”

Despite overall positive attitudes, areas for improvement remain. Stop, start, and continue codes were given to suggestions made by participants, or observed by the investigator. A bubble chart indicating the most common suggestions for each of stop, start, and continue suggestions are shown in Figure 38, Figure 39, and Figure 40, with the exception of other braille to skills include, as discussed above and shown in Figure 35.
The suggestions were further grouped into a topic category. These categories are represented by different bubble outline types. For example, a solid thick line represents a suggestion about the braille dot buttons. A category legend is shown in Figure 37.

Suggestions that were given by five or less participants were grouped by category, and are listed in Table 16, Table 17, and Table 18 (Appendix A). There were 50 additional continue suggestions, 24 additional stop suggestions, and 61 additional start suggestions. Since there was minimal convergence on these suggestions, they are not expected to be critical factors influencing the degree to which design criteria are met or unmet.

![Figure 37: Legend for suggestion bubble charts](image)

The “continue” suggestions indicate satisfactory areas of BrailleBunny’s design.

The most prevalent “continue” suggestions related to portability. Twenty participants said to keep the weight of BrailleBunny the same and 13 said to keep the size the same.

Similarly, 14 participants said that the braille dot buttons should remain the same size (about one centimeter in diameter). Nine participants found the toggle switch met their
needs, and the size, shape, and position could remain the same. Eight participants found the announce dot advanced setting to be particularly useful, and thought that it should be continued in future iterations. Seven participants said to continue telling the user which cell they got correct or incorrect. Seven participants found the tone of voice encouraging. Six participants found the spelling help advanced setting to be particularly useful. Seven said the stand size and concept met their needs. Finally, seven said that the concept where a raised button in read mode is selected should be continued.

Figure 38: Bubble chart of most prevalent "continue" suggestions, and number of participants who made the suggestion

The stop suggestions indicate areas that BrailleBunny could be improved. Most of the stop suggestions related to the buttons used to control the menu. There was a slight delay when the push button was pressed. This was programmed intentionally to prevent students from pressing the button accidentally, however, 16 participants said that the
delay was confusing or frustrating. Furthermore, the push button is very small and set within the housing making it hard to push \((n = 15)\). To exit an activity or menu level, the user must hold the push button for four seconds. This was difficult for many participants, and it was suggested that an additional exit button would be easier to use \((n = 7)\).

The power switch was intentionally tucked into the crook of one of the ears to prevent it from being pressed accidentally. However, 16 participants said that the power switch should be easier to locate, perhaps by being placed on the side of the device, opposite the push and toggle switches. Participants said that since the power switch is a slide switch, it is less likely to be pushed accidentally than a push button, and many other technologies have a power switch located on the side of a device.

The stand was designed to be a separate piece to BrailleBunny, which was coded as a “stop” suggestion for eight participants. Although this setup does enable the user to hold BrailleBunny in their hands without the stand in the way, participants thought the separate stand decreases the device’s portability, and was hard for some participants to navigate. Often, participants expected the stand to be attached to BrailleBunny, which led to BrailleBunny almost falling out of the stand on multiple occasions. To remedy this and maintain flexibility of use, participants suggested that a stand which has an option to be attached or detached could be designed, perhaps using a snap feature, or a magnet. In addition, eight participants suggested that rubber grips could be installed to the bottom of the stand to stop it from sliding on the table surface.

Certain tactile features of BrailleBunny should be improved. An embossed arrow was placed near the top corner of each side of BrailleBunny to help users orient the device in the read or write orientations. However, seven participants said that this arrow
was not useful because it didn’t feel like an arrow to them, or felt like it should be a button or switch. Additionally, seven participants found that when a braille dot button was flush with a surface, it was very hard to feel. It was suggested that adding a small dome, or texture to the top of each braille dot button would make them easier to discriminate.

![Figure 39: Bubble chart of most prevalent "stop" suggestions, and number of participants who made the suggestion](image)

The start suggestions indicate further areas that BrailleBunny could be improved.

Two of the most common start suggestions relate to how feedback is given. Ten participants suggested there should be the optional use of headphones. In a classroom environment, the audio feedback could quickly become distracting for other students. Furthermore, participants suggested that a refreshable braille display would help students transfer their learning to conventional sized braille (n = 9).
Nine participants agreed that improving the battery life would increase the usability and accessibility of BrailleBunny. There should be a charging port such that the battery does not need to be replaced (n = 9). When asked further about their desired battery life, participants agreed that the battery should last at least one day without needing to be charged, so that it could be charged overnight. P6 pointed out that even if the cost of batteries isn’t an issue, needing an adult to change the batteries could become a barrier for children with busy parents.

“P6: Personally, the issue when I had electronics as a kid wasn’t so much the cost of batteries but that sighted people and my parents around me were busy. So, when it would run out and I’d ask they’d say sure we’ll get to it and it would take months and months … unfortunately what would happen is the toy would go in the back of the closet. And what would happen is my mom would be like wow that’s such an awesome thing why didn’t you use it more and I was like well it ran out of batteries.”

Eight participants thought that more games should be programmed, and multiplayer games would be especially desirable. Similarly, seven thought that more variety and sub-levels within each activity should be programmed.

The audio feedback provided by BrailleBunny had desirable content, but could still be improved. The audio speed was too slow for many participants. Eight suggested that the speed should be adjustable since people who are blind or visually impaired are accustomed to using screen reader technologies that speak quickly. Another addition to the audio feedback is to have the push button beep when it is pressed, suggested by seven participants.
To aid students in orienting the device, texture should be added to one surface, as well as the use of full cells of braille or texture on dot one of cell one (n = 7). Additionally, to help students discriminate where one cell begins and the other ends, the notch between cells should be changed to a raised line, the height of a braille dot (n = 6).

Six participants thought that more cells should be added so that they can practice harder words. In particular, it would be meaningful for them to be able to spell their name. Four cells is insufficient for most students to spell their name.

Four prevalent start suggestions related to the braille dot buttons. Eight participants suggested that the braille dot buttons could be smaller, as small as half the size. Seven participants suggested that it would be more intuitive to push a dot down from the read side as one writes with a brailler, by pushing the dot selected down, as compare to pushing it up from underneath. Additionally, eight participants suggested that the orientation of the dots in two columns as a large scale version of what is written on paper is not useful when their method of writing is the use of a brailler. These participants suggested that instead, the buttons should be arranged like a brailler, where the buttons are shaped more rectangular than circular, and each hand is used to press three dots to write. However, this was not the preference of all participants even though slate and stylus was seldom used by participants in Canada. Participants noted that BrailleBunny mimics a common low-tech method for introducing students to braille; an egg carton with ping pong balls, or some variation. In the Philippines, the community partner said that there was no need for the dots to be arranged like a brailler, since her students do not have access to braillers and solely use the slate and stylus.
Overall, 19 participants experienced a technical error with the prototype during use. Of these, participants experienced between one and five errors, with an average of 1.9 errors per participant. As shown in Figure 41, the most common technical problem, experienced by nine participants, was that they couldn’t hear the task assigned during an activity. They often questioned the investigator for clarification or entered an answer that matched what they thought they had heard. Seven participants found that too much audio feedback was given when the announce dots setting was on, resulting in a significant delay before they were able to enter their answer. Five participants found that the toggle switch remained depressed when they released it, five found that the device misread if a braille dot button was fully depressed, four found that the audio quality was poor, three found that the braille dot buttons became depressed unintentionally, and one participant
each found that the read or write advanced setting announced the orientation incorrectly, and that there were slight errors in the Tagalog translations.

**Figure 41: Pie chart of technical errors experienced by participants**

Despite the presence of technical errors and numerous suggestions for improvement, most participants found BrailleBunny easy to use. Eight participants were asked to rate how easy they thought BrailleBunny was to use for them or their students (P2, P3, P4, P6, P12, P15, P16, P23). Not all participants were asked this prompt due to time limitations. Ease of use was positively rated by eight participants on a scale of 1-10 with 10 being the easiest. The ratings ranged from seven to nine, with an average score of 8.5. In addition to respondent feedback, coding allowed the researcher to draw out other instances in which the BrailleBunny met or did not meet the design criteria of being easy and independently operable. Across all participants, there were 81 instances of
BrailleBunny being easily and independently operable, and 38 of it not being easily and independently operable. The greatest contributors to BrailleBunny not being easily or independently operable were the small, set-in push button, and the small, hidden power switch, and delayed audio feedback.

Although BrailleBunny provides tactile feedback that is considerably larger than a conventional braille cell, 95% of the instances of the “transferable learning” code were “meets”. Nine participants suggested that a refreshable braille display would be beneficial, but there was no consensus on the ideal size of the braille dot buttons. Fourteen participants thought that the braille dot buttons should stay the same size, eight thought they should be smaller, and two thought they should be bigger. Twelve participants were specifically asked if they thought that learning on a large scale braille device such as BrailleBunny could transfer to conventional sized braille. Of these, 10 agreed that large scale braille would provide transferable learning to conventional sized braille. Two participants said that large scale braille would not transfer to conventional sized braille. These participants thought that a refreshable braille display was required to achieve learning outcomes. P14 commented on the applicability of larger scale braille to learning to read conventional braille, and how it promotes learning when the student is developing tactile discrimination skills.
“Investigator: And do you think that the size of the dots its ok or do you think it should be bigger or smaller?

P14: I think they are a good size.

Investigator: do you think that that would still help you learn braille even though they’re much bigger than a regular braille cell?

P14: I think so, just because when you’re in the beginning... I think when you’re first starting to learn I think it’s good to have them bigger because then you can tell, they’re easier to, like notice, when they’re big when you’re first learning because when you’re first learning you haven’t really developed as much of like a sensitivity to feeling braille, so I think that it’s good for like a beginner learner I think.”

Similar to the overall results considering all participants, the three participants from the Philippines said that they, their child, or their student(s) would/would have used BrailleBunny (P23, P24, P25). All three participants agreed that the power switch and push button should be made larger and positioned such that they are easier to access, the weight should be kept the same, and there should be louder volume options. Two participants thought that the braille dot buttons should be kept the same size (P24 and P25), while one participant (P23) thought that the braille dot buttons should be smaller. Similarly, two participants thought that the overall size of the device should be kept the same (P24, P25), while one participant thought that it should be smaller (P25). Two participants (P23, P25), thought that the action of holding the push button down for four seconds to exit a menu level or activity was difficult or confusing, and should be adapted. P23 and P25 also thought that a handle should be added to increase portability, and that a
battery charging port should be added so that the battery wouldn’t need to be frequently replaced.

The design criteria, factors contributing to criteria being met, and suggestions of improvement from the case studies are summarized in Table 12.
Table 12: Results of case study analysis

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Assessment</th>
<th>Suggestion for Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Positive</td>
<td>• Reduce cost</td>
</tr>
<tr>
<td></td>
<td>• English and Tagalog</td>
<td>• Chargeable battery with charging port</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>• Increase size of push and power switches</td>
</tr>
<tr>
<td></td>
<td>• Greater instances of “doesn’t meet” codes</td>
<td>• Relocate power switch to side of device</td>
</tr>
<tr>
<td></td>
<td>• Not affordable for many families in the Philippines, and may not be affordable for all families in Canada</td>
<td>• Consider alternative to feeling dots underneath in unmirrored mode</td>
</tr>
<tr>
<td></td>
<td>• Requires batteries to be replaced every 1-4 hours</td>
<td>• Additional languages</td>
</tr>
<tr>
<td></td>
<td>• Not suitable for people with multiple disabilities</td>
<td>• Change shape of dots so that they are rounded, or have some sort of texture change on top</td>
</tr>
<tr>
<td></td>
<td>• Requires two hands to use</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Power and push switches are quite small</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Power switch is difficult to locate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Users with poor motor skills may have trouble pushing dots up or feeling dots from underneath</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Difficult for people with reduced sensation to feel dots that are down</td>
<td></td>
</tr>
<tr>
<td>Accessible</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>• Correct technical errors</td>
</tr>
<tr>
<td></td>
<td>• Maintains ‘peg board’ function participants said they would use if audio functions failed</td>
<td>• Waterproof casing</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>• Design buttons so that they cannot come apart</td>
</tr>
<tr>
<td></td>
<td>• Many technical errors</td>
<td>• Build case to cushion if dropped, or build out of more durable plastic</td>
</tr>
<tr>
<td></td>
<td>• Not waterproof</td>
<td>• Build handle so it is less likely to be dropped</td>
</tr>
<tr>
<td></td>
<td>• Small parts that could come disassembled</td>
<td>• Attach stand to device body</td>
</tr>
<tr>
<td></td>
<td>• Not able to withstand being dropped</td>
<td></td>
</tr>
<tr>
<td>Durable/Reliable</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>• Make push button and power switch larger and more prominent</td>
</tr>
<tr>
<td></td>
<td>• High instances of “meets”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Most participants said it was easy to use</td>
<td></td>
</tr>
<tr>
<td>Easily and Independently Operable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enable Co-play and Cooperative Learning Among Students</td>
<td>Positive</td>
<td>Negative</td>
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<tr>
<td>-------------------------------------------------------</td>
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<td>----------</td>
</tr>
<tr>
<td></td>
<td>High instances of “meets”</td>
<td>Only two instances of “meets”</td>
</tr>
<tr>
<td></td>
<td>Increasing difficulty of activities to work through</td>
<td>Students can sit beside each other and play together, but no activities are designed specifically for multiple players</td>
</tr>
<tr>
<td></td>
<td>Variety of words and letters as tasks, but no sub-levels within activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cheer or trumpet sound to recognize right answer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Advanced settings which provide immediate feedback</td>
<td></td>
</tr>
</tbody>
</table>

| Negative | Only one story option | |

<table>
<thead>
<tr>
<th>Motivational</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High instances of “meets”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increasing difficulty of activities to work through</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cheer or trumpet sound to recognize right answer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Advanced settings which provide immediate feedback</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Story Activity: Must enter answer to hear rest of story</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Negative</th>
<th>Create activities which are designed for multi-players</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Increase gamification</td>
</tr>
<tr>
<td></td>
<td>Increase number of stories and stories ranging in content/appropriate age</td>
</tr>
<tr>
<td></td>
<td>Increase variability in each activity and sub-level</td>
</tr>
<tr>
<td></td>
<td>Ability to program student’s name, either for quizzing or encouraging student</td>
</tr>
<tr>
<td></td>
<td>Sound effect feedback when incorrect</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Positive</th>
<th>Create activities which are designed for multi-players</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Increase gamification</td>
</tr>
<tr>
<td></td>
<td>Increase number of stories and stories ranging in content/appropriate age</td>
</tr>
<tr>
<td></td>
<td>Increase variability in each activity and sub-level</td>
</tr>
</tbody>
</table>

| Negative | |
|----------| |
|          | Re-design exiting mechanism, perhaps with another button |
| Portable | Negative | • No refreshable braille display  
• Only one story option | • Ability to program student’s name, either for quizzing or encouraging student  
• Sound effect feedback when incorrect  
• Add refreshable braille |
| --- | Positive | • High instances of “meets”  
• Small and lightweight, easily fits in any backpack, and easily carried by hand |
|  | Negative | • Battery life is only 1-4 hours depending on how audio-heavy the setting/activity selected is  
• Battery cannot be charged, and requires replacing when it runs out  
• No case to prevent dust or dirt accumulation, or buttons being pressed during travel  
• Stand is separate piece  
• No handle |
| Provide Real Time Auditory and Tactile Feedback | Positive | • High instances of “meets”  
• Advanced settings respond immediately  
• Student is corrected immediately  
• Feedback such as “nice try”, “great job”, etc. is positive and encouraging  
• Student is required to try three times, before answer is taken up. Student must correctly enter answer when it is taken up to continue  
• Tagalog and English options  
• Raised braille dots in “read” or unmirrored mode represent a large scale braille cell. Dots can be felt to give the concept of which dots are raised and un-raised in each letter |
|  | • Feedback could be geared more to the student’s response. Instead of saying which cells/dots are incorrect and giving solution, it could tell them what they wrote instead, or if they made a common mistake such as a reversal.  
• Sound effect feedback when incorrect  
• Reduce audio delay when push button is pressed  
• Add speed and verbosity settings  
• Tell student what they wrote instead of just telling them it was wrong  
• Reduce language level |
| **Safe** | • Ear cover cheat sheet provides real size braille | • Refreshable braille display, or ability to interface with a display  
|  | **Negative**  
|  | • Audio delay when push button is pressed  
|  | • Some language is not developmentally appropriate for young children  
|  | • No refreshable braille display  
|  | • Waterproof casing  
|  | • Design buttons so that they cannot come apart  
| **Transferable Learning to Reading and Writing** | • High instance of “meets”  
|  | • Participants had no major safety concerns  
|  | • No pinch points  
|  | • Minimal shock risk (9V battery), however, housing is not water proof  
|  | • Buttons are assembled from small parts, that could come apart  
|  | • Increase variety of stories in story level  
|  | • Add additional words or options to program words that are meaningful to students  
|  | • Program automatic withdrawal of prompts based on student progress  
|  | • Program activities in contracted braille in addition to uncontracted, as well as spatial sense lessons, math, and maybe music  
|  | • Tell user what they have written, not just if they got the question right or wrong  
|  | • Refreshable braille display or option to interface with display  
| • High instance of “meets”  
| • Immediate audio feedback and tactile feedback  
| • Phonological awareness promoted through letter level teaching letter sounds  
| • Knowledge of letter names promoted through all activities  
| • Listening skills promoted through story level  
| • Active learning required in all activities  
| • Tactile discrimination skills promoted through braille dot buttons  
| • Real size braille is located on ear covers  
| • Geared towards young children enables early braille exposure  
| • Letter, word, and story levels are centered around student testing  
| **Negative**  
|  | • Increase variety of stories in story level  
|  | • Add additional words or options to program words that are meaningful to students  
|  | • Program automatic withdrawal of prompts based on student progress  
|  | • Program activities in contracted braille in addition to uncontracted, as well as spatial sense lessons, math, and maybe music  
|  | • Tell user what they have written, not just if they got the question right or wrong  
<p>|  | • Refreshable braille display or option to interface with display |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>• Mirrored and unmirrored modes for reading and writing with a</td>
<td>• Add additional sub-levels and variety within activities</td>
</tr>
<tr>
<td>slate and stylus however, it is not true ‘reading’ since braille is</td>
<td>• Track student progress and customize lessons to student needs</td>
</tr>
<tr>
<td>not real sized</td>
<td>• Program name, or other meaningful words for meaning-centered learning</td>
</tr>
<tr>
<td>• Only one story is programmed</td>
<td></td>
</tr>
<tr>
<td>• Only one meaning centred approach is programmed, the story</td>
<td></td>
</tr>
<tr>
<td>level</td>
<td></td>
</tr>
<tr>
<td>• Withdrawal of prompts is not automatic, relies on instructor</td>
<td></td>
</tr>
<tr>
<td>selecting settings</td>
<td></td>
</tr>
<tr>
<td>• Only uncontracted braille is programmed</td>
<td></td>
</tr>
</tbody>
</table>
8.4 Discussion

Despite identified areas for improvement, the user feedback was very positive. Although BrailleBunny provides tactile feedback that is considerably larger than a conventional braille cell, 95% of the instances of the “transferable learning” code were “meets”. This aligns with a 2019 study by Barlow-Brown et al. where children who experienced large tactile braille learnt braille letters at a much faster pace than children learning standard tactile braille only [86]. Twenty participants said that they or their child/student(s) would or would have used BrailleBunny. Two were unsure if they would/would have used it (P2 and P14), and three said they wouldn’t (P7, P17, P21). The participants who said they wouldn’t or were unsure had concerns about the applicability of the device to their context of braille use since BrailleBunny is geared towards use of a slate and stylus, not a brailler.

In future iterations, many of the criteria can be further met by adding to the code, and adjusting the menu button controls (size, position, additional button for exiting level). In particular, the greatest contributors to BrailleBunny not being easily or independently operable were the small, set-in push button, and the small, hidden power switch, and delayed audio feedback. These elements are easily rectified. The investigator expects that the criteria that will be the hardest to address, and where there is the least data is accessibility. For BrailleBunny to be useful for students who are not learning to write with a slate and stylus, they must push dots up from underneath the device which could be difficult for students with poor motor control or very poor tactile discrimination skills. Although this could be helped with a setting that reads dots that are pressed down in the unmirrored mode as selected, this does not reduce the need for students to push dots up from underneath the device to reset their answer. A custom mechanism that resets dots
mechanically could be explored however, it will be challenging to maintain the slate and stylus translation concurrently.

The user group needs to be further analyzed. Participants who did not fit the initial target user group tested BrailleBunny in Canada, and many agreed that they would use it or would have used it. In Canada, students do not typically learn to write braille with a slate and stylus. If the device not to be used in Canada, the question of how to design the buttons is considerably simpler, since the student would flip the device to write. However, the positive feedback indicates that there may be applications in Canada as well as the Philippines.

Financial accessibility is another major area for development. The range of cost expectations closely aligned with the cross section of technology detailed in Chapter Five. However, participants did acknowledge that technology for people who are blind is often much more expensive than the sighted equivalent, as outlined by P6.

“Investigator: if this was commercially available how much do you think you would pay for a device like this?

P6: it gets tricky hmm... I think hmm...I'm trying to imagine if I had a blind kid and I wanted them to sit down and do braille, I think I would be willing to pay 200 dollars for it. That would be quite reasonable

Investigator: do you think that number is driven up by the fact that technology for blind people is outrageously expensive?

P6: yeah it's just something we have to deal with unfortunately.”

To improve the financial accessibility of BrailleBunny, the manufacturing cost of BrailleBunny could be reduced. However, costs would have to be reduced to at least one
tenth of the initial manufacturing cost to meet the cost expectations of participants in the Philippines. Despite participants’ positivity about BrailleBunny, the investigator expects that there may not be a high enough demand for BrailleBunny to drive the cost this low considering the low incidence of visual impairment and blindness.

8.5 Limitations
Although the device assessment was conducted by a variety of users, the results are subject to some limitations. BrailleBunny was designed with users in developing countries in mind. However, the bulk of the data was collected from users in Canada. Additionally, due to the researchers and participants being in different countries, only participants with internet access were able to participate in the Philippines and not all participants were able to be observed. Furthermore, the study was conducted solely in English. This may have reduced the voice of users living in rural areas or of lower economic status. The youngest participant was 10 years old and no children who had multiple disabilities trialled the device. Considering the prevalence of multiple disability in visually impaired and blind populations, future studies should prioritize feedback from users with multiple disabilities [87]. Furthermore, each participant trialled the device for only 15-30 minutes. A longitudinal study would be required to measure literacy outcomes.
Chapter 9

Conclusions and Future Work

9.1 Conclusions

To address the need for assistive technologies to help children with sensory disabilities learn to read in the Philippines, a prototypical device, BrailleBunny, was developed through the work of this thesis. The state of existing technology for braille literacy education was determined and the effectiveness of these technologies was examined. A set of ideal design criteria were determined through literature reviews complemented by a systematic review, a semi-structured interview with a community partner, and a user needs questionnaire completed by Lopez [15][18][19]. It was determined that the device should promote transferable braille literacy skills including writing with a slate and stylus for children with or without a variety of disabilities including but not limited to autism, learning disabilities, motor impairments, any type of vision impairment ranging from completely blind to low vision, and children as young as age five years old. The device should be able to be used daily to aid in learning when teachers cannot give 1:1 attention due to large class sizes, provide real time auditory and tactile feedback, and function in either English or Tagalog (the languages which are taught in the Filipino curriculum). The device must be accessible to the user considering physical and financial accessibility, as well as availability in low-resource areas. The device should be durable and reliable, maintainable in a low-resource setting, and usable in multiple ways such that it maintains some function if a single component fails. It should be safe, easily and independently operable, and enable co-play and cooperative learning. To entice students to use the device, it should be engaging, motivational, and
portable. An iterative, parallel, and co-design process was followed to produce the prototypical device. Through an internal assessment and a series of case studies with 25 participants across Canada and the Philippines, BrailleBunny was found to meet all design criteria except for accessible, and durable/reliable. Future directions to improve the extent to which all criteria are met were summarized.

**9.2 Future work**

The user group should be re-defined to ensure that all potential user needs are fully met. Considering the positive feedback received in Canada and the Philippines, the needs of users in other developing countries should be examined and BrailleBunny should be tested by more participants in these countries to determine if there are commonalities in user needs and experience. BrailleBunny can be further developed through iterative design by initiating the suggestions given by the participants.

Limitations of this research should be addressed by completing additional testing in the Philippines and testing with users who are younger than 10 years old and/or have multiple disabilities. Furthermore, a longitudinal study should be completed to measure literacy outcomes.
References


[12] S. Ovaska and K.-J. Räähä, “Parallel design in the classroom,” in *Conference*


Nov. 2000.


https://store.humanware.com/hca/braillenote-touch-18-braille-notetaker-tablet.html?CAGPSPN=pla&gclid=CjwKCAiAgrfhBRA3EiwAnfF4tmMtJvpqFGB3p0LUmn6_-sq72jUHYNex0oUcISofiY1gcNFCWBhOZhoCpUAQAyD_BwE.

[Accessed: 03-Jan-2019].


[79] “Research on technology-enabled innovations to assist children with disabilities in the Philippines - Appendix A: Early Grade Reading Environment and Skills
Spectrum.”


Appendix A  
Supplemental Results Tables

Table 13: Participant slate and stylus experience

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<td>Uses slate and stylus occasionally</td>
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**Table 14: Demographic information**
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<th>Teacher, Parent/Guardian, Caretaker, Intervenor, Other</th>
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<td>Braille</td>
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<td>English, Chinese</td>
<td>Braille</td>
<td>Learning</td>
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<td>Braille</td>
<td>Learning or proficiency</td>
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<td>6.9 and 10</td>
<td>English, French</td>
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<td>Braille</td>
<td>Learning or proficiency</td>
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<td>Braille</td>
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Table 15: BrailleBunny levels, settings, and modes trialed by participants

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<th>Announce letter</th>
<th>Announce Flipped</th>
<th>Always Help the Student with Spelling</th>
<th>Mirrored Modes</th>
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Table 16: Additional, less prevalent suggestions coded as “continue” sorted by category and number of participants suggested

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<th>Category</th>
<th>Feature to Continue</th>
<th>Number of Participants</th>
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<td><strong>Activities</strong></td>
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<td></td>
<td>Progressing difficulty of levels</td>
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<td></td>
<td>Access levels freely without unlocking</td>
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<td></td>
<td>Story level</td>
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</tr>
<tr>
<td></td>
<td>Word level</td>
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</tr>
<tr>
<td></td>
<td>Exploration level</td>
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</tr>
<tr>
<td><strong>Audio</strong></td>
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<tr>
<td></td>
<td>Say &quot;Only write the letter in cell 1&quot;</td>
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</tr>
<tr>
<td></td>
<td>Good job</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>General audio feedback</td>
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</tr>
<tr>
<td></td>
<td>Consistent Audio</td>
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</tr>
<tr>
<td></td>
<td>Male voice</td>
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</tr>
<tr>
<td></td>
<td>Say &quot;Read mode&quot; or &quot;Write mode&quot;</td>
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</tr>
<tr>
<td></td>
<td>Announce letter written</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>say &quot;C makes the sound ...&quot;</td>
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</tr>
<tr>
<td></td>
<td>&quot;Try again&quot; etc.</td>
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</tr>
<tr>
<td></td>
<td>Option to turn off or on advanced settings</td>
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</tr>
<tr>
<td></td>
<td>Non synthesized voice</td>
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<tr>
<td></td>
<td>Say &quot;cell 1 spells the letter a&quot;</td>
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<tr>
<td></td>
<td>Speed</td>
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<tr>
<td></td>
<td>Easy to understand voice</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>4</td>
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<td></td>
<td>Take up answer &quot;Cell 1 should have the letter … cell 1 should have dots in….&quot;</td>
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<td>Applause/Trumpet/cheer sounds</td>
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<td><strong>Braille Dot Buttons</strong></td>
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<td>Spaced out braille dot buttons</td>
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</tr>
<tr>
<td></td>
<td>Easy to press - keep same resistance</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Pushing dot up and down</td>
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</tr>
<tr>
<td></td>
<td>Dots stay in same place when flipped</td>
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<td></td>
<td>Four cells</td>
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<tr>
<td></td>
<td>Completely flush braille dot buttons</td>
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<td>Not skip audio when you press the button while its playing</td>
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<tr>
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<td>Toggle (size specifically)</td>
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<tr>
<td></td>
<td>On off (size specifically)</td>
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<td>Push button to select</td>
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<tr>
<td></td>
<td>Buttons on side</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Push (everything)</td>
<td>3</td>
</tr>
</tbody>
</table>
Only a few buttons to memorize 3
On off (everything) 4

Name/Shape
Name 1
Bunny shape 3

Other
Requiring two hand use 1
Battery flap ridge (isn't distracting) 1
Arrows 1
Exchangeable ear cover 2
Grooves between cells 2
High contrast 2
Option to flip 3

Safety
No sharp corners 1
No wires 1
No tearing 1

Stand
Slide on table 1
Stand that doesn't clip 3

<table>
<thead>
<tr>
<th>Category</th>
<th>Feature to Stop</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activities</td>
<td>Unclear you only write the letter in cell 1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Only write the letter in cell 1</td>
<td>1</td>
</tr>
<tr>
<td>Audio</td>
<td>Tell user when they write an empty cell (for advanced setting)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Don't need a volume setting since the max volume is pretty quiet</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>&quot;Write side&quot; and &quot;read side&quot; is confusing - don't call it that</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Saying &quot;incorrectly&quot;</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>&quot;Erased&quot; indicates student is wrong</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Negative tone</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Advanced, un-succinct language. Ex: &quot;mode&quot;, &quot;announce&quot;, &quot;cell 1 dot 1 erased&quot;, &quot;selected&quot;, &quot;unselected&quot;, should say &quot;lesson&quot; instead of activity, say &quot;confirmed&quot; instead of &quot;Selected&quot;, or &quot;entering&quot; menu</td>
<td>5</td>
</tr>
<tr>
<td>Battery</td>
<td>9V battery</td>
<td>1</td>
</tr>
<tr>
<td>Braille Dot Buttons</td>
<td>Dots are too big</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Pushing dots up from underneath</td>
<td>5</td>
</tr>
<tr>
<td>Menu Buttons</td>
<td>Small toggle switch</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Toggle switch requires too much force</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Can't skip audio with toggle, or enter answer while audio is playing</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Small on off switch</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Name</td>
<td>1</td>
</tr>
<tr>
<td>Name / Shape</td>
<td>Bunny ears</td>
<td>3</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
<td>---</td>
</tr>
<tr>
<td>Other</td>
<td>Braille on ear cover is rough</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Braille on ear cover is not exactly transcribed from print</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>W on ear cover being out of order</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Mirrored braille on write side ear cover</td>
<td>5</td>
</tr>
<tr>
<td>Safety</td>
<td>Small parts</td>
<td>1</td>
</tr>
<tr>
<td>Stand</td>
<td>Legs in the way</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 18: Additional, less prevalent suggestions coded as “start” sorted by category and number of participants suggested**

<table>
<thead>
<tr>
<th>Category</th>
<th>Feature to Start</th>
<th>Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activities</td>
<td>Strategically ask questions - ex: don't start with hardest letter</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Follow curriculum - ex: Dolch words</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Coach with proper order of entering dots on slate and stylus</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Letter level - have them write the letter in all cells</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Option to turn off the &quot;makes the sound&quot; setting for more advanced students</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Clearer instruction for only writing in cell 1</td>
<td>1</td>
</tr>
<tr>
<td>Audio</td>
<td>Jump to that’s correct if all cells are right</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Announce everything that’s happening in a cell, not just the changed dot or letter written</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Verbosity setting</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Read back the word the student wrote (for advanced setting)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Tell you when you write an empty cell (for advanced setting)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>French and other languages</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sound effect for wrong</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Get less repetitive as time goes on - automatically withdraw prompts</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Say &quot;cell 1 dot 1 2 3 4&quot; instead of &quot;cell 1 dot 1.. Cell 2 dot 2&quot;</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Say “letter” instead of cell</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Program students name (say it or quiz it)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Advanced settings that self-interrupt, or user chooses to interrupt</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>If student gets the letter wrong, tell them what they wrote instead</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Let student know when they make a common mistake</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Ask &quot;What is S as in..&quot; instead of just saying &quot;S makes the sound…”</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Option to repeat the word</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Option for male or female voice, or other accents</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Louder volume options, perhaps through an additional speaker</td>
<td>4</td>
</tr>
<tr>
<td>Battery</td>
<td>Lithium battery</td>
<td>1</td>
</tr>
<tr>
<td>Category</td>
<td>Suggestions</td>
<td>Rating</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Low power mode</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Solar charging</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Indicator for when the battery gets low</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td><strong>Braille Dot Buttons</strong></td>
<td>Make braille dot buttons higher so that they are easier to discriminate</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Push braille dots like a stylus, make them small</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Braille dots on buttons (or other indicator to show which dot and cell is which)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Bigger braille dot buttons</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Separate dots and cells more</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Restore button so that user doesn’t need to push every dot up</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Setting to choose if you push dot down or up</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Change button mechanism so it’s one directional, and user doesn’t have to push dots up</td>
<td>4</td>
</tr>
<tr>
<td><strong>Durability/Reliability</strong></td>
<td>Easily cleaned</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Water tight</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Can’t be easily broken, be able to handle being dropped and falling on the ground, lots of button pushing of dots, perhaps with more durable plastic, especially the stand</td>
<td>4</td>
</tr>
<tr>
<td><strong>Menu</strong></td>
<td>Split menu for teachers and students</td>
<td>2</td>
</tr>
<tr>
<td><strong>Menu Buttons</strong></td>
<td>3 way toggle so the push button is combined with it</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Move on off switch to between ears</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Make toggle smaller</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Put on off switch in empty space on top of device</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>More space between push and toggle</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Up and down arrow instead of toggle</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Beep once for on and twice for off, or say powering off, or say welcome to BrailleBunny when turned on</td>
<td>3</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Print braille out onto paper</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Speaker in blank space on top of device</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Start line of braille over ear with full cell</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Jumbo braille for ear cover</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Only have cells - remove extra space and have cheat sheet over ear detached</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Ensure sense of progress</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Different animal shapes so students can choose</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Know which orientation (not just up or down) they are holding it, so however they hold it is correct</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Write notes</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Make accessible for students with profound or multiple disabilities</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Manual that goes along with device, instructions option on start-up, demo disk</td>
<td>3</td>
</tr>
<tr>
<td><strong>Portability</strong></td>
<td>Make it half the weight</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Make it bigger over all</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>Case</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Handle</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Stand</td>
<td>Raise stand</td>
<td>5</td>
</tr>
</tbody>
</table>
Appendix B
Questionnaires

Background Information Questionnaire

All participants are asked to respond to the questions under the “All Participants” Heading. Participants who are a teacher, parent/guardian, caregiver, or intervenor to someone who is blind or visually impaired are asked to respond to the questions under the “Teacher, Parent/Guardian, Caregiver, Intervenor” heading as well. If a participant does not want to answer a question, they may leave it blank.

For All Participants

General Information

1. What is your level of visual function?
   A. Normal vision
   B. Mild visual impairment
   C. Moderate visual impairment
   D. Severe visual impairment
   E. Blindness

2. Do you have a disability other than visual impairment or blindness?
   A. Yes (Please specify)
   B. No
   C. Prefer not to answer

3. Are you or have you ever been one of the following roles to someone who is blind or visually impaired? (Select all that apply)
   A. Teacher
B. Parent/guardian  
C. Caregiver  
D. Intervenor  
E. Other (Please specify)

4. **What is your gender? (Select one):**  
   A. Male  
   B. Female  
   C. Other (Please specify)  
   D. Prefer not to answer

5. **How old are you? (Please leave blank if you prefer not to answer):**

6. **Which country are you from? (Select one):**  
   A. Philippines  
   B. Canada  
   C. Other (Please specify)

7. **In which city do you live?**

   **Braille Knowledge**

8. **What is your level of braille knowledge? (Select one)**  
   A. I am proficient in Braille  
   B. I am learning Braille  
   C. I do not know braille

9. **If you are learning or have learned Braille, what age did you first begin to learn it?**
10. If you are learning or have learned Braille, what language(s) are you learning/have learned it in? Please list in order of use.

11. If you are learning Braille, please describe your braille knowledge:

12. If you do not know Braille, would you like to learn it?

13. If you do not know Braille, what is your reason for not having learned it?

Teacher, Parent/Guardian, Caregiver, Intervenor

Please fill out the following questions as they relate to the person or people who you are or have been a teacher, parent/guardian, caregiver, intervenor, or other role to:

General Information

1. What is their level of visual function?
   A. Normal vision
   B. Mild visual impairment
   C. Moderate visual impairment
   D. Severe visual impairment
   E. Blindness

2. Do they have a disability other than visual impairment or blindness?
   A. Yes (Please specify)
   B. No
   C. Prefer not to answer

Braille Knowledge

3. What is their level of braille knowledge? (Select one)
A. Proficient in Braille
B. Learning Braille
C. Do not know Braille

4. If they are learning or have learned Braille, what age did you first begin to learn it?

5. If they are learning or have learned Braille, what language(s) are they learning/have learned it in? Please list in order of use:

6. If they are learning Braille, please describe their Braille knowledge:

7. If they do not know Braille, do you think they would like to learn it?

8. If they do not know Braille, what do you think their reason is for not having learned it?

9. What is their gender? (Select one):
   A. Male
   B. Female
   C. Other (Please specify)
   D. Prefer not to answer

10. How old are they/were they when you were in your role?
Online questionnaire for participants who could not complete semi-structured interview

First, participants will respond to the background information questionnaire. If the participant responds that they play a specific role to someone who is blind or visually impaired, the survey will also have them respond to the background questionnaire that asks them question(s) about the population they work with. Then, they will watch the video. If the participant responded that they had some level of visual impairment, they will be directed to questions that assess the device from their perspective as a potential user. If the participant responded that they play a specific role to someone who is blind or visually impaired, the survey will also have them respond to question(s) assessing the device for the person(s) they play that role to.

Background

All Participants

General Information

1. What is your level of visual function?
   A. Normal vision
   B. Mild visual impairment
   C. Moderate visual impairment
   D. Severe visual impairment
   E. Blindness

2. Do you have a disability other than visual impairment or blindness?
   A. Yes (Please specify)
   B. No
   C. Prefer not to answer
3. Are you or have you ever been one of the following roles to someone who is blind or visually impaired? (Select all that apply)
   A. Teacher
   B. Parent/guardian
   C. Caregiver
   D. Intervenor
   E. Other (Please specify)

4. What is your gender? (Select one):
   A. Male
   B. Female
   C. Other (Please specify)________________________
   D. Prefer not to answer

5. How old are you? (Please leave blank if you prefer not to answer):

6. Which country are you from? (Select one):
   A. Philippines
   B. Canada
   C. Other (Please specify)

7. In which city do you live?

Braille Knowledge

8. What is your level of braille knowledge? (Select one)
   A. I am proficient in braille
   B. I am learning braille
   C. I do not know braille
   D. If you are learning or have learned braille, what age did you first begin to learn it?
9. If you are learning or have learned braille, what language(s) are you learning/have learned it in? Please list in order of use:

10. If you are learning braille, please describe your braille knowledge:

11. If you do not know braille, would you like to learn it?

12. If you do not know braille, what is your reason for not having learned it?

Teacher, Parent/Guardian, Caregiver, Intervenor

Please fill out the following questions as they relate to the person or people who you are or have been a teacher, parent/guardian, caregiver, intervenor, or other role to:

**General Information**

13. What is their level of visual function?
   
   A. Normal vision
   
   B. Mild visual impairment
   
   C. Moderate visual impairment
   
   D. Severe visual impairment
   
   E. Blindness

14. Do they have a disability other than visual impairment or blindness?
   
   A. Yes (Please specify) _______________________________
   
   B. No
   
   C. Prefer not to answer

**Braille Knowledge**

15. What is their level of braille knowledge? (Select one)
A. Proficient in braille
B. Learning braille
C. Do not know braille

16. If they are learning or have learned braille, what age did you first begin to learn it?
17. If they are learning or have learned braille, what language(s) are they learning/have learned it in? Please list in order of use:
18. If they are learning braille, please describe their braille knowledge:
19. If they do not know braille, do you think they would like to learn it?
20. If they do not know braille, what do you think their reason is for not having learned it?
21. What is their gender? (Select one):
   A. Male
   B. Female
   C. Other (Please specify)
   D. Prefer not to answer
22. How old are they/were they when you were in your role?

Device Assessment

Participants who are Blind or Have Low Vision

Please fill out the following questions as they relate to yourself if you were to use the device to learn braille:

Motivational/Engaging

23. Does this device seem like something you would want to use?
   A. Yes
B. No
C. Unsure

*Enabling Co-Learning*

24. Does this device seem like something you would use with other students?
   A. Yes
   B. No
   C. Unsure

*Transferable Learning to Reading and Writing*

25. Does this device seem like it would be an effective learning tool for learning braille for you?
   A. Yes
   B. No
   C. Unsure

26. Does this device seem like it would be an effective learning tool for learning to write with a slate and stylus for you?
   A. Yes
   B. No
   C. Unsure

27. How old do you think someone would have to be to use this device?

*Accessibility*
28. What accessibility needs would you want this device to meet?

29. Would this device meet your accessibility needs?
   A. Yes
   B. No
   C. Unsure

30. If commercially available, how much would you pay for this device or a product similar to it?

31. What level of braille knowledge do you think you would need to be able to use this device?
   A. No braille knowledge
   B. Some knowledge of braille alphabet
   C. Ability to spell in braille
   D. Other

**Durability**

32. If the electronic functions failed, would you find it useful to use without the audio feedback?
   A. Yes
   B. No
   C. Unsure

**Portability**

33. How long would you like the batteries to last?
   A. 1 week
   B. 1 month
34. **For how long do you think you would use this device in one sitting?**
   
   A. 10 minutes or less
   B. 30 minutes
   C. 1 hour
   D. 2 hours
   E. More than 2 hours

35. **What do you think about the weight of the device?**
   
   A. Too heavy
   B. Too light
   C. Just right
   D. Unsure

36. **If the weight of the device is too heavy or light, how much do you think it should weigh?**

37. **What do you think about the size of the device?**
   
   A. Too big
   B. Too small
   C. Just right
   D. Unsure

38. **If the size of the device is too heavy or light, how big do you think it should be?**

39. **Easily and Independently Operable**

   **Do you think you would be able to use the device independently?**
   
   A. Yes
   B. No
C. Unsure

_Tactile Feedback_

40. The braille dots are each about 1 centimeter (or a bit less than half an inch) in diameter. Do you think that this size is appropriate?

A. Too big
B. Too small
C. Just right
D. Unsure

_Safety_

41. Are there any safety considerations that you think need to be incorporated in this device?

_Additional Comments_

42. Do you have any additional comments or suggestions for improving the device?

_Participants who are a Teacher, Parent/Guardian, Caregiver, Intervenor_

Please fill out the following questions as they relate to the person or people who you are or have been a teacher, parent/guardian, caregiver, intervenor, or other role to:

Please fill out the following questions as they relate to yourself if you were to use the device to learn braille:

_Motivational/Engaging_
43. Does this device seem like something they would want to use?
   A. Yes
   B. No
   C. Unsure

**Enabling Co-Learning**

44. Does this device seem like something they would use with other students?
   A. Yes
   B. No
   C. Unsure

**Transferable Learning to Reading and Writing**

45. Does this device seem like it would be an effective learning tool for learning braille for them?
   A. Yes
   B. No
   C. Unsure

46. Does this device seem like it would be an effective learning tool for learning to write with a slate and stylus for them?
   A. Yes
   B. No
   C. Unsure

47. How old do you think they would have to be to use this device?
Accessibility

48. What accessibility needs would you want this device to meet?

49. Would this device meet their accessibility needs?
   A. Yes
   B. No
   C. Unsure

50. If commercially available, how much would they pay for this device or a product similar to it?

51. What level of braille knowledge do you think they would need to be able to use this device?
   A. No braille knowledge
   B. Some knowledge of braille alphabet
   C. Ability to spell in braille
   D. Other

Durability

52. If the electronic functions failed, would they find it useful to use without the audio feedback?
   A. Yes
   B. No
   C. Unsure

Portability

53. How long would they like the batteries to last?
   A. 1 week
B. 1 month
C. More than 1 month

54. For how long do you think they would use this device in one sitting?
   A. 10 minutes or less
   B. 30 minutes
   C. 1 hour
   D. 2 hours
   E. More than 2 hours

55. What do you think about the weight of the device?
   E. Too heavy
   F. Too light
   G. Just right
   H. Unsure

56. If the weight of the device is too heavy or light, how much do you think it should weigh?

57. What do you think about the size of the device?
   A. Too big
   B. Too small
   C. Just right
   D. Unsure

58. If the size of the device is too heavy or light, how big do you think it should be?

   *Easily and Independently Operable*

59. Do you think they would be able to use the device independently?
   A. Yes
B. No
C. Unsure

*Tactile Feedback*

60. The braille dots are each about 1 centimeter (or a bit less than half an inch) in diameter. Do you think that this size is appropriate?
   A. Too big
   B. Too small
   C. Just right
   D. Unsure

*Safety*

61. Are there any safety considerations that you think need to be incorporated in this device?

*Additional Comments*

62. Do you have any additional comments or suggestions for improving the device?
Appendix C
Case Study Semi-Structured Interview Prompts

Interview prompts for participants who are teachers, parents, or above the age of 21

Remind participant that they do not need to answer a question if they do not want to. To decline to answer, they should say “pass”, or “skip”.

Motivational/Engaging

- Did you have fun trying this device?
- Did this device motivate you to use it?
- Did you find this device engaging?

Transferable Learning to Reading and Writing and Enabling

Co-Learning

- Could you see yourself using this device?
  - Do you think you could/would use this device with other students?
- Do you think it is an effective learning tool?
  - For braille in general (position of dots in the cells)
  - For a slate and stylus (mirror images of braille, writing from left to right, delayed feedback in a conventional slate and stylus)
- Do you think that this device enables:
  - Development of basic literacy skills (phonological awareness, knowledge of letter names, language skills)
  - Development of tactile discrimination skills
  - Early exposure to braille
• How young a user do you think could use this device?

**General Device Feedback**

• What is the best feature of this device?
• What is the worst feature of this device?
• What features would you add to the device?

**Accessibility**

• Did this device meet your accessibility needs?
  o Have participant clarify what their accessibility needs are
• If commercially available, how much would you pay for this device or a product similar to it?
• What level of braille knowledge do you think you would need to be able to use this device?
• The target user group are children who are blind or visually impaired, but also may have poor motor skills, poor tactile discrimination skills, or who have additional disabilities. Do you think the device would be usable for that population?

**Durability**

• Today, did you encounter any errors where the device didn’t work as you thought it should have?
• If the electronic functions failed, would you find it useful to use the device without the audio feedback?
• Do you think that this device would be durable enough to withstand your typical use?
Can you describe your typical use?

**Portability**

- How long would you like the batteries to last?
- For how long do you think you would use this device in one sitting?
- What do you think about the weight of the device?
  - Is it too heavy, too light, just right?
- What do you think about the size of the device?
  - If you would change the size of the device, what how big do you think you would make it?

**Easily and Independently Operable**

- On a scale from 1 to 10, how easy was the device to use?
  - Were any of the buttons difficult to use?
- Would you be able to use it independently?
- What device features would you change to make it easier to use?

**Auditory Feedback**

- Could you understand what the device was saying to you?
- Do you think the feedback was ______ enough?
  - Immediate
  - Specific
  - Positive
  - Encouraging
• Do you think the feedback guided you to determine the answer independently?

• How would you improve the feedback the device provides?

**Tactile Feedback**

• What did you think about the tactile feedback? (braille dots, braille printed on device)
  
  o What do you think about the size of the braille dots specifically?
    
    ▪ Too big, too small?
    
    ▪ Is it easy enough to discriminate?

  o How would you improve it?

**Safety**

• Do you think this device would be safe?
  
  o Would it be a choking hazard?

• Are there any safety considerations that you think need to be incorporated in this device?

**Additional Comments**

• Is there anything else you want to tell me about your experience with the device?

• Do you have any other suggestions for improving the device that you haven’t had the chance to say already?
Interview prompts for participants aged 21 and under

Remind participant that they do not need to answer a question if they do not want to. To decline to answer, they should say “pass”, or “skip”.

Motivational/Engaging

- Did you have fun trying BrailleBunny? / do you think kids would have fun trying BrailleBunny?
- If you could choose, how long do you think you would want to play with it? / they would

General Feedback

- What did you like about it?
- What didn’t you like about it?
- What would you add to it?

Transferable Learning to Reading and Writing and Enabling Co-Learning

- Do you think BrailleBunny could help you learn braille?

Easily and Independently Operable

- Do you think this was easy to use or hard to use?

Durability

- Did you encounter any errors where it didn’t work as you thought maybe it should have?
Accessibility

- Ask about buttons if they used them
  - Were any of the buttons on the side hard to use?

Auditory Feedback

- Could you understand what the device was saying to you?
- Was there anything else you thought it should say to help someone learn?

Tactile Feedback

- Were the braille dot buttons easy or hard to feel?
- Do you think they should be the same size, bigger or smaller?

Additional Comments

- Is there anything else you think we should change?
Appendix D
Ethics Clearance

May 09, 2019

Dr. Claire Davies
Assistant Professor
Department of Mechanical and Materials Engineering
Queen’s University
Kingston, ON, K7L 3N6

Dear Dr. Davies:

GREB TRAQ #: 6020836
Title: "CMCH-043.17 Matuto, Mabusa, Magare: Learning to read in braille through play"

The General Research Ethics Board (GREB) has reviewed and cleared your request for renewal of ethics clearance for the above-named study. This renewal is valid for one year from May 30, 2019. Prior to the next renewal date, you will be sent a reminder memo and the link to ROMSO to renew for another year. You are reminded of your obligation to submit an Annual Renewal/Closure 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/Completed Form in ROMSO 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. 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. To submit an adverse event report, access the application at http://www.queensu.ca/traq/signon.html, click on "Events," under "Create New Event" click on "General Research Ethics Board Adverse Event Form."

You are also reminded, that all changes that might affect human participants must be cleared by the GREB. For example, you must report changes in study procedures or implementation of new aspects into the study procedures. Your request for protocol changes will be forwarded to the appropriate GREB reviewers and/or the GREB Chair. To submit an amendment form, access the application 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."

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

Yours sincerely,

Chair, General Research Ethics Board (GREB)
Professor Dean A. Tripp, PhD
Departments of Psychology, Anesthesiology & Urology Queen’s University

c.: Elizabeth Hoskin, Co-investigator

Figure 42: Ethics clearance

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