# ASSETS: G: BrailleBlocks: Braille Toys for Cross-Ability Collaboration

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## ABSTRACT
Braille literacy rates are dropping among blind students in the United States, prompting what experts have described as the "Braille Literacy Crisis" [15]. However, for these students, Braille remains crucial for literacy and employment [19]. BrailleBlocks is a system to motivate blind or visually impaired children to learn Braille with a sighted parent. BrailleBlocks includes a set of wooden blocks, representing Braille cells, and an interface with games for parents. We conducted user studies with five sighted parents and six blind visually impaired children. Children preferred games with sound effects, specifically Hangman and the Animal Name Game. Parents commended the system as a spelling tool and found the screen display of Braille letters to be a helpful reference. Children created new ways to use the system beyond the games we provided, such as for storytelling and by stacking blocks into structures. We identified concrete ways to improve the system, including generating progress reports for parents and developing a portable version.

## Author Keywords
Accessibility, blind, visually impaired, education, braille, children, collaboration

## ACM Classification Keywords
K.3.1 [**Computer and Education**]: Computer Uses in Education – *Collaborative Learning.*

## 1. PROBLEM AND MOTIVATION
Braille literacy is on the decline among blind students in America. In 1960, over 50% of blind students in the United States were Braille literate. In 2017, less than 8% of blind students in the United States surveyed by the American Printing House for the Blind were identified as Braille readers. Education experts have expressed alarm at this decline, calling the shift the "Braille literacy crisis" [15].

Accessible technology, such as audiobooks and text-to-speech software, may be a catalyst for this crisis. While assistive tools make new media and educational resources more accessible, they may lessen motivation for learning Braille. Braille is also difficult and time consuming to learn, which could push students to find alternative reading methods. Despite the new and emerging methods of reading with assistive software, Braille is still the literacy standard for visually impaired people. Learning Braille also increases chances of employment and develops important literacy skills, such as spelling and reading comprehension [19].

The benefits of Braille, coupled with the declining desire to learn it, motivate us to encourage visually impaired people to learn Braille. To explore the possibilities for more engaging and inclusive Braille tools, we introduce BrailleBlocks. BrailleBlocks is a collaborative learning environment consisting of a tangible block set and a collection of associated, cooperative games on a graphical user interface [5]. BrailleBlocks supports interactive games that can be controlled by physically assembling Braille letters and words. The system provides audio and multimedia feedback about words as they are constructed.

## 2. BACKGROUND AND RELATED WORK
This section provides an overview of tangibles in education, current tools for Braille education, and how BrailleBlocks builds on the foundation of this related work.

### 2.1 Interactive Tangible Blocks in Education
Outside of learning Braille, tangible blocks have often been used in education, both for blind and sighted learners. Incorporating tangible activities into education can increase engagement for learners [17, 20] and stems from Piaget's theory of constructivism and the concept of "hands-on" learning [3].

Introductory programming tools have often used the notion of assembling blocks to create programs [18]. StoryBlocks uses tangible blocks to enable children to create audio stories and introduce early coding concepts [9]. Microsoft's Code Jumper, previously known as Project Torino, uses a set of connectible pods to enable children to construct programs that represent music and other audio [12].

Each of these systems combines tactile interaction with audio output to create an engaging and accessible learning experience. BrailleBlocks builds upon the success of these systems and applies the approach to learning Braille.

### 2.2 Braille Education Tools and Toys
Commercially available Braille toys are limited in selection compared to the toys available for sighted children. Many of the toys that are available take a tangible, block-based approach, such as PlanToys *Braille Alphabet A-Z Set* [16]. This set includes thin rounded square blocks with indented alphabets along with the alphabet's Grade 1 Braille representation on the bottom of the block.

BrailleBricks, a proof-of-concept prototype, comprises a set of Lego blocks with a slightly enlarged Braille representation on their surface [4, 10]. Each block represents a single letter.

Children can play with the blocks by sticking them onto an included Lego mat to create words and sentences. Tack-Tiles, another block-based educational toy, uses small Lego-sized blocks with an enlarged Braille representation embossed onto the surface [22].

Educators have also created Do-It-Yourself (DIY) tools and toys as alternatives to commercial products, such as baking edible Braille pizzas and using baking tins to represent enlarged Braille cells [7,8]. These projects demonstrate that there are a variety of ways to incorporate Braille into children's play, but that the burden of providing these tools currently rests on teachers and parents.

In contrast to these low-tech solutions, BrailleBlocks introduces tangible computing techniques to enable new forms of interaction between visually impaired children and their collaborators.

## 2.3 Braille Games and Apps

Researchers have explored how to support Braille learning through mobile games and applications, and have developed suites of games to build literacy skills. BraillePlay [11] is a set of smartphone games that reinforce Braille concepts for visually impaired learners through flashcards and word games. BraillePlay vibrates if the user touches an area of the screen that represents a Braille dot. GBraille [1] is a mobile game that encourages players to practice Braille through Hangman and a keyboard-controlled Asteroids game. mBraille [13] is an application that supports children in writing the Braille alphabet in multiple languages.

BrailleBlocks incentivizes children to practice Braille via similar word games, but incorporates tangible blocks to support more embodied learning [14]. BrailleBlocks also focuses on collaborative learning by providing a separate interface with visual aids for sighted parents.

# 3. UNIQUENESS OF THE APPROACH

BrailleBlocks builds on related work by integrating tangibles with interactive games to create an engaging learning experience between visually impaired students and sighted parents. This is also among early work in applying the tangible computing approach to Braille education.

BrailleBlocks has three components: (1) a tangible block and peg set, (2) a computer interface for a sighted collaborator (in our studies this was a parent), and (3) an overhead webcam for tracking blocks and providing feedback (Figure 1). To keep the system affordable, BrailleBlocks are made with low cost materials (wood and cardboard) and the interface can be used on systems that people may already have (laptops, tablets, etc.). The BrailleBlocks interface translates Braille into English text so that parents who don't know Braille can participate in the activities and learn Braille with their child. Our learning goals with this version of BrailleBlocks are to engage children in constructing letters and words, and for parents and children to collaboratively play word games using Braille.

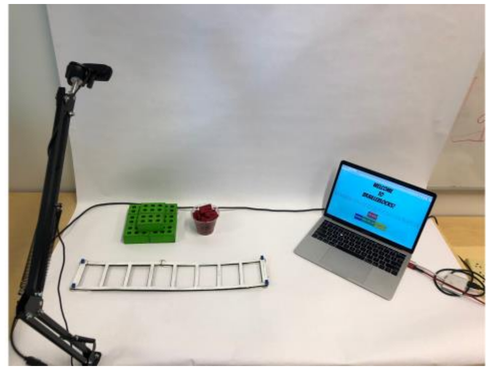

**Figure 1. The physical components of BrailleBlocks: An overhead webcam, blocks and pegs to create Braille letters, a white cardboard frame to place the blocks in, and a laptop with the BrailleBlocks application.**

## 3.1 Formative Design and Prototyping

We developed the BrailleBlocks system through iterative prototyping and testing with Braille educators. We first constructed a non-interactive, cardboard prototype of the blocks and play area frame. We demonstrated this prototype to a K-5 teacher and a Braille specialist who offered feedback about the size of the blocks, the choice of games, and the appropriate age levels for our prototype. Based on their feedback, we focused our initial development on supporting early-stage Braille learning activities such as tactile recognition and spelling.

## 3.2 Tangible Block Set

BrailleBlocks are a set of bright green wooden blocks, with six holes in each block, and a set of red wooden pegs representing the Braille dots. We chose red and green as high contrast colors for children with low vision, and to support easy prototyping of the computer vision system.

**Figure 2. A user is placing pegs into the blocks to create Braille letters, and placing blocks in the cardboard frame to create words.**

Each block represents a single Braille cell. A child constructs a Braille letter by placing red pegs in the blocks, corresponding to the raised dots of the Braille letter (Figure 2). For example, to create the letter "A", a user would place one peg in the top, left-most hole of the block. To make it easier for children to form words from individual blocks, BrailleBlocks includes a tactile frame for holding the letters as they are assembled.

## 3.4 Companion Application

To support collaborative play between visually impaired children and their sighted parents, or other collaborators, BrailleBlocks includes a companion application that shows games and visual representations of Braille. The application is presented on a laptop that is connected to an overhead webcam. The application displays instructions and prompts, encouraging parents to take part in the activities (Figure 4). As the child assembles blocks, the application recognizes the Braille characters that the child has written and shows the corresponding text on screen.

## 3.5 Games

BrailleBlocks includes the following games: Animal Name Game, Hangman, and Word Scramble.

In the Animal Name Game, children attempt to guess an animal based on an audio clue of the sound that the animal makes (Figure 3). The game is intended to encourage children to use the blocks to practice spelling in Braille.


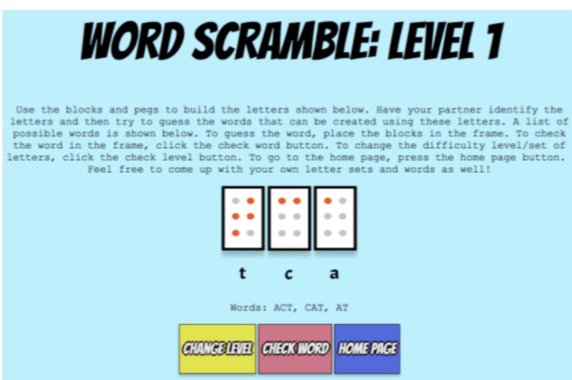


**Figure 3 (top). The Animal Name Game selection page. Figure 4 (bottom). Level 1 of the Word Scramble game.**

BrailleBlocks also includes the traditional word-guessing game Hangman. Hangman can support practicing spelling skills and can promote critical thinking through guessing. The Word Scramble game emphasizes Braille reading skills (Figure 4). In this game, the parent is presented with a scrambled word and creates that word using blocks. The parent presents this word to the child, who feels the blocks and attempts to decipher a word. The child then rearranges the blocks to unscramble the word.

All games have a "Check Word" button, as seen on the Word Scramble interface in Figure 4. Parents can press this button to get an English text translation of the Braille their child has built (see Block Detection and Translation). They can use this feature to check if their child's solution is correct and then provide them with appropriate feedback

## 3.6 Block Detection and Translation

BrailleBlocks uses computer vision to track the blocks and identify the Braille letters that they represent. While we designed the games to include the parent as an active participant, automatically recognizing blocks enables parents to participate even if they cannot read Braille.

The computer vision components are written in Python and use the OpenCV library. When the parent presses the "Check Word" button, the system captures a photograph of the work area using the overhead webcam (Figure 5). The system locates the four corners of the frame, marked by blue Lego blocks, and crops the image (Figure 6). We apply a color mask to extract the positions of the red pegs and use the location of the pegs to convert the image to an equivalent text representation (Figure 7).

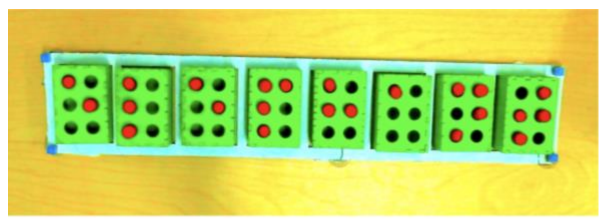

**Figure 5 (top). The image taken by the overhead webcam after the parent hits the "Check Word" button. Figure 6 (middle). The clipped image after the blue blocks in the corners are detected. Figure 7 (bottom). The image after the color mask is applied to extract red from the original image. The green circles are where the pegs in the original image were.**

## 3.7 Study

We conducted a usability study to observe how sighted parents and blind children collaborated and learned with BrailleBlocks. Our study included five participant families, with six child participants total. Four of the families included one child, while one included two children. Among the participants, all adults were sighted and all children were visually impaired. For two of the families, sighted siblings were present.

## 3.8 Analysis

We transcribed the video recordings from each session. We identified themes using open coding techniques [21]. Our themes included 1) verbal instructions, 2) physical guidance, 3) how the games were played, 4) subjective comments about learning, engagement, and fun, and 5) creative play and storytelling.

# 4. RESULTS AND CONTRIBUTIONS

## 4.1 Interactions Between Parents and Children

One goal in developing BrailleBlocks was to involve parents in their child's Braille education. During the study, we observed that parents typically took the lead in the activity, provided their child with instructions and prompts, and gave them feedback about their Braille characters.

While each game included its own set of instructions, parents often adapted gameplay to best suit their child's interests and familiarity with Braille. Families often used Hangman and the Word Scramble as guessing games to work on deductive reasoning in addition to spelling. During Hangman, one parent gave hints such as "this word is the name of a dog that we know." Their child then proceeded to narrow down the options by asking clarifying questions like "Is it close to a Dachshund?" Once the child figured out the word, she began to write the dog's name using the blocks and pegs rather than guessing verbally. For the Word Scramble, parents spontaneously provided clues to help their children guess the word. For example, one parent would provide hints like "where are you __, finish the sentence" for the word "at", or "you drink hot ___" for the word "tea".

**Figure 8. A participant family using BrailleBlocks. The parent is using a hand-over-hand guidance technique with their child to orient them with the blocks.**

Another instructional strategy that emerged was hand-over-hand guidance (Figure 8). Parents would place their hand over their child's hand as a strategy to help the child feel letters, orienting them to the holes on the blocks and spaces between the blocks. The level of physical guidance varied across families. For a child participant in the beginning stages of learning Braille, their parent placed their hand over the child's hand for all the activities. For children who were more experienced with Braille, parents offered physical guidance when the child explicitly asked, but still used a similar hand-over-hand strategy.

## 4.2 Physical Form

We chose to make enlarged Braille blocks for ease of technical implementation and to support early Braille learners, who often work with enlarged representations. Enlarged Braille is often used for early Braille learners to help with tactile perception and develop spatial awareness skills. Overall, parents were positive about the use of enlarged blocks, and likened BrailleBlocks to other Braille education tools such as the Swing Cell, a commonly used Braille learning tool [6].

## 4.3 Learning through Games

In designing the initial set of games and applications, we drew from prior work in creating Braille-based educational games. We also considered how each game could support collaboration between children and their parents. A few children found some of the games too difficult, while others found some of the games too simple, often depending on the child's current knowledge of Braille and their age. We were pleasantly surprised to see that families were often able to adapt the activities to an appropriate difficulty level.

While our study sessions were too brief to assess the effectiveness of BrailleBlocks as a long-term learning tool, participants seemed to genuinely enjoy playing the games. Parents noted that their children spent a significant amount of time engaged in the study activity, and could focus and think about Braille for a reasonably long period of time (approximately an hour). We are optimistic that BrailleBlocks can serve as a complement to other Braille learning tools and activities. After testing BrailleBlocks, participants also suggested integrating BrailleBlocks into other learning activities such as spelling and critical thinking.

## 4.4 Engagement and Creativity

Both visually impaired children and their sighted siblings found BrailleBlocks to be interesting, often reaching out and starting to play with the blocks before the study began. Some participants built elaborate structures using the blocks, pegs, frame, and webcam and told imaginative stories about what they built (Figure 9). In addition to developing literacy skills, BrailleBlocks could encourage creativity and further motivate children to use the system. By combining an approachable form factor with interactive activities, we hope that BrailleBlocks can become a useful and engaging tool for young Braille learners and their families.

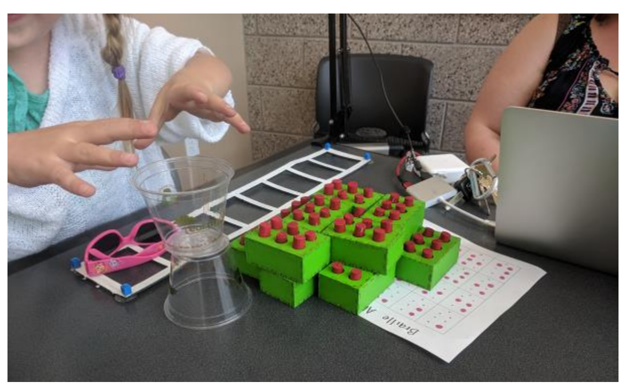

**Figure 9. A participant family using BrailleBlocks for creative play. The child participant stacked the blocks built a story around the blocks, pegs, frame, and webcam.**

Families engaged with the audio in BrailleBlocks in several ways, laughing at humorous sound effects and contributing their own sounds to the games. For example, during the Animal Name Game, parents sometimes augmented the system's animal sounds with their own sounds and occasional audio clues. One parent made all the animal noises herself, rather than using the system. When testing the games, it quickly became clear that augmenting tangible interaction with audio facilitated greater engagement.

## 5. CONCLUSION

Braille is crucial for teaching blind or visually impaired children the basics of literacy, but its adoption may be hindered by the quantity and quality of currently available educational resources. We developed BrailleBlocks to explore the possibilities of creating engaging and collaborative Braille-based toys and activities. During this study, we evaluated BrailleBlocks with families and identified key feedback for building Braille literacy tools for visually impaired children and sighted companions. Our prototype and its evaluation show that combining tangible blocks and interactive audio games can bring children and parents together to practice and play with Braille. Additionally, documenting the creation and iterative testing of these systems could lead to new guidelines for accessible, affordable educational tools for blind children.

## 6. REFERENCES


[1] Maria C. C. Araújo, Antônio R. S. Silva, Ticianne G. R. Darin, Everardo L. de Castro, Rossana M. C. Andrade, Ernesto T. de Lima, Jaime Sánchez, José Aires de C. Filho, and Windson Viana. 2016. Design and Usability of a Braille-based Mobile Audiogame Environment. In *Proceedings of SAC 2016*. (p. 232238.)

[2] Cynthia L. Bennett, Erin Brady, and Stacy M. Branham. 2018. Interdependence as a Frame for Assistive Technology Research and Design. In *Proceedings of ASSETS 2018*. (p. 161-173.)

[3] Barbara Blake and Tambra Pope. 2008. Developmental psychology: Incorporating Piaget's and Vygotsky's theories in classrooms. In *Journal of Cross-Disciplinary Perspectives in Education* Vol. 1, No. 1 (p.59 - 67.)

[4] Dorwina Nowill Foundation for the Blind. 2016. Meet Braille Bricks #BrailleBricksForAll. Video. Retrieved September 13, 2019 from www.youtube.com/watch?v=qV79fzEVr_s.

[5] Vinitha Gadiraju. 2019. BrailleBlocks: Braille Toys for Cross-Ability Collaboration. In *Proceedings of ASSETS 2019*. (p.688-690).

[6] Richard Goldberg, Randal Cole, Arielle Drummond, and Diane Brauner. 2005. Apparatus and method for Braille instruction, U.S. Patent Application 10/689,796, Filed April 21, 2005.

[7] Amy Hurst and Jasmine Tobias. 2011. Empowering Individuals with Do-It-Yourself Assistive Technology. In *Proceedings of ASSETS 2011*. (p.1118).

[8] Judith Hurst. 1997. Talk from the VI teachers' lounge.

[9] Varsha Koushik, Darren Guinness, and Shaun K. Kane. 2019. StoryBlocks: A Tangible Programming Game to Create Accessible Audio Stories. In *Proceedings of CHI 2019*, Paper 492, 12 pages.

[10] The LEGO Group. 2019. Braille Bricks. www.legobraillebricks.com/.

[11] Lauren R. Milne, Cynthia L. Bennett, Richard E. Ladner, and Shiri Azenkot. 2014. BraillePlay: Educational Smartphone Games for Blind Children. In *Proceedings of ASSETS 2014*. (p.137-144.)

[12] Cecily Morrison, Nicolas Villar, Anja Thieme, Zahra Ashktorab, Eloise Taysom, Oscar Salandin, Daniel Cletheroe, Greg Saul, Alan F. Blackwell, Darren Edge, Martin Grayson, and Haiyan Zhang. 2018. Torino: A Tangible Programming Language Inclusive of Children with Visual Disabilities. *Human-Computer Interaction*. (p.1-49).

[13] Lutfun Nahar, Azizah Jaafar, Eistiak Ahamed and A. B. M. A. Kaish. 2015. Design of a Braille Learning Application for Visually Impaired Students in Bangladesh. *Assistive Technology*, 27:3, (p.172182.)

[14] Manuela Macedonia. 2019. Embodied Learning: Why at School the Mind Needs the Body. *Frontiers in psychology* vol. 10 2098.

[15] National Federation of the Blind. 2009. The Braille literacy crisis in America.

[16] PlanToys. Braille Alphabet A-Z. www.global.plantoys.com/shop/learningeducation/braille-alphabet-a-z.html.w

[17] Sara Price, Yvonne Rogers, Michael Scaife, Danae Stanton, and Helen Neale. 2003. Using 'Tangibles' to Promote Novel Forms of Playful Learning. *Interacting with Computers* 15, no. 2. (p.169-185.)

[18] Mitchel Resnick, John Maloney, Andrés Monroy-Hernández, Natalie Rusk, Evelyn Eastmond, Karen Brennen, Amon Millner, Eric Rosenbaum, Jay Silver, Brian Silverman, and Yasmin Kafai. 2009. Scratch: Programming for All. *Communications of the ACM*. (p.60-67)

[19] Ruby Ryles. 1996. The impact of braille reading skills on employment, income, education, and reading habits. *Journal of visual impairment and blindness* 90. (p.219-226).

[20] Abigale Stangl, Jeeeun Kim, and Tom Yeh. 2014. Technology to Support Emergent Literacy Skills in Young Children with Visual Impairments. In *Proceedings IDC 2014*. (p. 321-324).

[21] Anselm L. Strauss. 1987. Qualitative analysis for social scientists. *Cambridge University Press*.

[22] Tack-Tiles. 1999. www.tack-tiles.com/