A Tangible Math Game for Visually Impaired Children

Ana Cristina Pires[1,2], Sebastian Marichal[3], Fernando Gonzalez-Perilli[2], Ewelina Bakala[2], Bruno Fleischer[2], Gustavo Sansone[2], Tiago Guerreiro[1]
[1]LASIGE, Faculdade de Ciências, Universidade de Lisboa, Portugal
[2]Universidad de la Republica, Montevideo, Uruguay
[3]Universitat Pompeu Fabra, Barcelona, Spain
acdpires@fc.ul.pt, sebastian.marichal@upf.edu, fernando.gonzalez@fic.edu.uy, ebakala@fing.edu.uy, fleischer.bruno@gmail.com, gsansone@fadu.edu.uy, tjvg@di.fc.ul.pt

ABSTRACT
We present iCETA, an inclusive interactive system for math learning, that enables children to autonomously engage and solve additive composition tasks. It was designed through a set of participatory sessions with visually impaired children and their educators, and supports math learning through the combination of tangible interaction with haptic and auditory feedback. Tangible blocks representing numbers 1 to 5 were used to add or subtract and correctly solve the task embedded in a computerized game. Our approach aims to provide better scaffolding for understanding the abstract concept of a number by working with different representations of that number, as size of a block, Braille, color and audio feedback.

ACM Classification Keywords
H.1 Information Systems: Models and principles: User/ Machine Systems: Software psychology

Author Keywords
Tangibles; Multimodal; Visually impaired; Cognitive training.

INTRODUCTION
One common way to introduce mathematical concepts is the use of manipulatives as external representations, as an additional resource of information to focus on the underlying concepts. Embodied, constructivist and constructionism theories shed light on the importance to manipulate and operate concrete material, using the body to deepen abstract conceptualizations [11, 8, 7]. The use of external representations as manipulatives decreases cognitive load, allowing the children to focus on the understanding of the abstract concept, reinforces its understanding, and increases the effective capacity of working memory by the stimulation of several sensory modalities simultaneously [1]. Also, distributing pieces of mental operations into actions on physical or digital objects may simplify and help gain deeper knowledge [1].

ASSETS'19, October 24–28, 2019, Pittsburgh, PA, USA

ACM ISBN 978-1-4503-6676-2/19/10.
DOI: https://doi.org/10.1145/3308561.3354596

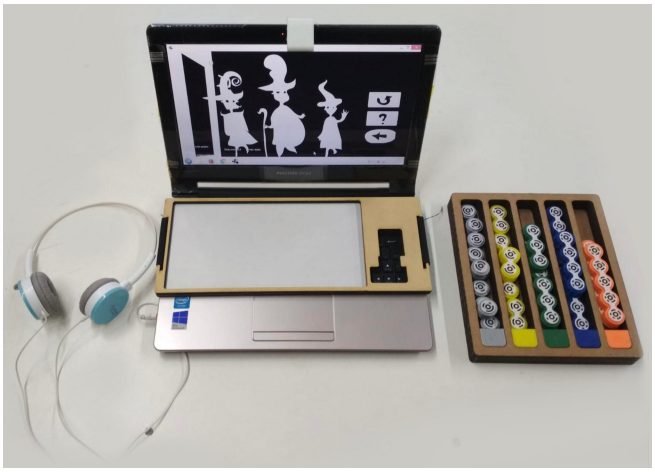

Figure 1. iCETA: headphones, computer, mirror in the camera, tangible blocks and working area on top of the keyboard.

There has been limited research dedicated to help visually impaired (VI) users to incorporate mathematical concepts taking advantage of tangible manipulatives and multimodal systems. Jafri et al. [4] propose several educational activities based on the distribution of three-dimensional geometric figures that are analyzed by the computer that provides immediate feedback through sound codes. Also of interest, Thieme et al. [10] proposed a physical programming system for teaching programming based on interconnected multimodal beads to create digital music or stories, and Koushik et al. [5] created tangible objects that represent a component of an interactive story to teach programming.

Building on these ideas, and on an identified need of tools to promote math learning, we set out to develop an auditory computerized game to be played with tangible blocks. These efforts build on our previous work in developing a visual multimodal tangible system, CETA.[6]. In that system, an audio-visual game was displayed in the tablet and children had to solve the additive composition tasks by manipulating the tangible blocks. We observed that the use of tangible blocks had a positive impact in their mathematical ability after two weeks of training [9]. Hence, the adaptation of CETA could be very suitable for fostering mathematical abilities of

VI children while playing with tangible objects that represent numbers, if adequate adaptations were made. In this paper, we present iCETA and detail the main design changes performed to make the approach to be inclusive.

DESIGN PROCESS

The iterate design of iCETA involved the participation of 11 VI children (6 legally blind) aged between 5 and 10 years old from special education schools in Montevideo (Uruguay), as well as other relevant stakeholders (2 school directors, 3 elementary teachers, 1 music teacher and 1 IT teacher). In 16 participatory design sessions, children and stakeholders helped to define and create proper training tasks, interface elements and interaction modalities, exploiting the possibility of the interaction with objects, multisensory experiences, narrative and the potential of digital tools. Our design process began with semi-structured interviews to stakeholders in order to identify the objectives and needs, materials and tasks for math learning in the school. Findings informed the design of early prototypes that were iteratively discussed and improved. Each session with prototypes was the input for a new iteration in the design of the interface, blocks, working area, music and sound, and narrative of the game, following an iterative process of development-feedback-development.

ICETA

Inclusive CETA (iCETA) is the adaptation of CETA, a mixed-reality, open source, low-cost and portable system created to be used in school settings [6]. iCETA is a system that consists of a set of blocks detected by the camera (see Figure 1) and the camera is redirected towards the working area using a mirror. The blocks are recognized through TopCode markers [3]) and the computer provides auditory feedback.

Blocks

We were inspired by the cuisenaire rods [2] so largely used with young children in schools. Blocks represent values from 1 to 5. They vary in size (e.g., "2" is twice the size of "1"), texture, Braille and colors. Blocks have tactile division marks to split the units, and each unit has the shape of a circle. The TopCode markers were also used inside each circle to reinforce the recognition of each unit. In our final design sessions, children easily identified that the blocks were sums of units.

Working area and storage box

Besides a working area to play with the blocks, we created a box where each of the blocks can be organized by its number (see Figure 2). This allowed the children to have the blocks organized ready to be used, which is likely to reduce cognitive load and enable more efficient manipulation of the blocks.

Learning TUI Objectives

We identified two levels of learning objectives: a) multimodal reinforcement - auditory and haptic feedback, and b) math training tasks of additive composition and decomposition of numbers from 1 to 10. All the tasks were designed to first display a specific sound that repeats *n* times and the children have to put the blocks that together compose such number.

Figure 2. Blocks representing values from 1 to 5, similar to cuisenaire rods. Blocks varies in size, texture, braille and colors.

Music and sounds

Three sound parameters were tested: tempo (temporal sequence between 1 and 2, for instance), pitch and timbre. Tempo is personalized because children exhibit differences to distinguish between the sound of the end of the block and the start of the sound of a new block. We created different timbres and pitches related to the action required by the character of the game (steps, knocking door, stir the magic potion). Binaural sound was used to differentiate the sound of the recognition of the blocks from the one of the number required by the game.

Narrative and gamification

We created a new game, "Logarin", named after the main character: a young magician that does everything wrong and needs help to achieve the objective of becoming a great magician. To do that, children must help him by performing spells, or organizing a music band, etc. The creation of levels according to the narrative allowed children with high and low performance in mathematics to have fun and be challenged. We also took into account gamification elements as the main character, microworlds, obstacles and levels.

OUTLOOK

iCETA has been piloted in schools and was welcomed by both children and educators. It provides a playful and rich multi-sensorial environment for children with different visual abilities to learn math. One of our future goals is to expand the amount of math concepts to be conveyed by the game. We are also exploring the usage of intelligent objects with built-in electronics that can provide more diverse feedback (speech, sound, vibration and force), to support novel ways of interaction and learning. In addition, we intend to apply this approach to other learning domains as computational thinking.

ACKNOWLEDGMENTS

We thank children and educators. This project was funded by Agencia Nacional de Investigación e Innovación, Fundación Ceibal, and by Espacio Interdisciplinario, Uruguay, (FSED-2-2016-1-131112), and by FCT-Fundacao para a Ciencia e a Tecnologia, through project mIDR (AAC02/SAICT/-2017, project 30347, cofunded by COMPETE/FEDER/FNR), and LASIGE Research Unit, ref. UID/CEC/00408/2019.

REFERENCES

[1] Alissa N. Antle and Alyssa F. Wise. 2013. Getting Down to Details: Using Theories of Cognition and Learning to Inform Tangible User Interface Design. *Interacting with Computers* 25, 1 (01 2013), 1–20. DOI: http://dx.doi.org/10.1093/iwc/iws007

[2] Georges Cuisenaire. 1968. *Les nombres en couleurs*. Calozet.

[3] Michael Horn. 2012. TopCode: Tangible Object Placement Codes. *Retrieved from httpz/l users. eecsnorthwester. edit/mmhorn/topcodes* (2012).

[4] Rabia Jafri, Asmaa Mohammed Aljuhani, and Syed Abid Ali. 2015. A Tangible Interface-based Application for Teaching Tactual Shape Perception and Spatial Awareness Sub-Concepts to Visually Impaired Children. *Procedia Manufacturing* 3 (2015), 5562–5569. DOI:http://dx.doi.org/10.1016/j.promfg.2015.07.734

[5] Varsha Koushik, Darren Guinness, and Shaun K. Kane. 2019. StoryBlocks: A Tangible Programming Game To Create Accessible Audio Stories. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM, New York, NY, USA, Article 492, 12 pages. DOI: http://dx.doi.org/10.1145/3290605.3300722

[6] Sebastián Marichal, Andrea Rosales, Fernando Gonzalez Perilli, Ana Cristina Pires, Ewelina Bakala, Gustavo Sansone, and Josep Blat. 2017. CETA: Designing Mixed-reality Tangible Interaction to Enhance Mathematical Learning. *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI 17* (2017). DOI: http://dx.doi.org/10.1145/3098279.3098536

[7] Seymour Papert. 1980. *Mindstorms: Children, Computers, and Powerful Ideas*. Basic Books, Inc., New York, NY, USA.

[8] Jean Piaget. 1954. *The Construction of Reality in the Child*. Basic Books, New York.

[9] Ana Cristina Pires, Sebastián Marichal, Fernando Gonzalez Perilli, Ewelina Bakala, Bruno Fleischer, and Gustavo Sansone. in press. Building blocks of mathematical learning: digital and tangible manipulatives lead to different strategies in number composition. *Frontiers in Psychology* (in press).

[10] Anja Thieme, Cecily Morrison, Nicolas Villar, Martin Grayson, and Siân Lindley. 2017. Enabling Collaboration in Learning Computer Programing Inclusive of Children with Vision Impairments. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS '17)*. ACM, New York, NY, USA, 739–752. DOI: http://dx.doi.org/10.1145/3064663.3064689

[11] Lev S. Vygotsky. 1978. *Mind in society: The development of higher psychological processes*. Harvard University Press. (Original manuscripts [ca. 1930-1934]), Bloomington, IN, USA.