Annual Review of Cybertherapy and Telemedicine

Volume 3 Year 2005 ISSN: 1554-8716

Interactive Media in Training and Therapeutic Intervention

Editors:
Brenda K. Wiederhold, PhD, MBA, BCIA
Giuseppe Riva, PhD, MS, MA
Alex H. Bullinger, MD, MBA

Interactive Media Institute

Training Blind Children to Develop Mathematics Skills Through Audio

J. Sánchez, H. Flores

Department of Computer Science
University of Chile

Abstract: *A number of studies using computer applications have been designed to improve learning in children with visual disabilities. Some research studies use audio-based interactive interfaces to enhance learning and cognition in children with visual disabilities. The development of mathematics learning through virtual environments has not been studied in the literature. This work presents the design, development, and usability of two audio-based virtual environments: AudioMath and Theo & Seth, interactive virtual environments based on audio to develop mathematics learning of children with visual disabilities. AudioMath and Theo & Seth were developed by and for blind children. They participated in the design and usability tested the software during and after implementation. Our results evidenced that audio embedded into virtual environments can be a powerful interface to develop mathematics learning in blind children.*

INTRODUCTION

Virtual environments based on audio to foster learning and cognition has been increasingly developed for people with visual disabilities. Diverse studies have focused on the design of audio-based interfaces and evaluated their impact on learning and cognition.[1-8] Most of them are based on interactive software that cannot be fully adapted to their needs and requirements. Actually, some of them are fixed prototypes without enough flexibility and versatility.
A seminal study developed the first proof-of-concept application to navigate virtual environments through audio by blind children.[2] The study used audio to enhance spatial cognitive structures and found that spatial sound can be used to develop spatial navigation skills in a virtual environment. Some studies designed experiences with audio stimuli to simulate visual cues for blind learners,[4] finding that by using 3D audio interfaces blind people can help to localize a specific point in a 3D space. They performed with precision but slower than sighted people concluding that navigating virtual environments with only sound can be more precise to blind people in comparison to sighted persons.[4]

Another study describes the positive effect of 3D audio-based virtual environments.[9] A study in the same line of research used sensory virtual environments through force feedback joysticks simulating real places such as the school or work place. They probed the hypothesis that by providing appropriate spatial information through compensatory channels the performance of blind people can be improved.[10]

A research project in the same direction of[2] concluded that a traditional computer game, Space Invader, can be replicated with 3D sound. Researchers used force feedback joysticks as input interface by letting to play blind to sighted children to share the same experience.[3] An interesting study tested blind and sighted people with covered eyes across audio stimuli by tracing specific places through sound. The skill to hold in mind the specific localization without concurrent perceptual information or spatial update was evaluated.[11]

A trend in the literature is the absence of long-term usability studies on audio-based virtual environments. The literature sustains that spatial audio may have a reduced impact when it is not associated to specific cognitive tasks. There is also a demand for more rigorous and systematic usability studies by and for children with visual disabilities.

Learning the basics of mathematics has been a current issue in literacy literature. Most studies worldwide agree that children do not learn mathematics adequately in the early grades. This has a tremendous impact on further learning. In a world heavily based on science and technology children without understanding the basics of math limit their role in the society. Children with visual disabilities are not the exception. Actually in many respects this issue is radicalized in these children. When blindness is associated to social deprivation the issue of learning primary school mathematics is really a critical issue.[12-14] Thus one of the greatest challenges for children with visual disabilities has been the access and learning of mathematics information.[13] Early learning and practice may project a better construction of mathematics knowledge in visually impaired children.[12]

In this study we intended to foster learning and practice of mathematical concepts such as positional value, sequences, additive decomposition, addition, sum, subtraction, multiplication, and division. Theo & Seth was developed to enhance mathematics learning such as the concept of number and basic operations. AudioMath is used to assist learners with visual disabilities in learning concepts such as establishing correspondence and equivalency relationships, memory development, and differentiating tempo-spatial notions.

DESIGNS

Models. AudioMath has different components. *Specific content* models the representation problem to generate a grid with a pair of related tokens between them to be solved by the child. *Random card generator* is the editor that allows setting the level of complexity and contents from a gallery. *Computer model* is the representation of the real problem. It includes state system variables such as number of correct token pairs, time, and score as well as parametric variables such as level, content, and user name. *Projection* implies transforming input signals to changes perceived by blind users either audible or tactile. It bridges system and interfaces through bidirectional feedback from and toward the user actions. *Interface* includes input/output interaction devices such as audio, keyboard, mouse, force feedback joystick, and tablets.

The model is based on a matrix with rows and columns. There are four levels of complexity: Level 1 with four tokens (two rows and two columns), level 2 with six tokens (three rows and two columns), level 3 with twelve tokens (three rows and four columns), and level 4 with sixteen tokens (four rows and four columns). Colors are used for children with residual vision.[15] This model meets the minimum standards proposed by[16] for software design, and thus validating AudioMath as an appropriate virtual environment to be used for the learning of children with visual disabilities.

The model of Theo and Seth has two components that define the interaction of the learner with the application. *Virtual Environment*: The composing elements are: *Interface Controls* (in charge of controlling the volume), *help* (a system to orient the user to use the keystrokes in the application), and *activities* (containing the specific contents of mathematics). *Interface:* The elements of I/O interfaces are the keyboard and the audio system. The interface coordinates the user interaction with audio feedback. *Software and hardware Tools*. AudioMath and Theo & Seth were developed by using Macromedia Director 8.5. In particular, AudioMath was developed with a library of routines for external joystick control, Xtra RavJoystick. A joystick Side-Winder was used in conjunction with Force Feedback, mouse, keyboard, and Wacon tablets.

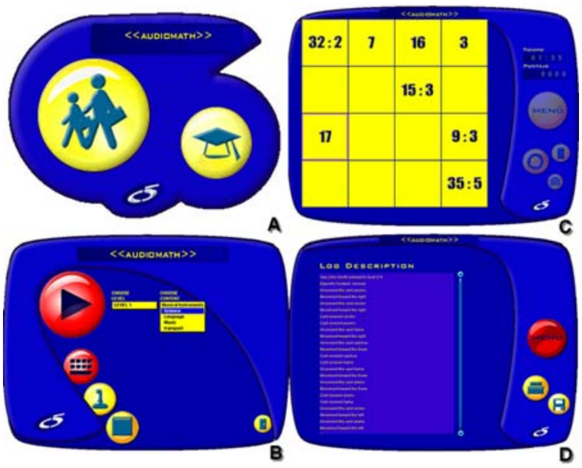

Figure 1. *Interfaces of AudioMath*

Interfaces. The principal interfaces of AudioMath for children with residual vision are displayed in Figure 1. For blind children interfaces are only audio-based. A is the identification screen with two modes: facilitator or student (two buttons). B considers the level of complexity (list box), content (list box), and input device (buttons). Content can be filled, upgraded, and edited by using different media. C is the main interface of AudioMath and includes options such as the position of the card grid, accumulated score, time elapsed (through speech), restart, register, and exit (through buttons). D includes a logging actual use register (buttons) describing each game and movements.

Theo & Seth is game-based and includes interesting mathematics learning activities with different levels of complexity. The metaphor used resembles a grange with two major virtual environments: the kitchen and the henhouse. Two personages interact with the learner and exert actions during the game. The kitchen covers two topics: 1. The henhouse is a virtual space were learners learn how to do sum and rest (figure a), 2. Introduce ordinal numbers and to

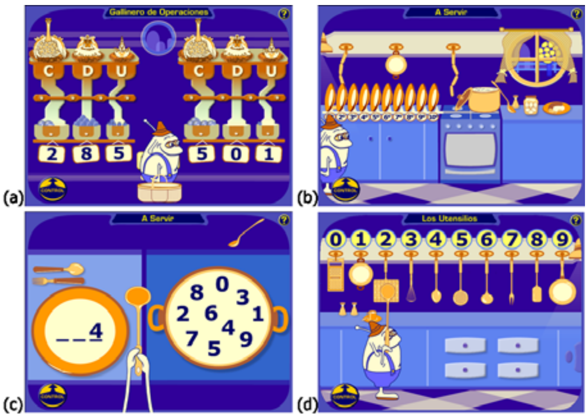

Figure 2. *Interfaces of Theo & Seth*

form soup of numbers (see figure b and c), and 3. Cardinality, including the number, the position in the numerical straight line and information about the antecessor and successor (figure d).

Interaction. AudioMath allows interaction with available interface elements such as buttons and text screens through keyboard. Each interaction triggers an audio feedback and a high visual contrast screen to be perceived by children with residual vision. The child has to move through a grid and open the corresponding token. Each cell has associated music tones that identify the position in the grid. Sound is listened when moving through cells. When open a token the associated element is visible by triggering an audio feedback. For example, if the image is a car, a real traffic car sound is triggered. When open a correct token pair a feedback is set. Finally, when all pairs are made the time used, the final score, and feedback are given.

AudioMath can be interacted through keyboard, joystick, and tablets. A few keystrokes are used with the keyboard. These devices have been used in different applications developed by the research group after testing with children with visual disabilities. The Microsoft SideWinder joysticks in conjunction with Xtra RavJoystick for Macromedia Director allow grading the user position in the grid and give direct feedback with different forces. Counter forces to the movement are generated per each token position change as well as vibratory forces indicate to be near to the grid edge: up, down, left, and right. Force Feedback Joysticks allow direct interaction with diverse degrees of freedom. A plastic graphic grid is posed on the tablet defining the position of each token. A pen is used to point and select interface elements.

During interaction with Theo & Seth children were exposed to cognitive tasks. They had to solve diverse concrete tasks that complement and enrich the experience with the virtual environment. Tasks involved exercises by using simple concrete materials used in everyday life. The way children interact with the software is through keyboard and sound. All the interaction is thought in such a way that children can navigate without assistance. To support this at the very beginning there is a tutorial to learn how to use the keyboard by orienting them about the localization of keystrokes necessary to navigate the virtual world. Once embedded in the environment children can navigate freely and autonomously by interacting with different interfaces.

AudioMath and Theo & Seth emphasize learning concepts such as establishing correspondence and equivalency relationships, memory development, and differentiating tempo-spatial notions. AudioMath were implemented by integrating mathematics content based on the current school curriculum. We embedded the software with mathematical concepts such as positional value, sequences, additive decomposition, multiplication, division, subtraction. We wanted to observe how audio-based virtual environments can foster the construction of mathematics learning in the mind of children with visual disabilities.

METHODOLOGY

Participants. The study with AudioMath was developed with ten children ages 8 to 15 who attend a school for blind children in Santiago, Chile. The sample was conformed of 5 girls and 5 boys. Most of them have also added deficits such as diverse intellectual development: normal, slow normal, border line, below to normal, and with mental deficit. Four special education teachers also participated. All learners met the following prerequisites: to be legally blind, to know the natural numbers, to express sequences orally, to order numbers, to decompose numbers through audio means, to mentally estimate results of additions and subtractions, to mentally determine products and coefficients, to mentally decompose numbers in additions, to manipulate multiplication tables efficiently, and to have notions of fractions.

Theo & Seth was usability tested with nine 7 to 8 years old learners with visual disabilities, four totally blind and five with residual vision. All of them are legally blind. Testing was applied in a school for blind children in Chile. We observed learners responses to both the use of only audio-based virtual environments and the interaction with virtual environments and associated cognitive tasks. Subjects were pre and post tested on mathematics learning.

Evaluation Instruments. Two measurement tests were used to evaluate the impact of AudioMath on learning and practice of mathematical concepts such as positional value, sequences, additive decomposition, multiplication, and division: evaluation of mathematics knowledge test[17] and a usability evaluation test for end-users. The evaluation of mathematics knowledge test measures: The capacity to understand numbers (oral and written), skills necessary to make oral and written calculations, skills to count numeric series and graphic elements, and skills for mathematics reasoning.

Two measurement tests were used to evaluate the impact of Theo & Seth: 1. Precalculus Test (by Neva Milicic and Sandra Schmidt) that evaluates the development of mathematics reasoning in students in early primary school; 2. Mathematics Knowledge Test (Benton and Luria), that evaluates the mathematics knowledge of first grade students. The Mathematics Knowledge Test was adapted to the specific needs of learners with visual disability.

Figure 3-4. *Children solving cognitive tasks with AudioMath and Theo & Seth*

Procedure. Children were tested in the school from July to November 2003, twice a week, and two one hour sessions per week. They followed the steps of pre-testing (evaluation of mathematics knowledge test), interacting with applications, solving cognitive tasks (see Figure 2 and 3), and post-testing (evaluation of mathematics knowledge test). Interacting with AudioMath and solving cognitive tasks were the main steps of the study. During these steps children were observed and assisted by four special education teachers filling check lists and registering observed behaviors. They also applied a usability evaluation test for end-users developed by the authors.

COGNITIVE IMPACT

During the interactive sessions we realized that mathematical content used was appropriate to the educational level of the sample. We analyzed the results case by case because the sample was not homogeneous in key variables

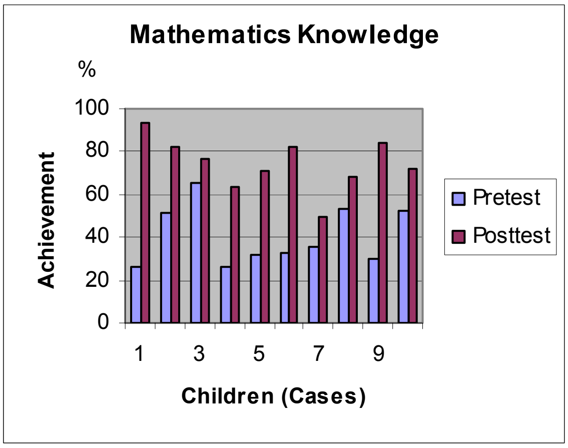

Figure 5. *Pretest-Posttest gains in mathematics knowledge*

such as cognitive deficits and different degrees of blindness.

Children performed increasingly well in the mathematics knowledge test. An overall view of initial results shows pretest – posttest gains in mathematics knowledge (see Figure 5), thus indicating that interaction with AudioMath associated with cognitive tasks can improve mathematics learning in these children.

In mathematics learning the results were promising. Most evaluated mathematics content was well attained by learners with visual disabilities. The highest gains were in oral calculation (75%) and countdown of numeric series (100%). We believe that these results were also partially due to a better attitude of the children toward work and mathematics knowledge construction such as multiplication tables and use of mathematics operations. They impacted positively on learners by increasing their certainty.

In Theo & Seth the subjects were pre and post tested on mathematics learning. Preliminary results concerning the pre calculus test indicates that children evidence positive changes in mathematics knowledge. Interesting results were obtained when blind children presented an added deficit such as mental development. In these cases the learning of concepts such as cardinality showed important pretest-posttest gains.

Our results indicate that learners with more mathematics learning gains were those that participated by solving associated cognitive tasks. Thus we can conclude that the audio-based virtual environment by itself does not have an isolated impact on mathematics learning. Concrete cognitive learning tasks are powerful supports to the interaction with the audio interfaces. These children have not formal abstract thinking that is somehow embedded in the software. Then concrete tasks are necessary to accompany interaction experiences with audio-based interactive environments.

At the beginning most children did not even know the space distribution of keystrokes in a keyboard. At the end of the experience they used software commands efficiently. A tutorial included may have helped them in this task.

Colors used in the graphical interface such as yellow and blue produced a good contrast for children with residual vision. However the variations types of the same color used did not allow differentiating one element to the other and thus children with low vision got confused.

Audio stimuli such as sound of bird's whispers, personages, tools and devices of the kitchen

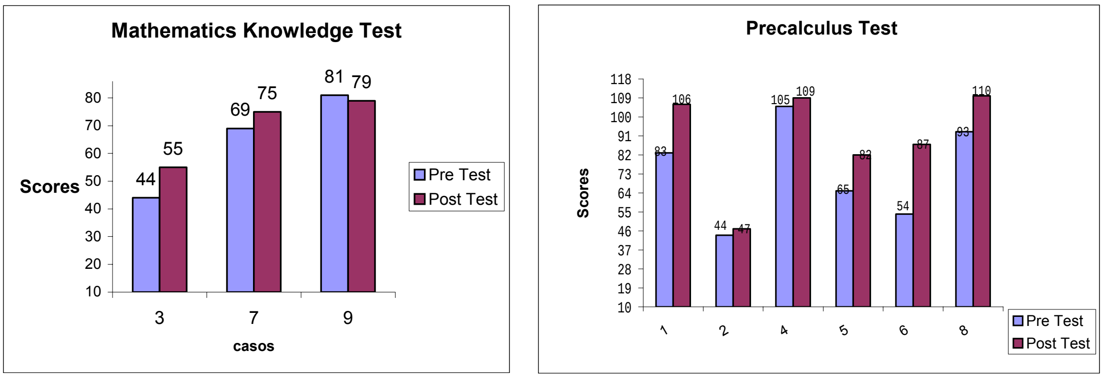

Figure 6-7 *Pretest-Posttest gains in mathematics knowledge*

motivated and help them to interact with the software more actively. We have also found that to attain meaningful learning sound-based environments should be accompanied with cognitive tasks involving written number recognition and reproduction.

Finally, we can conclude that thanks to the interaction with AudioMath and Theo & Seth, and the associated cognitive tasks learners with visual abilities developed mathematics skills. This is a major result in our research because we are initially observing that audio-based virtual environments can foster the construction of mathematics learning in the mind of children with visual disabilities.

DISCUSSION

We have introduced AudioMath and Theo & Seth, virtual environments designed to enhance memory and mathematics skills in children with visual disabilities through audio. The software was made by and for children with visual disabilities. They participated actively in the development of the software. We have also designed interfaces for both blind and children with residual vision. A usability study was implemented with end-users, facilitators, observers, and experts.

AudioMath and Theo & Seth were highly accepted by end-users. They liked, enjoyed, and were motivated when interacted with the software. The flexibility of this application is also a plus. Teachers, children, and parents can include new objects and sounds to adapt them to their needs. Thus, children with visual disabilities can choose sounds to be interacted with and embed them into AudioMath and Theo & Seth. Content can be changed and updated easily. Both virtual environments can be used to support learning primary school mathematics.

The use of concrete materials was also a plus in this study. The children's understanding was easier when they first interacted with concrete materials and then with AudioMath and Theo & Seth. Parallel interaction with both concrete material and AudioMath/Theo & Seth was also an advantage. Once they developed their own mental model of the software the interaction was enriched.

Force Feedback Joysticks introduced a new scenario in virtual environment for blind children. They can provide information and tactile sensations through force feedback. This can help to decrease audio stimuli and relief possible acoustic pollution. Joysticks are devices with a high potential of use due to the availability of many buttons.

Our model fits well the learning of primary school mathematics concepts such as positional value, sequences, additive decomposition, multiplication, and division. Children performed increasingly well in the mathematics knowledge test. Oral calculation and countdown numeric series were highly achieved as well as numeric and associative memory. Concrete cognitive tasks were crucial in this achievement. We firmly conclude that interaction with AudioMath and Theo & Seth associated with cognitive tasks can help to improve mathematic learning in these children.

More qualitative data are being analyzed. Most of them are case study because each child with visual disabilities is a whole case that deserves a deep analysis to construct meaning about the role that can play audio-based devices in learning general and specific domain skills.

Finally, we are convinced that further research studies we are implementing right now concerning mathematic learning will reaffirm our hypothesis that audio-based virtual environment can foster the construction of mathematics learning in the mind of children with visual disabilities.

Acknowledgements: This report was funded by the Chilean National Fund of Science and Technology, Fondecyt, Project 1030158.

REFERENCES

Baldis, J. (2001). Effects of spatial audio on memory, comprehension, and preference during desktop conferences. In *Proceeding of the ACM CHI 2001*, Seattle, Washington, USA, March 31 – April 5, 2001. Vol 3, 1. pp. 166-173.

Lumbreras, M. and Sánchez, J. (1998). 3D aural interactive hyperstories for blind children. *International Journal of Virtual Reality 4(1. pp.,* 20-28.

McCrindle, R. and Symons, D. (2000). Audio space invaders. In *Proceedings of the Third International Conference on Disability, Virtual Reality and Associated Technologies*, *ICDVRAT 2000*, Sardinia Italia, 23-25 September, 2000. pp. 59-65.

Mereu, S. and Kazman, R. (1996). Audio enhanced 3D interfaces for visually impaired users. *Proceedings of CHI'96*, ACM Press. (1996).

Sánchez, J. (2000). 3D interactive games for blind children. In *Proceedings of Technology and Persons with Disabilities, CSUN 2000*. Los Angeles, USA.

Sánchez, J. (2001). Interactive virtual acoustic environments for blind children. In *Proceedings of ACM CHI ´2001*, pp. 23-25. Seattle, Washington, USA, March 31 – April 5, 2001.

Tan, H. (2000). Haptic interfaces. *Communications of the ACM, 43(3)*. pp. 40-41.

Winberg, F. and Helltrom, S. (2000). The quest for auditory manipulation: the sonified Towers of Hanoi. In *Proceedings of the Third International Conference on Disability, Virtual Reality and Associated Technologies*, *ICDVRAT 2000*, Sardinia Italia, 23-25 September, 2000. pp. 75-81.

Cooper, M. and Taylor, M. E. (1998). Ambisonic sound in virtual environments and applications for the blind people. In *Proceedings of the Second European Conference on Disability, Virtual Reality, and Associated Technologies, ECDVRAT 1998*, Skövde, Sweden, 10-11 September, 1998. pp. 113-118.

Lahav O. and Mioduser, D. (2000). Multisensory virtual environment for supporting blind persons' acquisition of spatial cognitive mapping, orientation, and mobility skills. In *Proceedings of the Third International Conference on Disability, Virtual Reality and Associated Technologies, ICDVRAT 2000*, Sardinia Italia, 23-25 September, 2000. pp. 53-58.

Loomis, J., Lippa, Y., Klatzky, R. and Golledge, R. (2002). Spatial updating of locations specified by 3-D sound and spatial language. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28 (2),* pp. 335-345. 2002

Edwards, A. D. N. and Stevens, R. D. (1993). Mathematical representations: Graphs, curves and formulas. In D. Burger and J. C. Sperandio (ed.) *Non-Visual Human-Computer Interactions: Prospects for the visually handicapped*. Paris: John Libbey Eurotext, (1993), pp. 181-194.

Sahyun, S., Gardner, S. and Gardner, C. (1998). Audio and Haptic Access to Math and Science - Audio graphs, Triangle, the MathPlus Toolbox, and the Tiger printer. *Proceedings of the 15th IFIP World Computer Congress*, Vienna, September 1998, pp. 78-86.

Scadden, L. (1996). Making mathematics and science accessible to blind students through technology. *Proceeding of Resna 96 Annual Conference*, (1996), June 7-12, Salt Lake City, Utah, pp. 51-58.

Rigden, C. (1999). The eye of the beholder-designing for colour blind. *British Telecommunications Engineering*, Vol. 17, January.

Sánchez, J., Baloian, N. and Flores, H. (2004). A methodology for developing audio-based interactive environments for learners with visual disabilities, *Proceedings of the World Conference on Educational Multimedia, Hypermedia & Telecommunications, ED-MEDIA 2004*, Lugano, Switzerland, June 21-26.

Chadwick, M. and Fuentes, M. (1980). *Evaluation of Mathematics Knowledge* (adaptation of Benton-Luria test). Santiago, 1980.

Contact

Jaime Sánchez, Ph D.
Department of Computer Science
University of Chile
Blanco Encalada 2120
Santiago, Chile