AudioMath: blind children learning mathematics through audio

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ABSTRACT

Diverse studies using computer applications have been implemented to improve the learning of children with visual disabilities. A growing line of research uses audio-based interactive interfaces to enhance learning and cognition in these children. The development of short-term memory and mathematics learning through virtual environments has not been emphasized in these studies. This work presents the design, development, and usability of AudioMath, an interactive virtual environment based on audio to develop and use short-term memory, and to assist mathematics learning of children with visual disabilities. AudioMath was developed by and for blind children. They participated in the design and usability tested the software during and after implementation. Our results evidenced that sound can be a powerful interface to develop and enhance memory and mathematics learning in blind children.

1. INTRODUCTION

Audio-based interfaces to foster cognition in blind children have been increasingly developed for people with disabilities. A number of studies have focused on the design of audio-based interfaces and evaluated their impact on learning and cognition (Baldis, 2001; Lumbreras, & Sánchez, 1998; McCrindle & Symons, 2000; Mereu & Kazman, 1996; Sánchez, 2000; Sánchez, 2001; Tan, 2000, Winberg & Helltrom, 2000).

Most of these studies are based on interactive software that cannot be fully adapted to their needs and requirements. Actually, most 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 (Lumbreras & Sánchez, 1998). The study used audio to enhance spatial cognitive structures and found that spatialized 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 (Mereu & Kazman, 1996). As a result, they found 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 (Mereu & Kazman, 1996).

Other studies describe the positive effect of 3D audio-based virtual environments (Cooper & Taylor, 1998). 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 providing appropriate spatial information through compensatory channels can improve the performance of blind people (Lahav & Mioduser, 2000).

A research work in the same track of (Lumbreras & Sánchez, 1998) concluded that a traditional computer game such as 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 (McCrindle & Symons, 2000). 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 (Loomis et al., 2002).

Studies focusing the development of computer applications to develop and enhance memory through virtual environments in people with disabilities are scarce. Some memory processes such as spatial distribution through virtual reality environments were developed by active participation of people with

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disabilities (Attree et al., 1996). As a result, active participation enhanced memory for spatial layout whereas passive observation enhanced object memory.

Other studies have also used immersive virtual reality to analyze spatial memory in patients with brain damage. They developed a test as proof-of-concept of the critical role that can be played by virtual reality as experimental tool for memory purposes (Morris et al., 2000). The use of virtual reality was also found to be relevant to improve the validity and reliability of neurological evaluation and rehabilitation (Rizzo et al., 2002). The impact of spatial audio on memory was analyzed concluding that audio stimuli improves memory and perceived comprehension by choosing spatial audio instead of non spatial (Baldis, 2001).

A trend in the literature is the absence of long-term usability studies. Increasing voices in the field are sustaining that spatial audio may have a reduced impact when it is not associated to specific cognitive tasks. Besides to the need for sound-based virtual environment studies there is a demand for more rigorous and systematic usability studies by and for children with visual disabilities.

A most recent study have developed a sound-based virtual environment for children with visual disabilities to enhance memory and fully tested the software with diverse children concluding that it can help to enhance the development and practice of short-term memory in children with visual disabilities. (Sánchez and Flores, 2003, 2004).

Learning the basis 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 (Edwards & Stevens, 1993; Sahyun et al., 1998; Scadden, 1996). Thus one of the greatest challenges for children with visual disabilities has been the learning of, and access to, mathematics information (Sahyun et al., 1998). Early learning and practice may project a better construction of mathematics knowledge in visually impaired children (Edwards & Stevens, 1993).

In this study we intended to foster learning and practice of mathematical concepts such as positional value, sequences, additive decomposition, multiplication, and division. Through opening pairs of tokens in a board with several levels of difficulty, the child has to find the corresponding pair of tokens in accordance with the mathematical content. Thus 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.

2. DESIGN OF AUDIOMATH

2.1 Model

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). Colours are used for children with residual vision (Rigden, 1999). This model meets the minimum standards proposed by (Sánchez et al., 2004) for software design, and thus validating AudioMath as an appropriate virtual environment to be used for the learning of children with visual disabilities.

2.2 Software and hardware Tools

AudioMath was developed by using Macromedia Director 8.5 and 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.

2.3 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.

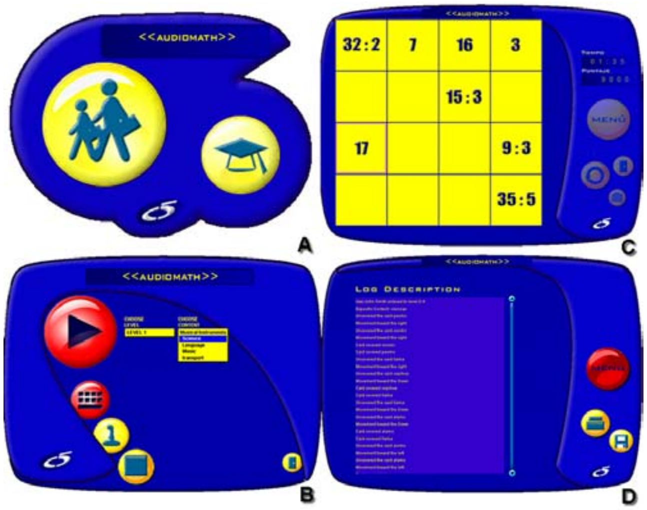

Figure 1. *Interfaces of AudioMath*

2.3 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.

3. COGNITIVE EMPHASIS

AudioMath was designed to enhance memory in blind children and children with residual vision. For reading and writing skills learners have to have developed visual and audio memory to discriminate graphemes and phonemes. This memory prevents to be confused by graphemes for spatial orientation as well as by phonemes with similar sounds. AudioMath allows children with visual disabilities to practice and rehearse their short-term memory.

These children practice audio memory (blind and children with residual vision) and visual memory (children with residual vision). The tasks implied to exercise audio/oral, visual/oral, audio/graphic, and visual/graphic memory. The software also emphasizes learning concepts such as establishing correspondence and equivalency relationships, memory development, and differentiating tempo-spatial notions.

AudioMath was implemented to go further than just enhancing general domain skills such as memory and tempo-spatial notions 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, and division. We wanted to observe how audio-based virtual environments can foster the construction of mathematics learning in the mind of children with visual disabilities.

4. METHODOLOGY

4.1 Participants

The study 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.

4.2 Evaluation Instruments

Three 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. Immediate audio memory test (Cordero, 1977), evaluation of mathematics knowledge test (Chadwick & Fuentes, 1980), and a usability evaluation test for end-users. The immediate audio memory test has the purpose to measure logic, numeric memory, and associative memory from audio stimuli. The evaluation of mathematics knowledge test measures: 1. The capacity to understand numbers (oral and written); 2. The skills to make oral and written calculations; 3. The skills to count numeric series and graphic elements; and 4. The skills for mathematic reasoning.

4.3 Procedure

Children were tested in the school from July to November 2003, twice a week, two one hour sessions per week. They followed the steps of pre-testing (immediate audio memory and evaluation of mathematics knowledge tests), interacting with AudioMath, solving cognitive tasks (see Figure 2 and 3), and post-testing (immediate audio memory and evaluation of mathematics knowledge tests). 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 behaviours. They also applied a usability evaluation test for end-users developed by the authors.

Figure 2-3. *Children solving cognitive tasks with AudioMath.*

5. 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 such as cognitive deficits and different degrees of blindness.

Children performed increasingly well in both tests: audio memory and mathematics knowledge. An overall view of initial results shows pre-test – post-test gains in mathematics knowledge (see Figure 4), thus indicating that interaction with AudioMath associated with cognitive tasks can improve mathematics learning in these children. Audio memory pre-tests – post-tests show some gains after interacting with AudioMath, thus indicating that short-term memory can be enhanced by using this software. Gains were higher in mathematics knowledge than audio memory (see Figure 5).

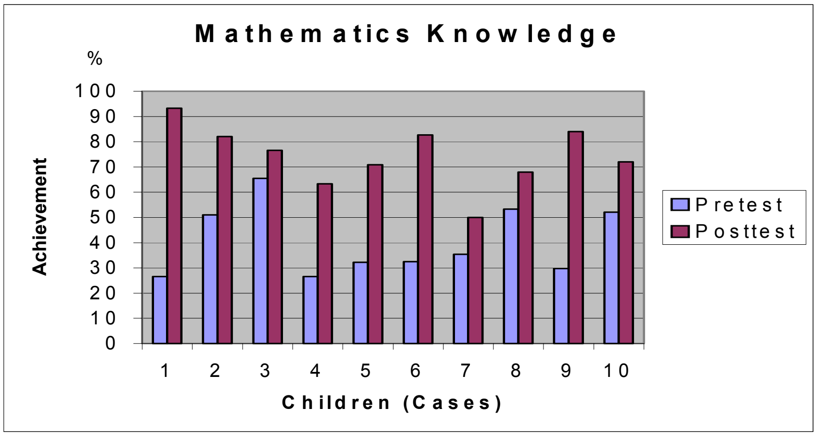

Figure 4. *Pre-test – post-test gains in mathematics knowledge*

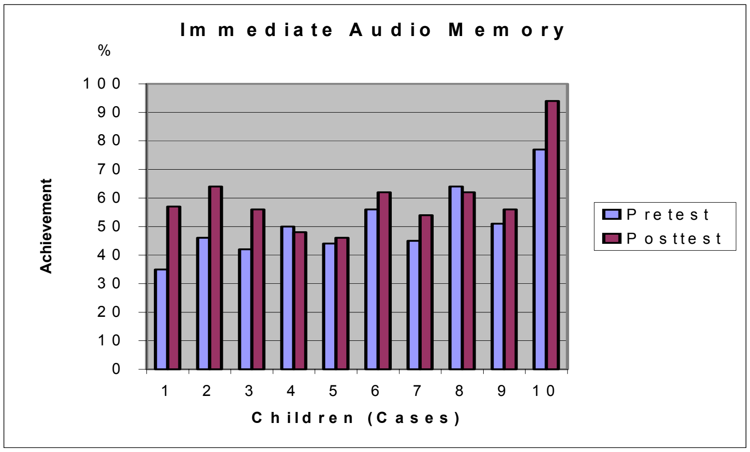

Figure 5. *Pre-test – post-test gains in short-term memory*

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.

Children also obtained high gains in short-term memory. They improved their numeric memory (69th percentile score), associative memory (65th percentile score), and logic memory (3rd percentile score). This means that they performed better than, or received a higher score than, 69%, 65%, and 3% of other learners that took the same tests.

Finally, we can conclude that thanks to the interaction with AudioMath and the associated cognitive tasks learners with visual abilities developed mathematics skills and short-term memory. 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.

6. DISCUSSION

We have introduced AudioMath, a virtual environment 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 was 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. Content can be changed and updated easily. AudioMath can be used to support memory when learning specific concepts and processes in a given subject matter. AudioMath can be used for 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. Parallel interaction with both concrete material and AudioMath was also an advantage. Once they developed their own mental model of the software the interaction with AudioMath 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 both tests: audio memory and mathematics knowledge. 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 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.

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