# Developing Mathematics Skills through Audio Interfaces

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## Abstract

Diverse views have highlighted the use of audio to foster learning and cognition in blind children. The idea is to use computer sound and voice to explore audio senses as vehicles for knowing and thinking. Most studies have explored the impact of audio on general domain cognitive processes. A few studies have explored specific domains such as mathematics. This study presents the design, development, and usability evaluation of an audio-based virtual environment to enhance learning of mathematics knowledge in blind children. After interacting with the software we found that blind children were highly motivated and enjoyed the experience. We also observed that they solved problems and learned basic mathematics knowledge such as addition, subtraction, and cardinality. Our preliminary results indicate that audio-based virtual environments can help to ameliorate the complexity of blind children learning mathematics.

## Keywords

Interfaces for blind children, audio-based navigation, usability, mathematics learning, blind children.

## 1 Introduction

Mathematics learning has been amply studied in current literacy literature. A number of studies tend to agree that most children have difficulties in learning mathematics. This fact has a critical impact on further learning. In a society heavily based on science and technology children without understanding basic mathematics knowledge may limit seriously their role in this society.

This limitation is also extensive to children with visual disabilities. Actually in many respects this issue is radicalized in children with visual disabilities. Diverse authors have posed that when blindness is associated to social deprivation the issue of learning primary school mathematics is really a critical issue [1, 12, and 13]. Thus the literature has claimed that one of the critical challenges for children with visual disabilities is to access to mathematics information, learn basic operations, and solve problems [13]. Early learning and practice of mathematics skills can facilitate a more meaningful construction of mathematics knowledge in children with visual disabilities [12].

The literature describes diverse audio-based computer applications [3, 4, 5, 6, 7, 8, 9, and 10]. Most of them emphasize the use of audio to develop general domain skills such as short-term memory, abstract memory, haptic perception, and tempo-spatial orientation. A few of them have integrated specific domain content such as curriculum mathematics including graphics and algebraic expressions [1, 12, and 13].

Audio interfaces can be used to foster learning and cognition in blind children. Diverse studies have proved that the use of audio through virtual environments can be a powerful auditory stimuli for children with visual impairments. Mathematics learning can be very complex to these children because of their poor abstraction skills and motivation for learning mathematics. We have designed, developed, and tested with blind children an audio-based interactive virtual environment to enhance mathematics learning such as the concept of number and basic operations.

In this study we intended to foster learning and practice of mathematical concepts such as positional value, sequences, additive decomposition, addition, subtraction, and cardinality. To do this we have constructed Theo & Seth, a game-based virtual environment that includes interesting mathematics learning activities with different levels of complexity.

During interaction children were exposed to cognitive tasks. They had to solve diverse concrete tasks that complemented and enriched the experience with the virtual environment. Tasks involved exercises by using simple concrete materials used in everyday life.

Our virtual environment was usability tested with nine learners with visual disabilities. Preliminary results concerning the pre-calculus test indicate 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.

# 2 Design

## 2.1 Model

The model has the following components: Model, strategy, computer representation, model of learner, evaluation, interface, and user (see Figure1).
*Model*, according to the cognitive skills to be developed diverse content is presented to the user by using a metaphor consisting in a grange with different elements to help children to solve arithmetic problems.
*Strategy*, Theo & Seth has embedded a strategy to be used in order to solve the problems posed. They are randomly presented but deterministic. According to different levels of learning the strategy varies in terms of the randomness of problems. For addition and abstraction the rule is $X + Y = Z \Rightarrow Z - Y = X$ and $Z - X = Y$.
*Computer representation*, which is developed with a functioning methodology and global variables allowing to maintain the coherence between the results and exercises posed to the user. In addition to state variables in memory there are saved variables in disc to link different game interaction video clips.
*Model of learner*, this is the part of the system in charge of saving the answers of the user and provides the grading results of problems solved by the user.
*Evaluation*, this component evaluates the students learning by analyzing the final results obtained by the learner and comparing them with the correct results. Learner obtains feedback of their results
*Interface*, this is the main component that receives and interprets the parameters entered by the user through keyword by certifying that the system can be understood by a blind user. It is in

charge of generating the projection of all interactions, state variables, and feedback from and to the system. The output is represented through audio and images.
*User*, corresponds to the person that uses and interacts with the application.

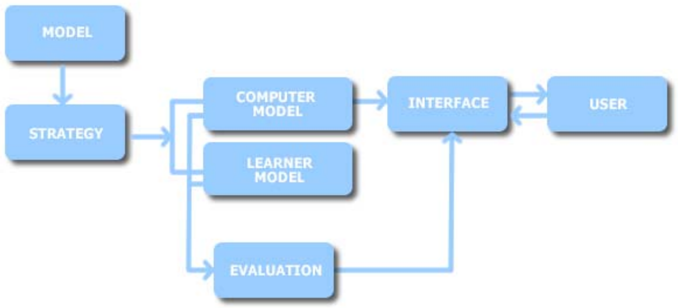


**Figure 1:** Software Model

## 2.2 Software and Hardware Tools

Theo & Seth was developed by using Macromedia Director 8.5 and Lingo. Animations were implemented with Macromedia Flash MX. Images for children with residual vision were designed with Macromedia Freehand MX and Macromedia Fireworks MX. Sound editing and recording were made with Cool Edit Pro 2.0 using mp3 format. The final application can be executed in any MS Windows environment. Interaction was designed to happen with a few keystrokes of a standard keyboard.

## 2.3 Interfaces

Content presentation and solving problem in Theo & Seth use diverse hypermedia sources such as sound, voice, animation, and high contrast images. Special emphasis was made on the quality of sound and the use of high contrast colors for children with residual vision.

The software is separated in different learning areas where the child learns numbers and can solve basic operations and problems. Theo & Seth is based on a spatial grange metaphor where lives a farmer, Theo, who is visited by Seth that helps him with the grange work. Seth, the assistant, is performed by the blind children.

Both personages interact with the learner and exert actions during the game. The metaphor used resembles a grange with two major virtual environments: the kitchen of numbers and the henhouse of operations (see Figure 2.a). The kitchen has two environments: To serve (Figure 2.b and 2.c) and the tools (Figure 2.d). The kitchen of numbers covers two topics: 1. Cardinality including the number, the position in the numerical straight line, and information about the antecessor and successor, and 2. Ordinal numbers and to form soup of numbers. The henhouse of operations is a virtual space where learners learn how to do sum and rest. It also includes a help option to familiarize children with the keyboard (see Figure 3).

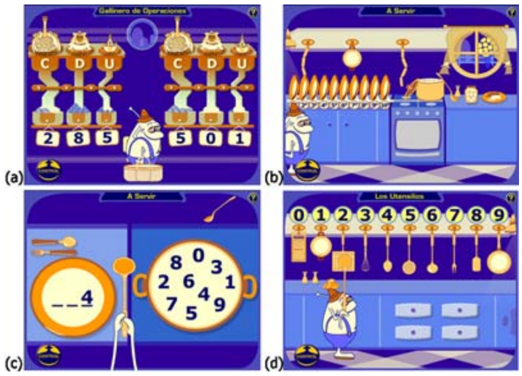

**Figure 2:** Interfaces of Theo & Seth

### *A. To serve*

This module is presented in the right side of the kitchen including ten dishes in the dishwasher to be served. The idea is that the child can form numbers up to three digits from a soup of numbers. The dishes are placed in order from the first to the tenth. The child has to select each dish in a corresponding order. This module has two levels. During level 1 the child forms two digit numbers and during level 2 the child forms three digit numbers. Both levels consider the following steps: 1. The child chooses the number to be formed and a voice mention the number chosen and it positional value (unit, tenths, hundreds), 2. The child chooses the number to be formed and the voice mention the number chosen, and 3. The voice indicates the number to be formed.

### *B. The tools*

This module is placed at the left side of the kitchen with different numbered tools hanged from 0 to 9. The child can choose three levels. Seth goes through the tools guided by the child and a voice indicates the number where is placed with antecessor and successor.

**Level 1**: The numbers are presented through sound by touching the tools and indicating the quantity represented.

**Level 2**: The numbers are presented without sounds.

**Level 3**: The child has to identify in a number the antecessor and successor.

The content of this module are: the concept of number, antecessor, and successor.

### *C. The henhouse of operations*

In this module a henhouse with six birds hatching is placed on the following way: a ostrich, a chicken, and a canary to the left side of the screen. The same distribution of birds is placed to the right to mimic units, tenths, and hundreds. The idea is perform addition and subtraction. The children guides Seth to the middle of the screen and press enter to perform the lever. Then birds start to put eggs and sing according to the amount of produced eggs and thus forming the numbers of the operation (addition).

This module is divided in four levels:

**Level 1**: The child observes what is happening without participating in the operation. When the numbers are ready a voice sums the produced eggs by the birds starting from canaries (unit). The resulting numbers is annotated in a basket that Seth brings to Theo who takes the eggs to be used by mentioning the number and then subtracting them to check how many eggs were not used.

**Level 2**: The child performs the operations, additions and subtractions by answering questions and indications giving through voice.

**Levels 3 and 4**: These levels were performed similar to levels 1 and 2, but sums and rests were more complex.

## 2.4 Interaction

The way the child interacted with the software was through keyboard and audio (sound and voice). This was thought is such a way that the child can perform the software without asking for help.


**Figure 3:** Keyboarding Help

To help to use the software autonomously there is a help that introduces to the children the use of the keyboard by orienting them through the position of keystrokes (see Figure 3).

During the interaction with Theo & Seth the child can navigate freely through different interfaces that provide the mathematics content and problems to be solved in a specific area.

## Cognitive Emphasis

The main objective of this work was to evaluate the impact of using Theo & Seth on the development of mathematics knowledge in boys ands girls with visual disabilities that attend the first years of Santa Lucía school in Santiago, Chile. Theo & Seth emphasizes learning concepts such as establishing correspondence and equivalency relationships, memory development, and differentiating tempo-spatial notions. In addition the software allows to the child to learn and develop the concept of number. It also assists learners to learn basic number operations such as addition and subtraction, and to familiarize them with the keyboard. Finally, Theo and Seth exercises short-term memory.

## 3 Methodology

### 3.1 Participants

The study was developed with nine children ages 7 to 8 who attend a school for blind children in Santiago, Chile. The sample was conformed of 6 girls and 3 boys. Four of them were blind (2 girls and 2 boys) and five had residual vision (4 girls and 1 boy). Six coursed first grade and three coursed second grade. 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 were legally blind.

**Figure 4:** Students interacting with software

### 3.2 Materials

We used concrete materials, macrotype, and Braille. The idea was that children can perform similar tasks as in Theo & Seth. We wanted children working in similar tasks as in Theo & Seth to relate real world tasks and the tasks presented by the software. The materials also helped us to evaluate from another dimension whether or not Theo & Seth can enhance mathematics learning.

### 3.3 Evaluation Instruments

Two measurement tests were used to evaluate the impact of Theo and Seth on learning and practice of mathematical concepts such as addition, subtraction, and cardinality. Precalculus test (Milicic & Smith, 1977) and mathematics knowledge test of Benton & Luria, adapted for children with special needs by Chadwick & Fuentes (1980). Usability tests for end-users were also used. The precalculus test has the purpose to measure the development of mathematics development of first grade learners. The 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.

The cognitive tasks used were (see figure 5):

***The Roulette***
*Content:* concept of number, antecessor y successor.
*Cognitive prerequisites*: notion of before/after and quantity.

*Description*: learners turn the roulette and indicate antecessor and successor of the number pointed by the arrow. Then they exchange questions about the antecessor y successor of specific numbers

***Game of Slugs***
*Content:* positional value of numbers and numeric composition/decomposition
*Cognitive prerequisites:* numeric positional value and the notion of quantity
*Description*: Learners participate in a circuit with four stops, each one with a mathematics exercise. Each learner has to go through the four stops by solving exercises. Once the learner solves the four exercises another student starts the game.

**Figure 5:** Students solving cognitive tasks

***The Lottery***
*Contents:* positional value of numbers, numeric composition/decomposition, complex addition and subtraction.
*Cognitive prerequisites*: notion of quantity, notion of more/less, number deconstruction up to three digits.
*Description*: learners play lottery. The teacher chooses a number from the tombola that indicates a mathematics exercise (addition or subtraction). As a result the solved exercise is written in the player's card. The winner is the one that get solved a complete line of exercises on the player's card or the whole card with fully solved exercises. The game ends when all learners get solved a complete line of exercises.

***The Store***
*Contents*: positional value of numbers, numeric composition/decomposition, complex addition and subtraction.
*Cognitive prerequisite*: The notion of before/after, quality, more/less, and number construction up to three digits.
*Description:* the classroom is transformed in a small supermarket where learners enter individually and the teacher gives $500 to each student. Learners have to arrange and choose what to buy and make as many subtractions and additions to fit the money to their shopping needs and limitations.

## 3.4 Procedure

Learners followed pretest, interaction with Theo & Seth (see Figure 4), solving cognitive tasks, and posttest. All tests were applied individually at the beginning before children interacted with Theo & Seth. Precalculus test was applied to first grade children and mathematics knowledge test was applied to second grade learners. Cognitive tasks were applied to 5 learners with visual disabilities each time they ended their work in a content unit.

# 4 Results

Learners evidenced positive changes in their mathematics knowledge after interacting with Theo & Seth. Cognitive tasks were very important in attaining these gains. Those learners participating in solving cognitive tasks showed higher precalculus test gains than children who did not solved these tasks. Totally blind learners obtained better pretest-posttest gains than learners with residual vision (see cases 1 and 6, Figure 6). Besides to their blindness cases 5 and 6 that have also intellectual disabilities got higher gains. Case 2 did not show precalculus gains but evidenced a greater attention and retention capacity, and attained high keyboarding skills at the end of the experimental activities.

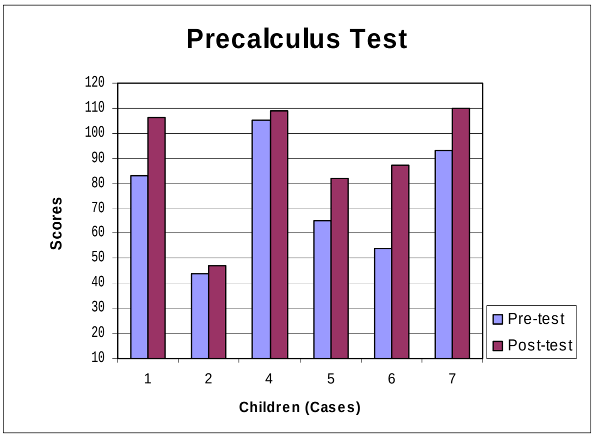


**Figure 6:** Percentiles Obtained in the Precalculus Test

Most learners presented gains in their mathematics knowledge as measured by the pretest-postest. Learners who presented major changes were those who interacted with Theo & Seth and participated in cognitive tasks. Case 8 obtained from the beginning excellent results solving problems correctly, working independently with the software, understanding the software, and solving the tasks correctly (see Figure 7). Even though cases 3 and 7 showed small gains in their mathematics knowledge they appear to be meaningful for their learning.

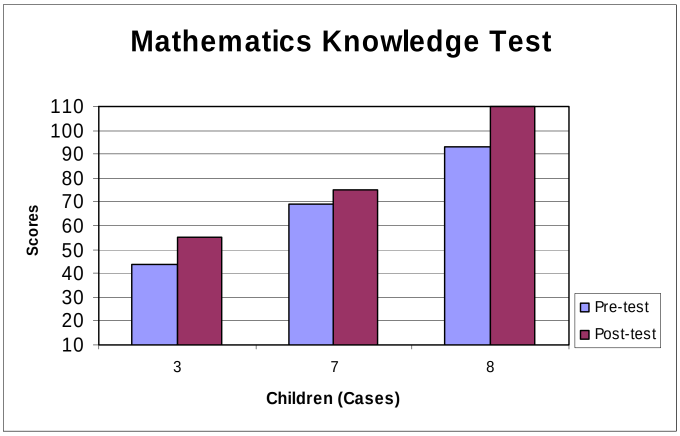


**Figure 7:** Percentiles Obtained in the Mathematics Knowledge Test

# 5 Discussion and Conclusions

Blind children obtained positive mathematics skills gains after interacting with Theo & Seth and solving concrete cognitive tasks. Those who have significant gains showed high motivation and interest to work with the software. Totally blind children showed major advances in their mathematics knowledge as well as those that solved cognitive tasks after interacting with the software. Children with residual vision presented small gains in mathematics knowledge.

At the beginning most of the sample did not know the keyboard distribution. At the end of the testing children showed an efficient use of the keyboard. The help option of the software as well as the continuous interaction with the computer helped them to develop keyboarding skills during interaction

Audio stimuli provided by the software such as bird sounds and songs, the movements of Seth, and the tools in the kitchen allowed children to be motivated and engaged. These sounds should be similar to real world sounds to be assimilated correctly by children.

Most children needed mediation when interacting with the software but this need was decreasing through the experience. At the end of the sessions learners showed totally independence when interacting with the software. We believe that this was radicalized by the fact that due to school regulations they only had contact with computers during the one hour session of this experience with almost no opportunity to practice during their free time.

We conclude that cognitive tasks were crucial to children with visual disabilities. These tasks motivated and increased the use of their active tact. When learning materials are interesting to children and based on everyday experiences their motivation to learning is increased. This is very important for children with visual disabilities because without vision to know through tact can help to construct meaningful learning. Thus software such as Theo & Seth should be complemented with cognitive tasks to accommodate learning for later generalization avoiding current verbalization behavior in blind children.

This study was a preliminary research concerning the developing of mathematics learning in blind children. We are designing long-term experiments with a bigger sample and audio-based software embedded with more complex mathematics content such as geometry to help us to better understand the way audio-based applications can help blind children to construct mathematics learning.

## 6 Acknowledgmemements

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