3D Sound Interactive Environments for Problem Solving

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ABSTRACT
Audio-based virtual environments have been increasingly used to foster cognitive and learning skills. A number of studies have also highlighted that the use of technology can help learners to develop affective skills such as motivation and self-esteem. This study presents the design and usability of 3D interactive environments for children with visual disabilities to help them to solve problems related with the Chilean geography and culture. We introduce AudioChile, a virtual environment that can be navigated through 3D sound to enhance spatiality and immersion throughout the environment. 3D sound is used to orientate, avoid obstacles, and identify the position of diverse personages and objects within the environment. We have found during usability evaluation that sound can be fundamental for attention and motivation purposes during interaction. Learners identified and differentiated clearly environmental sounds to solve everyday problems, spatial orientation, and laterality.

Categories and Subject Descriptors: J.0 General.

General Terms: Human Factors.

Keywords: Hyperstories, 3D sound, virtual world, problem solving, role-playing game.

INTRODUCTION
Children with visual disabilities are increasingly having more contact with virtual environments [2, 4, 7, 8, 9, 10, 18, 19]. Computer games have been used for entertaining purposes through accessibility interfaces.

Few initiatives have focused on the design of games to develop and rehearse cognitive skills in children with visual disabilities [3, 11].

Applications conceived for users with visual disabilities have been developed using auditory information as the main output channel and haptic devices for input [1, 7, 8, 10, 12]. These systems have been principally developed to help blind people to overcome their difficulties with standard interfaces such as the Web page "reader" Jaws. Other focus is the development of 3D audio interfaces used to develop the user's skills to recognize spatial environments through sound. However, we have no record of research work on virtual environments to solve problems by children with visual disabilities.

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Sound has also been used as input/output to develop learning and cognitive skills in blind children. Most applications use spatial sound to help children to develop abstract and short-term memory, haptic perception, collaborative skills, spatial abstraction, mathematics skills, and algorithmic thinking skills [9, 10, 13, 14, 17, 18].

An experience with audio stimuli to simulate visual cues for blind learners [8] have found that 3D audio interfaces help blind people to localize specific points in a 3D space concluding that navigating virtual environments through sound can be a precise task for blind people. Other studies describe positive effects of 3D audio-based virtual environments [2].

Authors have used sensory virtual environments through force feedback joysticks simulating real world places such as the school concluding that providing appropriate spatial information through compensatory channels the performance of blind people can be improved [4].

A research work replicated a traditional computer game such as space invader by using 3D sound. Authors used force feedback joysticks as input interface by letting to play blind to sighted children to share the same experience [7].

Authors evaluated the skill to hold in mind a specific localization without concurrent perceptual information or spatial update through the use of audio stimuli to trace specific places through sound [5].

A study to design and evaluate a spatial audio system that models the acoustic response of a closed environment with varying sizes and textures for blind user was implemented concluding that there was almost no difference in user perception of room sizes between sounds in real and simulated scenes [3].

Finally, a real-time 3D graphic game for low vision gamers was developed to propose general methods of making real-time 3D games accessible for virtual reality applications, e-commerce, and distance learning [19].

Studies to enhance problem solving skills through 3D sound in blind children are scarce. This research study presents the design, development, and usability testing of AudioChile a 3D sound interactive environment for children with visual disabilities. The system was designed to assist learners to solve everyday problems and thus knowing the life, culture, and idiosyncrasy of different geographical regions of Chile.

RESEARCH PROBLEM
Children with visual disabilities perceive the surrounding world differently to sighted children. Actually, to orient and mobilize in the real world they have to learn to exploit and use other senses such

as touch and hearing. To orient spatially within a surrounding environment is a complex process that requires learning to explore the smelling and textures as points of reference to search for objects in the environment.

Children with visual disabilities need to learn how to use their ears and interpret the surrounding world, localize sounds that serve as cues to orient and mobilize autonomously. Spatial sound stimuli can provide a stimulating atmosphere for developing thinking skills to cope with everyday situations and solve current problems and issues with independence.

AudioChile is a role playing game. Children have to travel through main Chilean regions where different hyperstories occur. The interaction is through sound and music. Within a region the child performs a personage and navigates through virtual environments looking for cues and information to do actions and take decisions. At the end the child can get the whole picture and information about the adventure.

PURPOSE OF THE STUDY

The main purpose of this study is to design 3D virtual environments based on hyperstories and assisted by stereo and spatial sound to develop problem solving skills in children with visual disabilities. This includes searching, mobilization, localization, designing strategies, and orientation skills.

Our study also includes a usability evaluation of the virtual environment. We have studied: 1. 2D and 3D graphic interfaces for children with residual vision, 2. Stereo and spatial sound interfaces, and 3. Problem solving strategies developed when using AudioChile.

MODEL

AudioChile is based on a model for implementing educational software for children with visual disabilities [15,16]. Basically, the model is centered on providing facilities for evaluation purposes and to give prompt feedback to the user. It also clarifies, for implementation purposes, similarities and differences between software for people with and without visual disabilities. The resulting architecture model after applying the developing model is depicted in Figure 1.

AudioChile has a *model* (metaphor) that represents three major Chilean cities. A personage has to navigate through these cities searching for cues and information to solve a posed problem.

Editors consist of a virtual world and the definition of its properties, objects, and personages.

The *knowledge representation model* is based on the mapping of real world behaviors in a virtual world, state variables (physics, kinetics, and luminous), and actions.

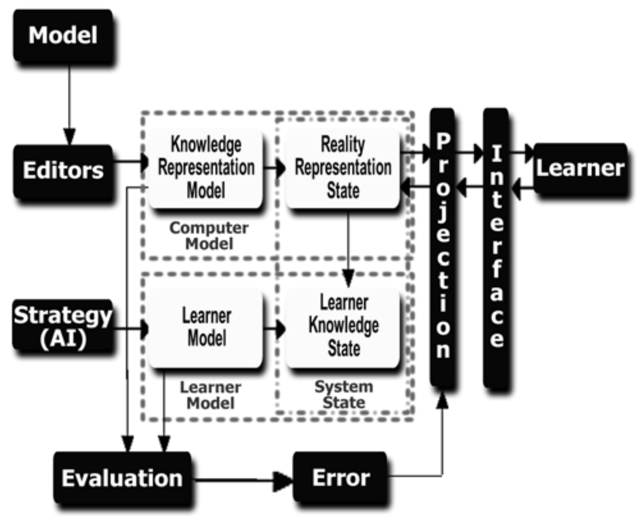

Figure 1. Architecture of the resulting software [15]

The *strategy* (AI) is in charge of following up the actions performed by the user. It provides a compass that perceives the user´s orientation within the virtual world, helping him/her to navigate and take actions.

The *learner model* is such that as the user goes through the adventure she/he can know and process more information to solve the problem in order to reach the end of the story.

Evaluation consists of an evaluation of the compass to provide information to the user to find diverse objects and personages within the virtual world.

Projection consists of 3D images and sound virtual worlds. It explores diverse fine representation qualities to get a high standard of use as well as to solve the problem posed.

SOFTWARE DESCRIPTION

AudioChile is composed of diverse hyperstories [6]. Once immersed in the 3D world the user can adopt a personage that can be a girl or a boy. Each story consists of an adventure to explore one of three geographical regions of Chile by navigating, interacting, and solving tasks and problems. Basically, the child has to find a cooper ingot in the region of Chiloé and return it to the region of Chuquicamata. To do this the child has to follow directions and cues given by some of the personages through the story. They constitute a subset of the major problem concerning with returning the cooper ingot to Chuquicamata.

Virtual personages and objects of an adventure have been designed for a 3D virtual world. All of them are designed according to real characters of the geographical zone in story.

Interaction occurs through actions such as to take, give, open, push, pull, look, speak, use, travel, check the backpack, movements, and turns (90 /180 degrees). These actions can be done by using the joystick forcefeedback and keyboard.

Diverse interactive elements have associated actions defined by a matrix that crosses the user's behavior and different elements to represent the viability of the operation.

Through the "take" action the personage can load elements during the adventure that can serve in future actions. To do this there is a virtual backpack to save these elements. The backpack is an interactive point that can be accessed and the content saved inside it can be checked to be used in conjunction with the surrounding environment.

All actions performed in the software such as menu actions and actions during the story itself have an audio feedback to understand what is happing in the story. For the menu and some actions there are stereo sounds. To navigate through the virtual world AudioChile uses 3D sound to get a better spatiality and immersion. Spatial sound is provided during obstacles orientation such as the boundaries of the labyrinth as well as the position of personages and objects within the virtual environment. When the user performs illegal actions for a certain element an error feedback is provided. Interaction through the software can occur by using general and specific planes.

AudioChile is performed in three Chilean regions: Chiloé, Valparaíso, and Chuquicamata. Relevant zone information is provided by hidden cues that allow users to visit and know aspects of the geography and traditions of Chile. To travel between zones users must attain certain objectives that can help them in futures tasks.

Virtual world navigation is delimited by labyrinths that allow mobility and freedom to the personage within certain parameters (can give turns of 90 and 180 degrees, and move forward). In any moment the user can save the performance in the story or restart it later from the same leaving point when quitting the game. Each time the user interacts with users a log file is created to know the results of the session. This information is used to create a story at the end of the adventure that summarizes the performed actions through the game and how they solved the posed problem (see Figure 2).

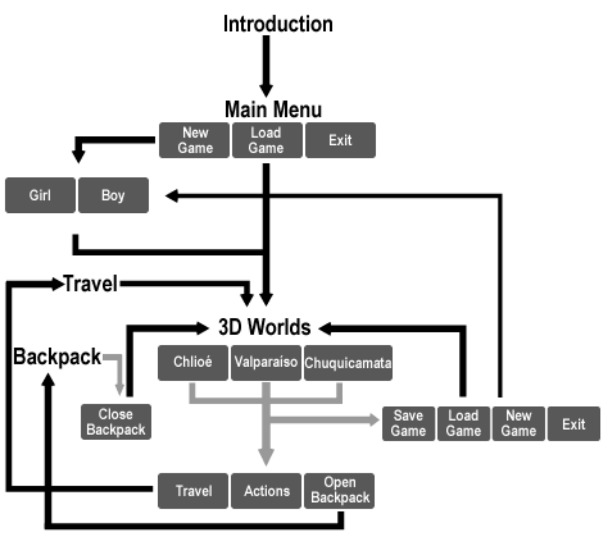

Figure 2. The Navigation Map

AudioChile has a compass to orient the user when searching for interaction with different objects and personages in order to solve the problem posed.

The software presentation allows easy access. Users with residual vision can identify elements on the screen through the use of contrasting colors and well defined images.

Mazes & Interfaces

AudioChile has defined mobility environments of three Chilean cities. They consist of three different labyrinths that the user has to navigate through the selected personage. Also, there are objects and personages with their defined positions within the virtual world (see Figure 3).

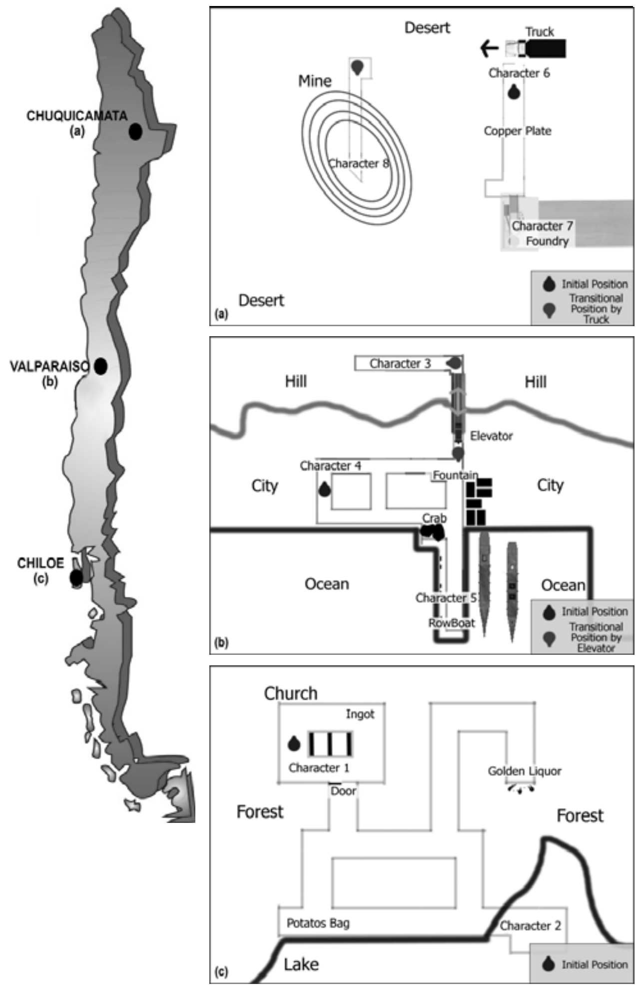

Figure 3. Labyrinth of three Chilean cities: (a) Chiloé, (b) Valparaíso, and (c) Chuquicamata. (Golden liquor is a typical liquor of Chiloé zone)

Three virtual environments represent the three Chilean cities. Each virtual world can be navigated through interacting with textures and special sounds. Each city consists of an introduction through audio and a typical music of the zone. Within the travel environment there are some representative places of different cities in order to trace the travel through Chile (see Figure 4).

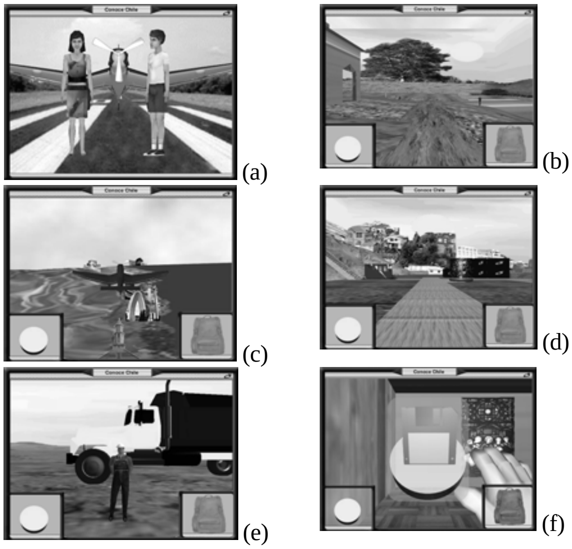

Figure 4. Screenshot of the graphic interface of AudioChile: (a) Personage menu; (b) Chiloé; (c) Travel; (d) Valparaíso; (e) Chuquicamata, and (f) Option menu (save game)

USABILITY TESTING

Participants

The sample was consisted of 6 Chilean children with visual disabilities, 4 boys and 2 girls ages 10 to 15 that attend a blind school in Santiago, Chile. Three children have low vision and three children with total blindness. Two of them are blind from birth, one child acquired blindness during childhood, two with good residual vision, and one with poor functional residual vision. Two special education teachers and one usability expert also participated in the study.

Children participated in four testing sessions each during four months. Each session was especially dedicated to one child in other to allow him/her to completely walkthrough the software.

Methodology

Each usability testing consisted of the following steps:

Introduction to the software. The user receives explanations about the purpose of testing and how to use the keyboard to interact with AudioChile. Teachers mediated to help children to orient when using the keyboard.

Software interaction. Users have to navigate throughout the virtual environment and according to their needs they can ask teachers for a better orientation.

Anecdotic record. Key data and observations of the child's interaction with the software are registered.

Application of usability questionnaires. The user answers questions asked by special education teachers.

Session recording through photography. Each session was photographed to register the child behavior during interaction.

Protocol reports of the session. All the data from the child's interaction is registered to get comments and suggestions to improve the software navigation.

Design and redesign. According to the comments and observations received the software is redesigned and some new functions are added.

Instruments

Three usability questionnaires were used during testing: 1. End-user questionnaire, 2. Prototype interface evaluation questionnaire, and 3. Problem solving understandability questionnaire. The end-user questionnaire was applied at the end of the usability sessions. It is basically a software acceptance test and consists of 18 closed statements with an answer scale of 1 to 10. It also contains 5 open questions. The prototype interface evaluation questionnaire was applied during the usability sessions. It is intended to evaluate images and audio feedback by including an observation instrument that has two parts: 1. A set of questions to identify images of personages and objects in the software, as well as to record observations during interaction is also included, and 2. A set of questions to identify input/output sounds and related associations made by blind children. It also contains observations recorded during interaction. The problem solving understandability questionnaire was applied during interaction and consists of a questionnaire with 10 open questions to evaluate the understandability of problems and tasks posed and related interface elements such as instructions, sounds, visual and sound cues, voice, navigation issues, and strategies to find hidden clues.

Figure 5. A blind user interacting with AudioChile

Procedure

The usability testing was first implemented in March 2004. Children pretested early prototypes of AudioChile during interaction (see Figure 5). The objective was to have an initial feedback about the sounds and images of the software in order to have early in the implementation phase information to orient the final design of interfaces. To get more detailed information we used the interface evaluation questionnaire.

The second stage of the usability testing was implemented in April 2004 after we processed the data from the first testing and redesigned and improved the prototype. Therefore at this stage we had a more advanced prototype. We used the prototype interface evaluation questionnaire.

The third stage of the usability testing was applied in two parts. We applied the end-user questionnaire to the same sample in two different moments: May and July. After each application we analyzed data from open and closed questions and took decisions about interface design/redesign. Both applications served to improve the usability of AudioChile.

RESULTS

The application of the prototype interface evaluation questionnaire gave us information about the presentation and use of the graphics and sound interfaces. The interface for the menu to associate actions of the personage were first planned in 2D format. These initial icons easily understood by sighted users were not appropriated in their representation for users with residual vision. For this reason we changed them with more representative images of associated actions to have a better effect on the user. This representation was made in a 3D format.

We also realized that there was a need to have sound feedback to allow certain logic of actions. Then we associated a characteristic sound to each action. For opposite actions we also provide the same feedback but inversed. In the same line, we used the keystrokes that have some relief (F, J) and those that surround them to orient easily within the keyboard.

The design of AudioChile was specially thought for blind children. Thus we emphasized the presentation of menus with one function at the same time based on the concept of circular menu. This idea came out after realizing that when designing software for sighted children the pointer of the mouse is crucial in the interface as well as always maintaining visibility by highlighting relevant controls and functions. Children with visual disabilities don't need to have a total visibility of the menu. Actually they currently select one option and then go through all the functions of the menu by using the keyboard. This gives more screen space to improve the design.

The idea of mapping objects through sound according to the four cardinal points (north, south, east, and west) worked very well for the user allowing them to identify behaviors such as reaching to a wall, a border of the forest, and a beach and avoiding to collide with some elements of the virtual world.

The associated sounds to the steps of the personage in different types of roads were modified many times to find the adequate sound for the steps and the type of terrain where the user walked.

From the application of the problem solving understandability questionnaire we got relevant information about the use of the software, the understanding of main instructions, the idea of finding a lost object, and thus understanding the whole problem. Children used the keyboard adequately and understood that the personage can take objects from the virtual world and save them in a backpack. They also identified, received, and understood the information provided by the software and applied it during the game.

Only one learner needed some mediation to navigate through the software perhaps due to the fact that the introduction to the software was too long. He may have lost the main objective and key directions to use the software. This needs to be improved to get a better mapping from users.

The application of the end-user questionnaire gave us very important information. We present this data by contrasting the software acceptability of children with residual vision and those totally blind. Later we present data comparing the results of the first and second testing.

Contrasting users

The motivation to interact with AudioChile was evaluated. To do this we posed 6 statements in the end-user questionnaire: 1. I like the software, 2. AudioChile is pleasant, 3. The software is challenging, 4. AudioChile makes me to be active, 5. I would like to play the software again, and 12. The software is motivating. The scores were between 1 (very low) and 10 (very high).

Children with residual vision showed a great motivation to interact with the software, with average scores of 9-10. Blind children mentioned lower motivation but it was still high, with scores between 7 and 9 points (see Figure 6). This is a very good result because in general children with visual disabilities of our sample were motivated to interact and walkthrough AudioChile.

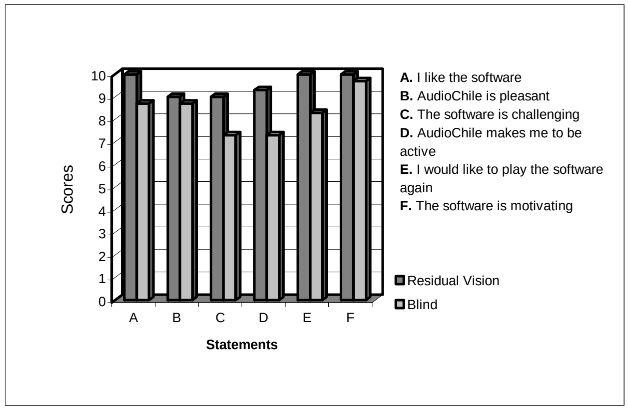

Figure 6. Motivation when interacting with AudioChile

A second relevant aspect is the software utilization. The statements considered were: 9. I felt in control of the software, 11. The software is easy to use, and 13. AudioChile adapts to my pace. Users with residual vision did not have difficulties when using the software (scores 8-10). Blind users had more difficulties to map the interaction with AudioChile (scores 5-7). Controlling the software and the easiness of use was more complex to blind children. Most children with visual disabilities mentioned that AudioChile adapts to their pace (scores 7-10) (see Figure 7).

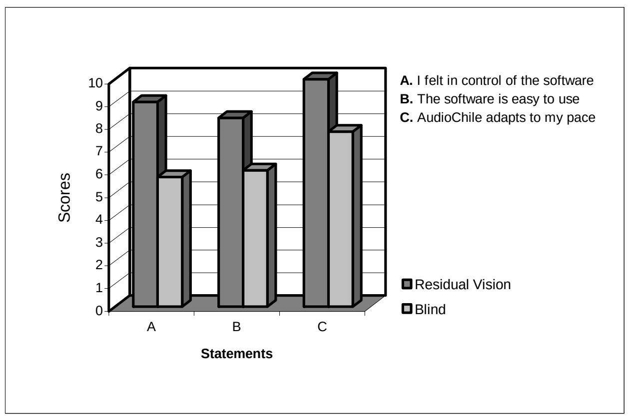

Figure 7. The use of AudioChile

To evaluate the sounds used in the software we considered the following statements: 15. I like the sounds of the software, 16. The sound are clearly identified, and 17. The sounds of AudioChile convey information.

As depicted in Figure 8 children with residual vision highly accepted the sounds (score 10). Blind children also accepted the sound of AudioChile (scores 9-10). This was a very sensitive aspect of this study because the software relies heavily on diverse sounds and voices.

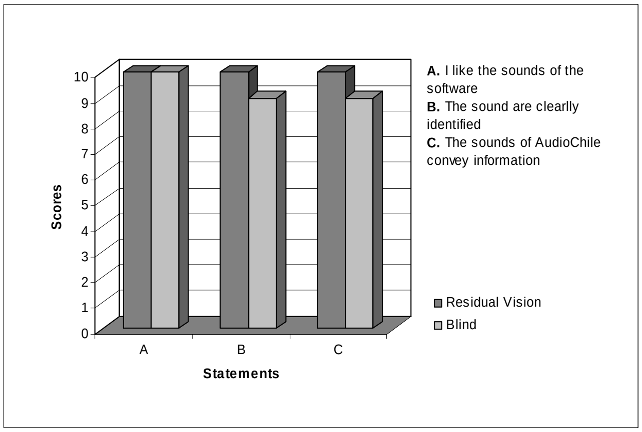

Figure 8. Perception of sounds of AudioChile

Initial and Final Testing

We also analyzed the user's final acceptance of the software before and after we redesigned and improved the software based on the results and requirements detected with the prototype interface evaluation questionnaire and the problem solving understandability questionnaire.

The contrasting results are displayed in Figures 9 and 10. We can observe that motivation increased after redesigning the software especially in software acceptability aspects such as likeness and pleasantness of the software as well of the activeness of the user. The acceptation of sounds increased after software redesign.

These results confirm our beliefs and experience concerning the importance of testing and retesting the software during implementation in order to design and redesign as much as it is possible when designing software for children with visual disabilities.

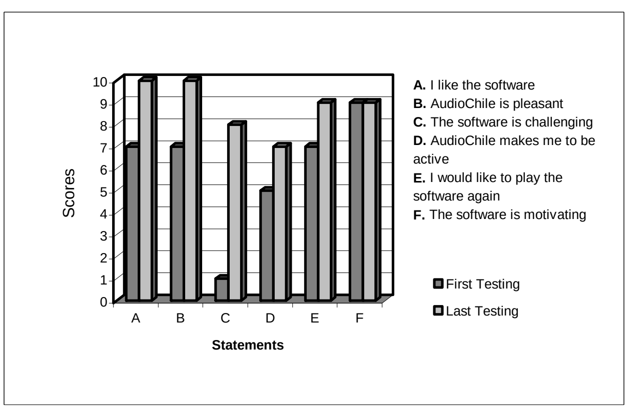

Figure 9. Motivation when interacting. First and last testing

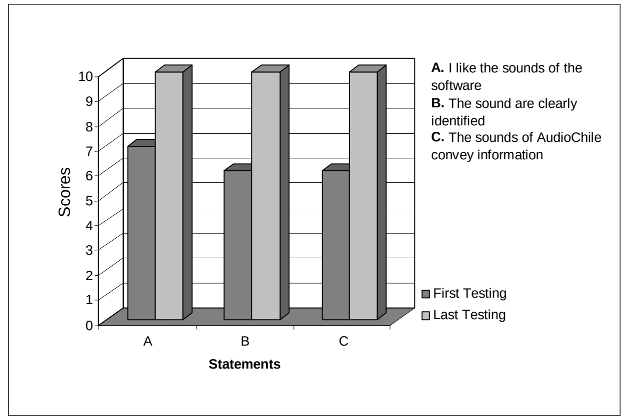

Figure 10. Perception of sounds of AudioChile. First and last testing

CONCLUSION

We have presented the design, implementation, and usability testing of AudioChile, a 3D sound virtual environment to assist the learning of problem solving in children with visual disabilities.

Children liked, accepted, used, and were very motivated with the software. After designing and redesigning 3D sound interfaces they mapped and navigated throughout the virtual environment.

Usability testing was crucial for mapping the end-user and the understandability of the software. Children with visual disability played a key role in the design and redesign of AudioChile by making suggestions, comments, and answering questionnaires to elicit information about how a 3D sound environment can map their needs and way of thinking.

Before we planed the usability testing we thought that the main idea was that the learner could discover events in the game without including a lot of cues. However after the first testing we had to add more instructions because learners needed many cues and instructions to orient themselves in the software to make it similar to their real environment.

When designing graphic interfaces for children with residual vision we found a clear issue of mental modeling. For a sighted person it is natural to see icons and associate them to certain actions. However, children with residual vision besides having difficulties recognizing certain icons did not associate them for the designed actions. After the first usability testing we changed icons to 3D format to obtain more fidelity in their representation. We also used stereo sounds that were the opposite in their related actions. For instance, sounds for opening were the opposite of closing sound.

The use of AudioChile has allowed children to differentiate and identify surrounding sounds that helped them to orient spatially. It also has helped them to improve the laterality and spatial concepts of up and down in relation to the north and south coordinates within a map. Sounds helped to catch the attention and motivated of children. The contrasting colors of the interfaces were also important for users with residual vision.

The visibility of graphic elements in the interface is also relevant. While sighted users prefer the visibility of possible actions and rapid access for a user with visual disabilities the main interaction device was the keyboard and the use of circular menus. This made us to design menus without caring about visibility by using representative icons with higher size to have a better feedback for users with residual vision leaving screen space to improve the representation of the interface by these users.

Finally, AudioChile is ready to be used with children with visual disabilities. Software design and redesign have been possible with the participation of children with visual disabilities in a Chilean school for blind. We envision a long term application of this software to evaluate the impact on the development of problem solving skills and thus helping these children to solving real life problem through sound.

FUTURE WORK

We are now working on the cognitive testing of AudioChile. We are interested in knowing what type of problem solving strategies can be developed by using this virtual environment as well as the paths followed and how sound help these children to develop cognitive strategies to solve everyday problems outside the virtual software.

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