Concept Mapping for Virtual Rehabilitation and Training of the Blind

Jaime Sanchez and Hector Flores

***Abstract*—Concept mapping is a technique that allows for the strengthening of the learning process, based on graphic representations of the learner's mental schemes. However, due to its graphic nature, it cannot be utilized by learners with visual disabilities. In response to this limitation we implemented a study that involves the design of AudiodMC, an audio-based, virtual environment for concept mapping designed for use by blind users and aimed at virtual training and rehabilitation. We analyzed the stages involved in the design of AudiodMC from a user-centered design perspective, considering user involvement and usability testing. These include an observation stage to learn how blind learners construct conceptual maps using concrete materials, a design stage to design of a software tool that aids blind users in creating concept maps, and a cognitive evaluation stage using AudiodMC. We also present the results of a study implemented in order to determine the impact of the use of this software on the development of essential skills for concept mapping (association, classification, categorization, sorting and summarizing). The results point to a high level of user acceptance, having identified key sound characteristics that help blind learners to learn concept codification and selection skills. The use of AudiodMC also allowed for the effective development of the skills under review in our research, thus facilitating meaningful learning.**

***Index Terms*—Auditory system, educational technology, learning, software testing.**

I. Introduction

NUMEROUS applications have emerged as a result of the use of new interactive technologies for the rehabilitation and learning of users with disabilities [1]–[3]. Some of these studies have used virtual environments to teach child pedestrians about road safety [4], to develop the social communication of children with autism [5] and to treat children with learning disorders [6]. In particular, several projects have been developed that focus on using virtual reality as support for the learning processes of blind children [7]–[10]. This kind of research has gone into depth on the use of specific multimedia interfaces, such as those based on audio in order to promote Blind users' interaction with the software. These studies conclude that these kinds of applications improve the understanding of specific content such as mathematics [7] and science [8], develop transversal cognitive abilities such as problem solving [7], [10], develop aspects of learning collaboratively [9], [11], and aid in the development of orientation and mobility skills [12], [13].

Several haptic interfaces have been studied for use by blind users [12], [14], [15], concluding that complementing haptic interfaces with virtual environments can be very encouraging and motivating, as well as can become critical elements for improving cognitive rehabilitation and learning processes [2].

Baños *et al.* [3] present a study that shows the different scenarios designed for the virtual rehabilitation (VR) treatment of flying phobia (FP), and the initial results supporting the effectiveness of this kind of tool for the treatment of FP in a multiple baseline study. All of these applications, though they have a significant impact on rehabilitation treatment, rely heavily on multimedia interfaces such as a specific input source. Unfortunately, a blind user is severely limited in using these kinds of tools. How, then, can a blind user participate in rehabilitation and learning processes by using interactive virtual technology?

One of the learning and rehabilitation techniques for sighted people that can also be used by blind users when adapted to their mental model is concept mapping, proposed by Novak [16]. A concept map is a tool for knowledge representation that puts meaningful learning into practice [16]. This technique is widely used with the support of virtual technology [17], [18], [19]. These technologies provide a series of resources that promote and facilitate learning through the use of concept maps. Some even allow for the generation of knowledge through the collaborative creation of maps [17]. However, these technologies have been developed mainly by using basic graphical user interfaces that are not accessible to blind people, marginalizing them from using these kinds of applications. A concept map allows us to identify the most relevant concepts from the content of a certain subject matter, to relate and organize them hierarchically, and to produce a graphic representation of the mental schematics associated with such content, all in one.

As such, there is consensus that the cognitive deficit associated with blind learners is more related to a lack of stimulation than to a lack of vision, which is why rehabilitation based on audible stimulus is a viable alternative [10]. This occurs mainly because stimulation is a fundamental process in learning, helping the learner to be active and interested in the learning process. Long-term studies have demonstrated that the use of audio is a viable way for stimulating users with visual disabilities [7].

In general, concept maps are used as a learning tool, which is to say that teachers use them as a methodology to mediate learning and as an educational source for introducing specific content. However, some have used this technique as a tool that favors cognitive rehabilitation, such as when it is used as a problem-solving technique by people with cognitive deficits for the development of skills such as grasping new concepts simply

Manuscript received April 09, 2009; revised July 14, 2009; accepted August 27, 2009. First published September 22, 2009; current version published April 21, 2010. This report was supported by the Chilean National Fund of Science and Technology, Fondecyt under Project 1060797 and in part by PBCT-CONICYT under Project CIE-05.

The authors are with the Department of Computer Science, Center for Advanced Research in Education, University of Chile, 2777 Santiago, Chile.

Digital Object Identifier 10.1109/TNSRE.2009.2032186

and schematically. In this way it is used as a mechanism for instruction and training, as in, for example, the improvement of meta-cognitive abilities in preschool children [20], or in the fields of psychology and human services. Clients' perceptions of helpful experiences in counseling [21], depression [22], and the attitudes associated with people who suffer chronic lower back pain [23] have also been described through the concept mapping method. Unfortunately, due to its graphic nature, concept maps cannot be utilized by learners with visual disabilities. This deprives them of using a technique that could help to improve the learning process, and thus make learning more meaningful to them. For this reason we have implemented a study that involves the use of audio-based software from the users' perspective in order to facilitate the process of the design and construction of concept maps.

The purpose of this study was to design and evaluate the use of an audio-based, concept-mapping tool that helps blind users to be able to construct concept maps, in order to improve their representation of knowledge and their learning capabilities, as well as a tool for meta-cognitive development. We provide a tool that allows blind users to be builders of their own learning, by monitoring and being aware of their own conceptual learning as a self-regulating learning activity.

II. Research Activities

The research activities involved in this study comprised three stages. One stage for observing how blind users construct concept maps using concrete materials. A second stage allowed for the design, development and evaluation of a software program for blind students to be able to develop concept maps. A third stage that consisted of a defined cognitive evaluation to determine how significant using this kind of tool might be for measuring the development of certain cognitive abilities in a group of visually impaired students. The participant groups in each stage were different in order to avoid bias in their participation in subsequent activities of the study.

A. Observing Blind Learners Using Concepts Maps

1) Sample: The sample was made up of 11, legally blind, fifth and sixth grade children, between nine and fifteen years of age. Two special education professionals, specialists in visual impairment, participated as facilitators. Of the sample selected, 100% of the children could use a keyboard correctly, 82% used Braille or Macro Type reading and writing systems efficiently (in accordance with the degree of their visual disability), 73% of them were girls and 27% boys, 27% were totally blind while 73% had low vision, and all of them were legally blind. Although the students participated in a normal educational process in a school for children with visual disabilities, none of them had ever had the opportunity to interact with concept maps as a learning technique.

2) Procedure: The observation stage was organized into seven, 2-h work sessions. During these sessions the blind learners were taught the concept mapping technique. They reviewed, completed and constructed concept maps individually and in groups (three groups of three children and one group of two children) with defined purposes, such as extracting meaning from written texts or expressing what they knew about a subject. Sticky boards were used for the insertion and rearranging of concepts, and a Braille ruler was used for writing concepts on a plastic material that allows for easy reading.

The objective of the observation stage was to evaluate the hierarchical concept relations that blind learners establish in their mental structure, as expressed through a concept map. Special emphasis was placed on observing the concrete organization that they made of their mental representations and the strategies that they used to create a map. Such information was necessary in order to design and develop a software program that aids and supports such activities.

3) Results of the Observation: From the anecdotal records gathered by the participant teachers during their observation and the analysis of each videotaped session, a series of concept mapping elements were defined and discussed such as hierarchy, links and the spatial location of significant elements for an adequate and pertinent use of concept maps by learners with visual disabilities. Based on the analysis of the initial observation activities, we can point out that the legally blind learners who participated in the evaluation could relate concepts by using the propositions of two or three different concepts, independent of the kind of activity involved. In addition, they were able to identify the structure of a concept map. It must be pointed out, however, that many of the relations they established were meaningless. This could be due to the fact that there was evidence of difficulties with reading comprehension, as well as difficulties expressing the meaning of concepts as units of meaning, and limited capacities for summarizing information. Lastly, the students needed concrete material and the aid of a facilitator in order to distribute the concepts spatially, to read and review their maps, and to represent the connections between concepts.

In the last sessions it was clearly observed that children with visual loss had less difficulty with designing concept maps than the totally blind children. This could be explained by the fact that the former can better manage some visual aspects and place concepts adequately, in comparison with totally blind children who do not have visual cues.

Fig. 1(a) represents a concept map based on typical dances in the country created by a legally blind student with concrete material, and with a clear problem of structure. In comparison, Fig. 1(b) depicts a concept map on the same subject that was created by a sighted child of similar age from previous research on concept mapping for sighted learners [24], clearly demonstrating a strong contrast between both images. According to our observation, this difference was produced by the blind child's lack of clarity as far as spatial positioning within the map he was creating. Visually impaired children tend to put hierarchically aligned concepts in a very lineal and sequential manner (vertical organization), making the task of constructing the map and its conceptual representation quite difficult. In the construction of a map by a sighted child, in general there is better spatial distribution, which provides coherence between previous concepts and new ones to be inserted.

The learners that participated in the study had never designed or interacted with concept maps before, a factor that was especially disadvantageous for the totally blind learners as concept maps are highly visual. Two learners did not present any major difficulties; they used Braille for reading and writing but

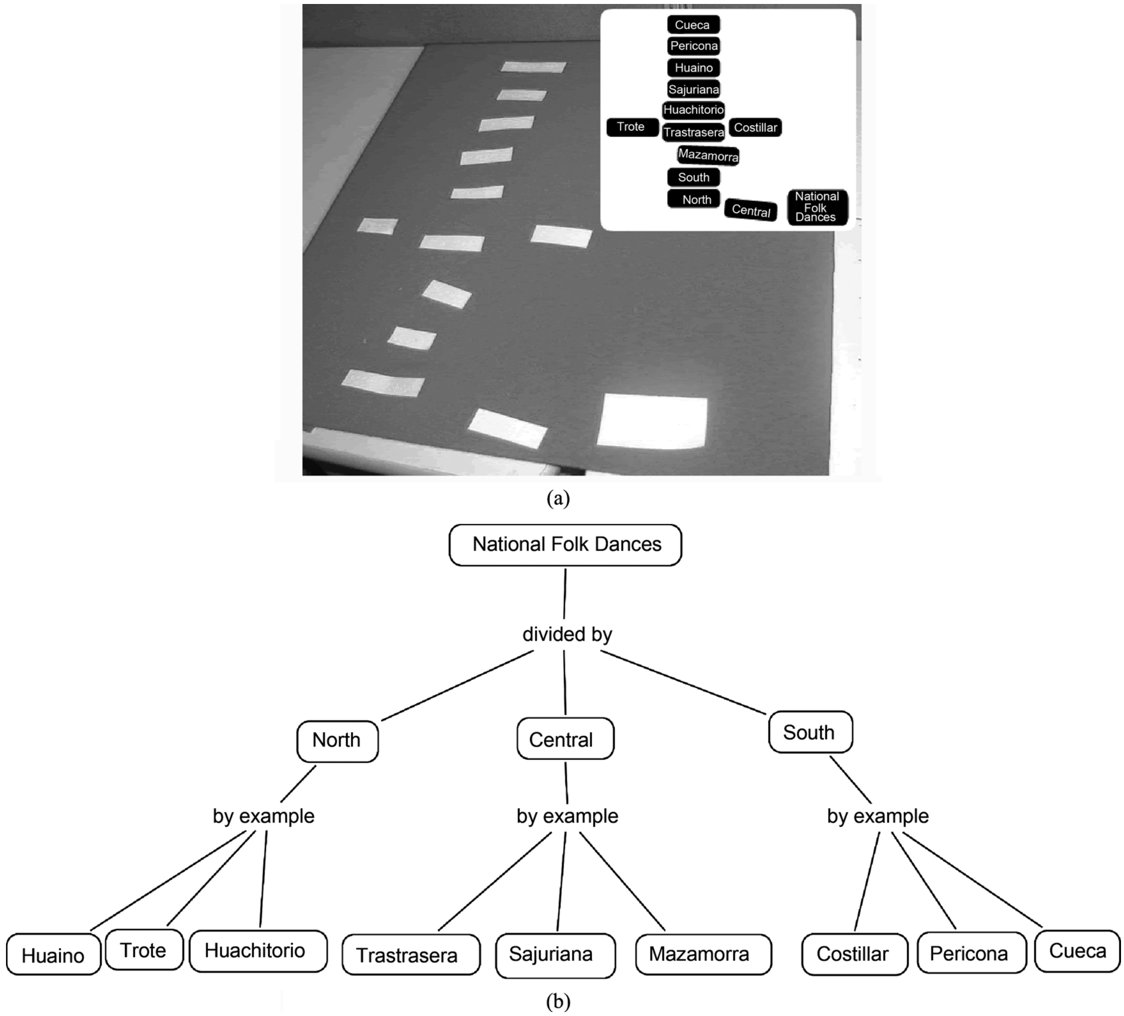

Fig. 1. (a) Representation of a map created with concrete material by a blind boy. (b) Concept map designed by a sighted boy for the same concepts.

had residual vision that allowed them to distinguish forms and colors, so that the visual referent was received.

The analysis of the maps was carried out and discussed by teachers, who reviewed and grouped them according to similarities in their design structure. This design structure would be explained according to the cognitive level of the participating children, so that the children from a certain age group would have a similar cognitive profile.

We considered two age groups: the first group (younger students) was between nine and ten years old (five participants), and the second group (older students) was between eleven and fifteen years old (six participants).

In general, it could be seen that maps constructed by students within a specific range of similar ages were alike. However, it was also observed that the differences between maps made by students with a higher age difference were substantial, with the older students presenting higher quality maps (more associations, more hierarchical levels, more meaningful conceptual relations). This implies that the older students displayed a better and clearer organization of concepts within the map, being able to create a more precise and high quality concept map. These students were able to make better use of the linking words, as well as to better relate the concepts to one another. These differences can be explained, given that these students possess more knowledge and experience than their younger classmates. These observations allowed us to define requirements for the design of AudiodMC, such as the following.

1) What elements are necessary for an easily recognizable hierarchy, which is to say, that clearly represents which concept is more important than the other, which in a visual concept map is expressed when one concept is above another.
2) That the connections must be integrated easily and directly, which means that the children must be able to easily create a proposition in the moment, showing clearly which concepts are related to each other and which word connects the related concepts.
3) That the spatial location of the elements must be easily recognizable, which means that the blind child must recognize the concepts' positions regarding the other concepts, in such a way as to clearly see a conceptual structure.

B. Design of AudiodMC

The design and development of AudiodMC (audio-based concept map designer) was based on software design methodologies for visually impaired people [25]. In order to use

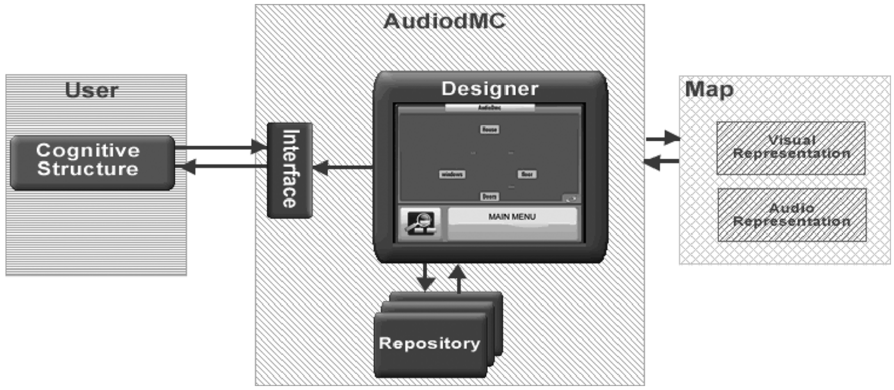

Fig. 2. Architecture model of AudiodMC.

AudiodMC it is necessary to utilize the keyboard, both for selecting specific actions and to navigate the map that is being created. Each action that the user takes in AudiodMC generates an audible feedback for the user to be able to control the actions that he/she performs. AudiodMC provides a predetermined gallery of concepts that can be included in the map that the user creates, or that can be previously installed by the teacher for a specific learning activity. Each concept included in the blind learner's map is characterized according to its level in the hierarchy, and its position in each of these levels is determined by a spatial-audio indicator that identifies its position on the map.

Fig. 2 shows the architecture of AudiodMC, the model of which is made up of the following components.

User	Creates the concept map through some activity that requires him/her to represent the structure and relations between the concepts included.
Designer	Corresponds to the concept map editor and provides the user with different functions for building the map based entirely on sound.
Interfaces	Set of I/O devices that allow for the user's interaction with AudiodMC (keyboard, graphic representation and audio system that describes the maps made).
Maps	Set of nodes and relations that the visually impaired user generates with AudiodMC, and which are represented through audio and simultaneously with graphics.
Storage	Stores the maps that the user has designed for future modification or evaluation.

In order to modify the position of the concepts, erase them or listen to their connections with other concepts, there are two methods that the user can choose from the following.

1) Concept by concept review, in which an associated submenu is available that allows the user to execute the following actions: create a proposition, listen to a concept, eliminate a concept, and review connections of a selected concept. Navigation of the map using this method allows the user to listen to the propositions that have been developed at the same time that audio feedback is provided on their position on the map. This allows the user to have control over the map editing and making processes.
2) Review by assigned proposition: This method allows the user to review the map starting from the existing relations between the concepts. The propositions are created through recordings that the user makes with the microphone, or by writing them with the keyboard.

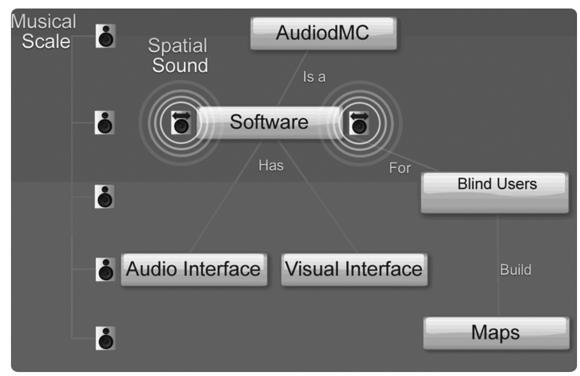

Fig. 3. Audio representation of a concept map with AudiodMC.

Each time the user enters into AudiodMC, he/she must write his/her name in order to create a storage compartment that saves all the maps that he/she creates, and to be able to continue with their construction whenever it is desired. The maps are saved with a name that the user defines, generating audio feedback for the user to be able to identify each one.

1) Interfaces: The components of AudiodMC are presented through an audio-based menu, in which all the options that are available to the user are presented in spoken text using a text-to-speech engine. These options are: 1) create a new concept, 2) create a category, 3) create a new map, 4) open a map, 5) record map, 6) read map, 7) list of concepts, and 8) map review.

Fig. 3 shows how the sounds in AudiodMC are distributed in an example of a concept map. In this figure, one can observe the use of spatial sound and a musical scale. The former corresponds to stereo sound that allows for a representation of the horizontal location of an element in space through the use of the arrows on the keyboard. The latter represents the hierarchical level of the map at a certain vertical location. Rather than using spatial sound, this position is represented by a musical scale (Fig. 3).

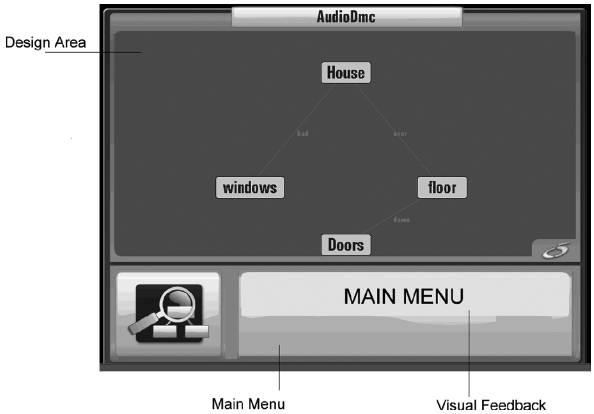

Fig. 4. Principal interface of AudiodMC.

Fig. 5. Blind users constructing concept maps with AudiodMC.

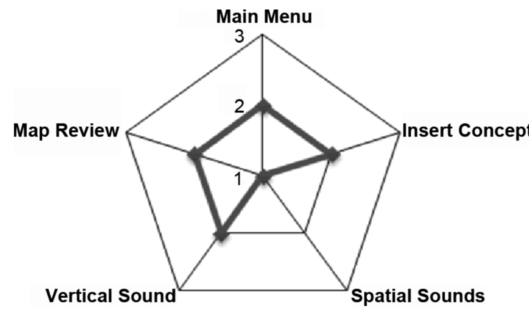

Fig. 6. Usability evaluation of AudiodMC.

To locate a concept on the map, first the user locates its horizontal position, followed by its vertical location, all of which is achieved through feedback from these sounds. In order to improve the interaction between AudiodMC and users with visual loss, the visual interfaces correspond to elements of high visual contrast, and with few objects per screen (Fig. 4).

The student interacts with the software through the keyboard, using mostly the direction keys to select the elements that AudiodMC provides. To create a map, the student must first choose a concept from the audio concept gallery. This gallery includes concepts that have been previously created by the student, as well as pre-established concepts from previous activities. To listen to the concepts that he or she can choose from, the student browses by means of the keyboard, listening to the reproduction of the text-to-speech engine for each available concept.

2) Interface Usability Evaluation: AudiodMC was subjected to a preliminary interface usability evaluation in order to make the application more apt for visually impaired users and adjusted to their ways of interacting and mental models.

Sample: A sample of twelve children between nine and fifteen years of age (eight girls and four boys) was established. Ten of them had visual loss and two were totally blind. The sample was separated into six pairs which participated in simple activities involving interaction with AudiodMC during a 40-min session. All participants were legally blind. During the entire evaluation, a special education professional specialized in visual impairment participated as the facilitator.

Instruments: An observation scale was used for the usability evaluation, which had as a main objective the identification of problems with the interaction between the users and AudiodMC.

Usability observations were made based on the assigned tasks, allowing observers to verify any issues regarding the users' interactions. Each task was evaluated on a scale of appreciation with a three-level achievement scale: level 1: very good, level 2: good, and level 3: deficient.

The tasks evaluated were 1) entry interface, 2) main menu, which contains the principal functions of AudiodMC, 3) tool for creating a new concept to be inserted into the map, 4) insertion of a concept into the design area of a concept map, 5) effectiveness of spatial location sound (horizontal), 6) effectiveness of concept hierarchy sound in the map during the design process which presents the vertical distribution of concepts, 7) review process of concepts in the concept map, in which relations are inserted and when it is possible to edit the map being created, and 8) process of recording the connections.

Procedure: The evaluation was held in the computer laboratory of the Santa Lucia School for the Blind in Santiago, Chile. The children had to carry out the eight previously described tasks with the AudiodMC software. Once the tasks were completed, with the aide of a facilitator the children proceeded to evaluate the software interfaces. Finally, the group of children and the facilitator met to share information in a group self-reflection on general aspects of the activity they took part in and the use of AudiodMC (Fig. 5).

Results: Of the six pairs that participated in the process, two commented that they could perform the activities proposed without any major problems. The other four pairs, on the other hand, commented that they had problems mainly because there was only a slight difference between the sounds representing concepts in the same hierarchy (spatial sound). In this way, four out of the five components of the interface were evaluated with a level two response (good) (Fig. 6).

The main menu component was, in general, well accepted by the users. The mechanism for the presentation of the items in this menu facilitates the interaction and could be more efficient (level two). The tool for inserting a concept was, in general, also well accepted (level two). However, at first the students had a hard time understanding how the categories and their concepts were structured. They stated that horizontal placement through spatial sound is a good idea, but that it must be more discreet in relation to the horizontal positions of the concepts (level one). It is for this reason that, after this evaluation, the software was redesigned to provide sound in five levels of horizontal location, thus improving the interaction during the process of creating a concept map. The vertical distribution of the concepts through audio cues was well accepted by the students (level two). They found that the elimination of the superposition of concepts is crucial in order to not be confused when putting one concept over another. The map review was one of the components of interaction that had the highest levels of acceptance of all the interfaces presented (level two), which was also reflected in the students' comments. This was due primarily to the fact that the interaction with this function is very easily navigated by using the keyboard for the map, resulting in precise audio feedback. It was also observed that as they used AudiodMC more and more, they better understood and interacted with AudiodMC. This shows that AudiodMC provides for easy use by the user, and does not require further instruction after the initial directions. Furthermore, over time the users became more familiar with the software's sounds, which improved the interaction. Four children displayed pertinent use of the software's physical interface by interacting adequately with the keyboard buttons, with the help of the facilitators. All of the students were able to enter and position the concepts in the map. In locating the concepts on the screen they used the auditory references, but when adding the following concepts they tended to confuse the position in which they should be located. This is due to the fact that they would lose track of the related position with regards to its location, because they thought that they were above the previous concept that had been entered. The children with low vision argued that it was essential to include visualization of the entire map both in graphic and audio format.

C. Cognitive Evaluation

In order to evaluate the cognitive impact of the use of AudiodMC, a study was developed that consisted of a classic, quasi-experimental, pretest/posttest research design with a control group. The study was based mainly on the analysis of the impact that the use of AudiodMC has on the development of general concept mapping skills such as association, classification, categorization, sorting and summarizing. The instruments used for each of these evaluations are presented below.

1) Sample: The sample defined for this stage of the study was made up of seven students between twelve and fifteen years of age. This group included two boys and five girls, in which one child had low vision and six were totally blind. The control group was made up of three students (between thirteen and fifteen years old), and the experimental group consisted of the remaining four (between twelve and fourteen years old). The groups were defined randomly. Two special education teachers specializing in blind children participated as facilitators and evaluators during the research study. All of the participating users utilize Braille as a mechanism for reading and writing; however those with partial vision could generally recognize figures and shapes, while those without partial vision could not.

2) Instruments: For the evaluation, two similar instruments were used for the pretest and the posttest, consisting of the same questions and different written texts designed to extract meaning in order to control for the learning that the children could have experienced if answering the same written text for a second time (posttest). Each of these instruments consisted of a questionnaire made up of five problems, and each problem related to one of the skills under review (association, classification, categorization, sorting and summarizing) that are necessary for the construction of a concept map. These problems allowed the student to face a situation in which he/she was obligated to develop the desired skill.

In addition, cognitive tasks that consisted of concept mapping activities through the use of concrete material and AudiodMC were also carried out

To evaluate the students' progress on the creation of concept maps, an evaluation scale was applied. This scale contained eight criteria that were all grouped together and associated to the skills under review, all of which are included in the process of creating the maps. This evaluation was applied to both the control group and the experimental group. The criteria were organized according to each of the five skills in the following way.

1) Association.
   a) Indicates relationships of meaning between two concepts through a line and a corresponding linking word.
   b) The relation is valid.
2) Classification.
   a) The horizontal and vertical relations established between concepts are correct.
   b) The map shows meaningful and valid connections between the different elements in the conceptual hierarchy.
3) Categorization.
   a) The map presents a hierarchical structure.
   b) Each of the subordinate concepts is more specific and less general than the concept observed above it.
4) Sorting.
   a) The map is organized.
5) Summarizing.
   a) User selects key concepts for inclusion in the map.

3) Procedure: This stage of the study was carried out in four steps: Preparation of concept maps (four sessions), pretesting (five sessions), application of cognitive tasks (eight sessions), and posttesting (three sessions). Each session lasted ninety minutes.

The objective of the preparation stage was for the students to familiarize themselves with the technique, structure and organization of concept maps. To these ends, for learning activities were created based on basic science content: living beings, animal classification and biological categories, and were carried out during four separate sessions.

Each learner played different games of association and classification regarding the content-related concepts, having to do with living beings. At the same time, the generic structure of a concept map and its essential components were explained to them with concrete material, using a relief model. Using this material as a model the students created a concept map as a group, using the ideas and concepts from the game that each group considered to be the most significant (Fig. 7).

The pretest was applied to the entire sample as a group during five sessions, adapting the time required to the pace of the learners.

The cognitive tasks consisted of four playful activities, the main content of which had to do with ecology and climate change. In these activities, the students performed an interactive

TABLE I
STATISTICAL ANALYSIS OF DIFFERENCES BETWEEN PRETEST AND POSTTEST SCORES

	Mean Pretest vs. Posttest						
	Group/Item	Associate	Classify	Categorizing	Sort	Synthesize	Total
Pretest	Control	0.1429	0.3889	0.4722	0.6667	0.1481	0.3638
	Experimental	0.2857	0.4167	0.5208	0.3125	0.3611	0.3794
Posttest	Control	0.3810	0.3889	0.5556	0.2500	0.7037	0.4558
	Experimental	0.5357	0.6667	0.6875	0.4375	0.5556	0.5766

Fig. 7. Group work in the preparatory stage.

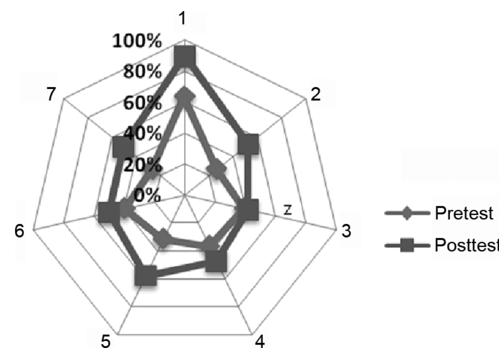

Fig. 8. General difference between the pretest and the posttest.

reading exercise, in which all the members of the group had to decide on the continuation of a storyline. Then they answered questions regarding the subject matter in the context of a board game, listened to a documentary and read a newspaper article. After having completed each task, the students were asked to extract the most relevant concepts from the tasks they had carried out and the contents they had learned, and to write these concepts down. Finally, they were asked to build a concept map that included all of the concepts they had recalled, through the use of concrete material (control group) and the AudiodMC software program (experimental group). The posttest was applied to the entire sample as a group during three, ninety minute sessions. Posttest and pretest instruments were similar and were administered under the same conditions.

4) Results: The most significant results have to do with the substantial differences in the pretest/posttest scores between the control group and the experimental group. Just as in the first stage, results showed that the older students built more elaborate maps than the younger students. In addition, it was shown that this situation was also due to the fact that the older students had more knowledge and experience than their younger classmates. As can be seen in Fig. 8, there was an increased score between the pretest and the posttest for each case that made up the sample.

In general, the experimental group obtained a higher pretest/posttest improvement (gain) than the control group (20% and 10%, respectively). This difference in favor of the experimental group can be seen for the majority of the skills under review.

In comparing the differences in achievement between the pretest and the posttest, it can be observed that both the experimental and control groups improved their total scores. In the case of the control group, there is a mean score of 0.36 for the pretest and 0.46 for the posttest, which implies an improvement in achievement by 10 percentage points. In the case of the experimental group, the pretest resulted in 0.38 points, while the posttest increased to 0.58, which means an improvement by 20 percentage points (Table I).

TABLE II
STATISTICAL ANALYSIS OF THE CONTROL GROUP

Control Group (Pretest/Posttest)	Mean	Std. Dev.	t	Sig.
Associate	-0.23810	0.08248	-5.000	0.038
Classify	0.00000	0.28868	0.000	1.000
Categorizing	-0.08333	0.14434	-1.000	0.423
Sort	0.41667	0.28868	2.500	0.130
Synthesize	-0.55556	0.11111	-8.660	0.013
Total	-0.09206	0.10280	-1.551	0.261

The items for which the increase between the pretest and the posttest were highest are the skills of classification. In this skill, the control group's scores remained at 39% achievement, while the experimental group increased 25 percentage points from 42% achievement to 67%. In the skill of sorting, in which the control group surpassed the experimental group in the pretest by 36 points (67% versus 31%), but is overcome by the experimental group in the posttest by 19 percentage points (25% and 44%). And in the skill of summarizing, the control group improved by 56 points (from 15% to 70% achievement), while the experimental group improved by only 19 points (36%–56%).

The student's t-test for dependent samples that was applied to the control group sample shows that the differences between the pretest and posttest scores are statistically significant only for the skills of association (Sig. $= 0.038$; $t = -5.0$; $p < 0.05$) and summarizing (Sig. $= 0.013$; $t = -8.66$; $p < 0.05$). As for achievement in the other individual skills measured, there are no statistically significant differences: Classification (Sig. $=$ 1.0; $t = 0.0$; $p < 0.05$), categorization (Sig. $= 0.423$; $t =$

TABLE III
STATISTICAL ANALYSIS OF THE EXPERIMENTAL GROUP

Experimental Group (Pretest/Posttest)	Mean	Std. Dev.	t	Sig.
Associate	-0.25000	0.13678	-3.656	0.035
Classify	-0.25000	0.31914	-1.567	0.215
Categorizing	-0.16667	0.29659	-1.124	0.343
Sort	-0.12500	0.32275	-0.775	0.495
Synthesize	-0.19444	0.27778	-1.400	0.256
Total	-0.19722	0.10651	-3.703	0.034

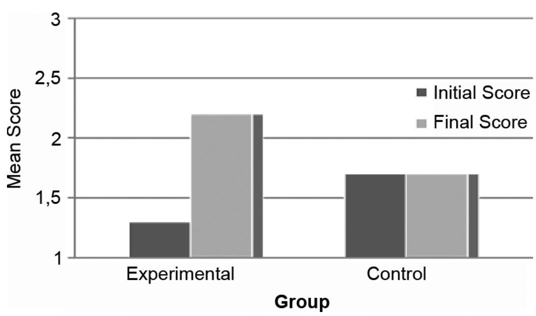

Fig. 9. General difference between the experimental and control groups for cognitive tasks.

-1.0; $p < 0.05$), and sorting (Sig. $= 0.130$; $t = 2.5$; $p < 0.05$). There were also no statistically significant differences for the total score of the items analyzed ($t = -1.55$; $p < 0.05$) (Table II).

Table III presents the data obtained from the experimental group. It is possible to appreciate a statistically significant difference between the results for the ability to associate (Sig. $= 0.035$; $t = -3.66; p < 0.05$) and the results for the total skills studied (Sig. $= 0.034$; $t = -3.70$; $p < 0.05$). The skills that did not obtain statistical significance were classification (Sig. $= 0.215$; $t = -1.567$; $p < 0.05$), categorization (Sig. $= 0.343$; $t = -1.124$; $p < 0.05$), and sorting (Sig. $= 0.495$; $t = -0.775$; $p < 0.05$).

The data gathered reveals that the experimental group had a statistically significant increase between the total pretest/posttest skills (Sig. $= 0.034$; $t = -3.703$; $p < 0.05$), unlike the control group, which did not have a significant increase (Sig. $= 0.261$; $t = -1.55$; $p < 0.05$). This result is significant for our study because it allows us to infer that the use of our methodology, with the support of the AudiodMC software, could have an effective and important impact on the development of certain skills used when producing concept maps (associate, classify, categorize, sort, and summarize).

In general, the results also allow us to point out that the ability to associate is one of the most important skills, in that it is essential for the learning process. This skill allows for the maintenance of coherence between the concepts studied, as well as allowing for the relation between the already-learned concept and a new concept.

In the evaluation carried out during the development of the cognitive tasks, it was shown that there actually was an increase in the average scores of the experimental group with relation to the control group (Fig. 9).

TABLE IV
STATISTICAL ANALYSIS OF COGNITIVE TASKS

Group	Mean	Std. Dev.	t	Sig.
Control	0.02500	0.37749	0.115	0.919
Experimental	-0.93750	0.59739	-3.139	0.052

For this analysis a student's t-test for related samples was carried out, comparing the achievements obtained by the participants at the beginning of the concept map development process and at the end (Table IV). In this way, the experimental and control groups were compared, observing that the experimental group presented a statistically significant increase between the pretest and posttest mean scores (Sig. $= 0.052$; $t = -3.139$; $p < 0.05$), while there was no statistically significant difference for the control group (Sig. $= 0.919$; $t = 0.115$; $p < 0.05$).

The fact that the experimental group obtained a statistically significant increase between the total pretest/posttest skills could be explained by the use of the AudiodMC software and accompanying cognitive tasks. This initial results point to the direction that confirms our hypothesis that the use of audio-based tools by people with visual impairments to be able to create concept maps could help with the development of the skills of association, classification, categorization, sorting and summarizing as a whole. AudiodMC could also function as a supportive tool for learning processes, helping such students to understand potentially complex concepts and their associated relationships, such as those in the field of science.

III. CONCLUSION

The objective of this study was to design and evaluate the use of a tool for blind users to be able to construct concept maps in order to improve their learning capabilities, and as a tool for meta-cognitive development, rehabilitation and training. Unfortunately, the software currently developed for the design of concept maps has a heavy visual component that marginalizes blind users from utilizing it. This situation is crucial in that it impedes blind users from accessing these kinds of tools, which help to strengthen learning. To these ends, we used our previous experience [7]–[9], [13], [24], [25] in the design of virtual environments and interactive software for creating concept maps for sighted people, in which we identified the most important and unique characteristics that a concept mapping software program should entail. Such characteristics include a program that is easy to use, that has a gallery of concepts that are easily accessible to the user, a mechanism for the total review of the map developed, and in which the relations are easy to create. Each of these characteristics was to be included in AudiodMC. From this initial step we were able to evolve to the AudiodMC program, considering the same functions as a conventional mapping software program, but adapting it for use by users with visual impairments. This implied the creation of a methodology that would allow for the implementation of a concept design program that included the participation of blind students from the very beginning. The idea was to integrate their feedback and comments into the process of product design, in such a way that it would be adjusted precisely to their specific needs, interests and way of knowing.

As a result of the design process for AudiodMC, we can point out that the steps that should be considered as priorities for the implementation of a methodology to create graphic representations for use by the blind are: selection of the most important functions for the construction of graphic representation; conversion of these functions so that they can be interpreted through audio feedback; and the definition of a system of unique feedback with few voiced items. There was also the issue of a trade-off between forming a correct representation based on the audio cues for the concepts in the map, and their being mapped in a structure that would not violate the principles of the concept mapping technique, which was something that we took into consideration during the entire design process.

The initial results obtained in this study, considering the limited sample size, point in the direction that AudiodMC, as an audio-based system, could probably allow for students to be able to learn and use the software as a learning tool or as a mechanism for rehabilitation and training in areas in which a concept map allows them to understand concepts and the relations between them in order to construct meaning. In this way, the use of a concept map could trigger a discussion and/or negotiation of concepts with a facilitator or a tutor, with the support and mediation of an interactive virtual rehabilitation environment. The idea is that virtual rehabilitation through the use of concept maps may generate spaces in which learners with visual disabilities can interact with the software environment in a natural and pertinent way, and in which the principal interactive and communication interface is made up of audio cues.

During the process for the evaluation of AudiodMC we discovered that the majority of blind users that participated in this study did not recognize the concept mapping technique, and showed that they did not possess the abilities necessary to approach these activities. However, in introducing them to the subject they quickly expressed their motivation, and it is worth emphasizing the concentration with which they took on the proposed activities. From this study, it was not possible to determine if the children produce more structured maps by using AudiodMC, as is the case with sighted children. However, we believe that would be relevant to analyze this situation in the next stage of our ongoing research.

In the study it was shown that for blind users it is very difficult to form a hierarchical structure of related concepts, and when they do it (using memory), they make a significant cognitive effort. It is for this reason that a preparatory stage was necessary in which the users internalized a basic hierarchical structure.

The study provides initial data indicating that the legally blind users who participated in this study may effectively create structured representations of concepts. Unlike the traditional way of building a concept map, AudiodMC allows for the structures to be created through the use of iconic and spoken audio (as well as through visual aids for those users with low vision). In this way our initial results indicate that the audio-based map makes sense, in that AudiodMC could facilitate navigation and the modification of the hierarchical structure of a concept map that the blind user does not see and which, in traditional contexts, would be carried out very slowly through the use of Braille and touch. More research is needed to reach more definitive conclusions.

One of the most important initial results shows that a user-centered software design of this nature may improve the interaction of the blind user with the resulting software. This may be due to the fact that this methodology actively involves users in the design process, considering their needs, interests, mental models, ways of knowing and ways of natural and intuitive interaction. AudiodMC was designed based on this methodology, making iterative redesigns in order to approximate its functionality to the users' mental model.

The process for the evaluation of the software's impact on the development of skills during the creation of concept maps, such as relating, classifying, categorizing, organizing and summarizing, provided initial data that points in the direction that the use of and interaction with AudiodMC may effectively allow the users to increase their development of such skills as a whole. These general abilities facilitate learning processes for students with visual impairments that participated in this study, but at the same time they are also abilities that allow the students to be able to perform better in other contexts, such as when they have to solve real-life problems. Such problems often involve the skills studied in our research, and range from domestic activities to school activities. This is because such skills are of a general order. We were also able to show that it is always necessary to have a preparatory process, so that the students understand and practice the process of building a concept map prior to its use in a formal context. The preparatory stage should clearly indicate what the technique of concept mapping consists of and how the concepts studied must be interrelated and associated.

Other important elements in this study were the research activities used, which were very important in the way that they support the use of the software through tasks. These tasks involved the students working not only with the software, but also sharing and discussing the concepts that they are studying with each other, and making use of the concrete material that they are to use in representing these concepts as well. Such tasks allow the students to generate a better level of abstraction of the concepts being studied. In this way, and as shown by our initial results, the evaluation of the cognitive tasks showed an increase in the scores obtained by the experimental group. This shows that the methodology proposed through the use of AudiodMC could be appropriate and promotes the development of the skills under review such as association, classification, categorization, sorting and summarizing.

One of the most important limitations of the study has to do with the reduced number of available users. Although we worked with a school for the blind, many of the students at this school also have other associated deficits, such as cognitive deficits, which considerably reduced the number of participants, as our study only considers the visual deficit variable.

Another limitation has to do with the students' interest in participating in activities that involve specific learning content. This is unlike, for example, activities that involve a video game, in which they express a much more appropriate attitude for this kind of an evaluation.

For a future redesign of AudiodMC that could improve upon the other skills included in our research (classification, categorization and ordering), we have considered integrating new resources into the software that would allow the user to interact in an orderly fashion with the concepts. Such resources would include a more flexible storage facility, in which the users could reorganize their concepts.

Finally, these preliminary results show little cues to define new strategies for the use of sound-based technologies in processes of conceptual representation for rehabilitation and training purposes by students with visual impairments, providing new ways for the use of tools like AudiodMC. This study proposes resources and methodologies for improving learning processes, while at the same time helps to create the conditions for increasing the possibility for a higher quality involvement and social inclusion of visually impaired students in an increasingly demanding society.

REFERENCES

[1] J. Gold, S. Kim, A. Kant, M. Joseph, and A. Rizzo, "Effectiveness of virtual reality for pediatric pain distraction during IV placement," *CyberPsychology Behavior*, vol. 9, no. 2, pp. 207–212, 2006.

[2] C. Takahashi, L. Der-Yeghiaian, V. Le, R. Motiwala, and S. Cramer, "Robot-based hand motor therapy after stroke," *Brain*, vol. 131, no. 2, pp. 425–437, 2008.

[3] R. Baños, C. Botella, C. Perpiñá, M. Alcañiz, J. Lozano, and J. Osma, "Virtual reality treatment of flying phobia," *IEEE Trans. Inf. Technol. Biomed.*, vol. 6, no. 3, pp. 206–212, Sep. 2002.

[4] J. McComas, M. MacKay, and J. Pivik, "Effectiveness of virtual reality for teaching pedestrian safety," *Cyberpsychology Behavior*, vol. 5, no. 3, pp. 185–190, 2002.

[5] E. Gal, T. Weiss, N. Bauminger, D. Goren-Bar, F. Pianesi, O. Stock, and M. Zancanaro, "Enhancing social communication of children with high-functioning autism through a co-located interface," *AI Soc.*, vol. 24, no. 1, pp. 75–84, 2009.

[6] L. Vera, G. Herrera, and E. Vived, "Virtual reality school for children with learning difficulties," in *Proc. 2005 ACM SIGCHI Int. Conf. Adv. Comput. Entertainment Technol.*, New York, 2005, vol. 265, pp. 338–341.

[7] J. Sánchez, "User-centered technologies for blind children," *Human Technol. J.*, vol. 45, no. 2, pp. 96–122, Nov. 2008.

[8] J. Sánchez and H. Flores, "Virtual mobile science learning for blind people," *CyberPsychology Behavior*, vol. 11, no. 3, pp. 356–359, 2008.

[9] J. Sánchez and T. Hassler, "AudioMUD: A multi-user virtual environment for blind people," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 15, no. 1, pp. 16–22, Mar. 2007.

[10] J. Sánchez and M. Sáenz, "Three-dimensional virtual environments for blind children," *J. Cyberpsychology Behavior*, vol. 9, no. 2, pp. 200–206, 2006.

[11] B. Plimmer, A. Crossan, S. Brewster, and R. Blagojevic, "Multimodal collaborative handwriting training for visually-impaired people," in *Proc. 26th Annu. SIGCHI Conf. Human Factors Comput. Syst.*, New York, 2008, pp. 393–402.

[12] J. Marston, J. Loomis, R. Klatzky, and R. Golledge, "Nonvisual route following with guidance from a simple haptic or auditory display," *J. Vis. Impairment Blindness*, vol. 101, pp. 203–211, 2007.

[13] J. Sánchez and M. Elías, "Guidelines for designing mobility and orientation software for blind children," in *INTERACT 2007, LNCS 4662*, C. Baranauskas, Ed. *et al.* : IFIP Int. Federation Inf. Process., 2007, pt. I, pp. 375–388.

[14] D. McGookin, S. Brewster, and W. Jiang, "Investigating touchscreen accessibility for people with visual impairments," in *Proc. 5th Nordic Conf. Human-Computer Interaction: Building Bridges*, New York, 2008, vol. 358, pp. 298–307.

[15] W. Yu and S. A. Brewster, "Evaluation of multimodal graphs for blind people," *J. Universal Access Inf. Soc.*, vol. 2, no. 2, pp. 105–124, 2003.

[16] J. Novak and B. Gowin*, Learning How to Learn*. New York: Cambridge Press, 1984.

[17] J. Coffey and A. Cañas, "LEO: A learning environment organizer to support computer-mediated instruction," *J. Edu. Technol. Syst.*, vol. 31, no. 3, pp. 275–290, 2003.

[18] J. Novak and A. Cañas, "The origins of the concept mapping tool and the continuing evolution of the tool," *Inf. Visualizat. J.*, vol. 5, pp. 175–184, Jan. 2006.

[19] K. Luchini, C. Quintana, J. Krajcik, and E. Soloway, "Designed for learners: Applying software engineering to the development of scaffolded educational software," *Int. J. Continuing Eng.: Official J. Int. Assoc. Continuing Eng. Edu. (IACEE)*, vol. 13, no. 3, pp. 366–386, 2003.

[20] A. Cassata and L. French, "Using concept mapping to facilitate metacognitive control in preschool children," in *Proc. 2nd CMC.*, San José, Costa Rica, Sep. 5–8, 2006, pp. 125–133.

[21] B. Paulson, D. Truscott, and J. Stuart, "Clients' perceptions of helpful experiences in counseling," *J. Counseling Psychol.*, vol. 46, pp. 317–324, 1999.

[22] D. Daughtry and M. Kunkel, "Experience of depression in college students: A concept map," *J. Counseling Psychol.*, vol. 40, no. 3, pp. 316–323, Jul. 1993.

[23] S. Knish and C. Peter, "Beliefs of low back pain sufferers: A concept map," *Can. J. Rehabil.*, vol. 12, pp. 165–177, 1999.

[24] J. Sánchez and P. Alarcón, A. J. Cañas, J. D. Novak, and F. M. González, Eds., "Concept map designer: A tool for and with the end-user," in *Proc. 1st Int. Conf.Concept Mapp. Concept Maps: Theory, Methodol., Technol.*, Pamplona, Spain, Sep. 14–17, 2004, pp. 563–570.

[25] J. Sánchez, N. Baloian, and H. Flores, "A methodology for developing audio-based interactive environments for learners with visual disabilities," in *Proc. ED-MEDIA 2004*, Lugano, Switzerland, Jun. 21–26, 2004, pp. 540–545.

Jaime Sanchez received the M.A., M.Sc., and Ph.D. degrees from Columbia University, New York, in 1983, 1984, and 1985, respectively.

He is Professor of Human-Computer Interaction at the Department of Computer Science in the University of Chile. He has developed several sound-based virtual environments for developing learning and cognition in blind children. Currently, he is working on audio-based mobile devices to help blind learners to develop and rehearse problem solving skills in real settings. His research interests include audio and cognitive development in blind learners, usability evaluation methods, game-based learning, and mobile learning. He has also authored several books on learning with computers.

Hector Flores received the B.Sc. degree in computer science from the University of Chile, in 2006. He has participated in a number of research and development projects concerning the use of information and communication technologies in education, in particular in innovative uses of technology to assist the learning of blind children. His research interests include human–computer interaction, software usability, video gaming, mobile technologies, concept mapping, and e-Learning.