AudioMUD: A Multiuser Virtual Environment for Blind People

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***Abstract*—A number of virtual environments have been developed during the last years. Among them there are some applications for blind people based on different type of audio, from simple sounds to 3-D audio. In this study, we pursued a different approach. We designed AudioMUD by using spoken text to describe the environment, navigation, and interaction. We have also introduced some collaborative features into the interaction between blind users. The core of a multiuser MUD game is a networked textual virtual environment. We developed AudioMUD by adding some collaborative features to the basic idea of a MUD and placed a simulated virtual environment inside the human body. This paper presents the design and usability evaluation of AudioMUD. Blind learners were motivated when interacted with AudioMUD and helped to improve the interaction through audio and interface design elements.**

***Index Terms*—Auditory system, collaborative work, communication system interfaces, interactive systems.**

I. Introduction

A GREAT deal of research has been made in the field of virtual environments [10]–[13], [16]–[18]. They differ in the approach, content, and interaction with the virtual environment. The approaches used in virtual environments for blind people are generally sound-based, spanning from just simple sounds to represent a hit with a door or wall, or a sound variable that increases when the user is approximating to an object, up to a more sophisticated and complex variety of sound such as stereo and 3-D sound.

Examples of this type of software can be found in AudioDoom [1], Audio Space Invaders [2], Terraformers [3], AudioVida, and AudioChile [4]. By means of AudioMUD, we want to test a different approach, using spoken text to describe the virtual environment and interactions with the software and other players.

The content used in virtual environments is generally focused on navigation through the representation of a real physical space or some type of labyrinth and the interaction with objects inside this space. In this paper, we include biology concepts just for content modeling by embedding the idea of virtual navigation inside the human body and interacting with organs and structures.

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In this paper, we focus mainly on the design and implementation of AudioMUD. Preliminary usability and cognitive evaluations were implemented at the end of this paper.

This study is focused on legally blind users and thus every time we mention blind people in the paper, we refer to legally blind users.

II. Background

The development of user-centered interfaces and technologies are crucial in designing for users with disabilities. It is not enough to add audio to an existing application or to use screen reader tools in order to assist the use of technology by users with visual disabilities [1]–[3], [17]. The mental model of blind users is different from sighted people in their interaction style in order to intake and process information in a different way [20]. The challenge is either to create custom made interfaces for these users or to adapt current interfaces to be more accessible to the user's mental model.

There are few tools that focus on different aspects of cognitive development in the field of software development oriented to visual impaired users. Among them we find studies on cognitive development such as spatial structures, short-term, spatial and abstract memory, haptic perception, mathematical abilities, navigation and orientation, and spatial and temporal cognitive structures [1], [4], [16]–[18], [21], [23]–[26]. Significant results have been achieved in the development of these cognitive processes by using audio as interaction mean for visual impaired users. Recent works on the use of sounds to enhance language abilities and problem solving have been implemented [24]. Most of these results have been relevant to conclude firmly that the use of audio can help to understand how blind children learn and cognize [4], [20], [24].

The increasing pace of technology growth has been hard to follow by current people. This is more critical for people with disabilities. Many of them do not have direct access to new technologies. Their opportunities to access information and work with technology are restricted, impeding their ability to be more active and integrated in a global world [2], [20], [24].

Sighted users have diverse mental models but many similarities exist among those from the same culture and experiences. Digital immigrants and digital natives have intuitive mental models in such a way that can access to information at different paces and use different strategies but in the long run, without any major difficulty.

Users with visual disabilities have entirely different ways to structure, order and perceive the world, assuming a singular mental model very different from sighted users [24]. This is a major issue they have to face with when using digital technologies based on graphical user interfaces. Nonvisual mental models have to cope with devices designed for users with visual mental models. It is not enough to provide them accessibility to those technologies because they have been designed from the beginning for users without visual impairments.

Some initiatives have incorporated screen readers and text-to-speech to diverse computing environments for people with visual disabilities, but they are not sufficient because the core applications are made from the scratch for a user with an entirely different mental model. Voice synthesizers known as text-to-speech (TTS) allow the written information to be interpreted through the ear. There are many applications known as screen readers that allow users to navigate through the screen and in this way to have access to any software based on text mode and graphical interfaces supported by the message system of the operating system. The main issue with this type of support is the proper design of the dialog between the user and computer because if it is not appropriate they can become unusable [27].

The fact of adding text-to-speech technology to different computer environments is not sufficient to achieve an adequate management of tools. This is because of the mental model. There are some interface designs for different computer tools centered on users with visual disabilities whose traditional paradigms are changed to orient them to the management of technology. These designs have implied important achievements in the management of desktop computer and mobile devices by blind users.

3-D virtual environments with sounds have been developed to construct a mental representation of the space and to develop cognitive abilities [28]. The work of [29] presents blind users to develop strategies for navigation to represent spatial structures with cognitive difficulty. This system was developed to be used with different output devices such concept keyboard, tablets, and haptic interface [30], and joysticks with force feedback [31].

Sound-based interactive interfaces for blind children have been critical to explore auditory means to enhance cognition. We have not embedded current sighted children applications with audio. Nor have we emphasized the use of screen readers in standard applications to be understood by blind children. Rather, we have mapped the particular mental models of these users; embed our interface tools accordingly, and thus helping them to map their environment to fully integrate them in a much more inclusive society.

In response to this issue, diverse interface designs have been implemented for users with visual disabilities to let them to utilize the technology more fully. One initiative in this line of research is centered on sound-based interfaces to enhance cognition in blind children. Our research group has been using 3-D sound to convey information and knowledge to exploit auditory senses to cope with the loss of vision. Systematic usability evaluation during development is used to implement blind children centered interface design. Namely, we identify key interface issues to map their mental models, needs, and ways of thinking [3], [4], [32]. This is fulfilled by implementing a user-centered design to embed in the software the way of thinking of the blind.

Virtual environments based on spatial sound have been oriented to assist the cognitive development of children with visual disabilities. Relevant data from these studies are helping us to design a map of the role that spatial sound can play in cognitive development. We are progressively agreeing that computer delivered spatial sound has a critical impact on cognitive development in blind children [2], [16], [21], [25], [33]–[36].

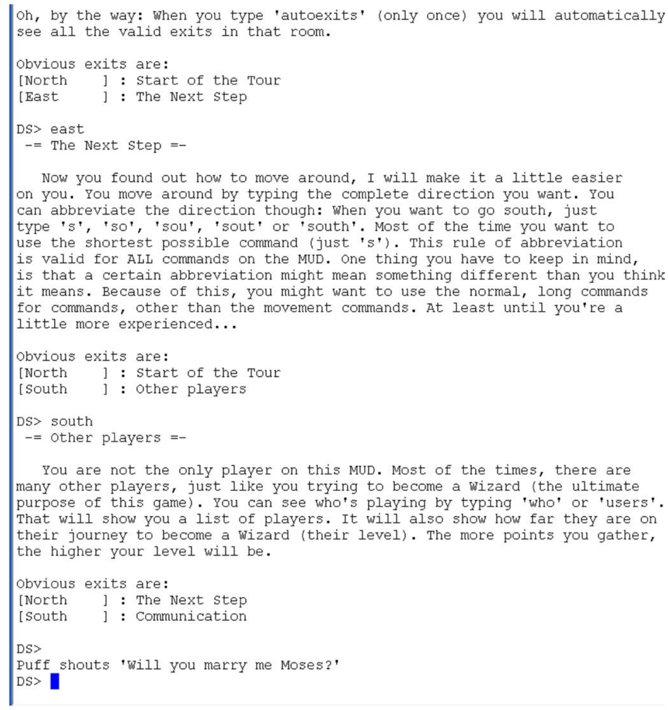

Fig. 1. Typical MUD.

This proposal introduces the design and usability evaluation of AudioMUD. We designed AudioMUD by using spoken text to describe the environment, navigation, and interaction, embedding some collaborative aspects into the interaction between blind users.

III. MUD

MUD is the acronym for multiuser dimension or multiuser dungeon [15]. The first MUD appeared in 1979 and was developed at the University of Essex. One of the most important features of this game was the introduction of the concept of multiuser games and the sharing of a virtual world [5]. Various players can access the server that stores a shared virtual world from different computers over a LAN or the internet, and they interact with this world and other players connected to the server.

Original MUDs are text-based without any graphical interface (see Fig. 1). Later, different versions of object-oriented MUDs appeared in the literature such as MOOs [6], [14]. The fact that original MUDs rely on text-based interfaces is considered a strong feature because it triggers the use of the imagination of players to construct their own mental model of the navigated space based only in small written descriptions [7]. Another interesting feature of this game is that it is partially based on adventure games [8].

MUD style games let users perform a set of actions in a virtual environment where a navigable space is provided, with restrictions, orientation, and direction. MUDs also have objects

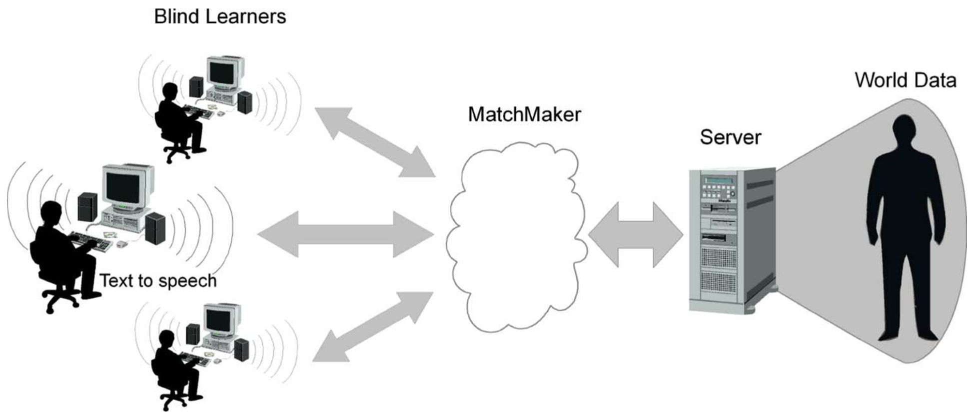

Fig. 2. Blind learners' interaction with AudioMUD.

to interact with. In some aspects, a MUD is a virtual reality, because it is an electronically represented space navigated by users. MUDs, by conception and in opposition to the traditional virtual reality, do not have spatial sounds and powerful graphics. The bet is that the user imagines and mentally recreates the virtually navigable environment [19].

IV. AUDIOMUD

A MUD has a high potential for describing spaces and interactions due to its text-based interface and the possibility of different type of interactions between players, and between them and the virtual environment. Conceiving this idea in mind we developed AudioMUD by using the approach of spoken text to represent a virtual environment, navigation, and interaction.

The content for modeling our proof-of-concept version of AudioMUD was the human body and the interaction with organs, structures, and processes. We chose this content because the biological processes fit well to the dynamic of spaces and interactions of MUDs. It was also clear that by teaching this content through MUDs the learning of biology can be more motivating and challenging to blind people. This is accomplished by locating the player within the human body and assigning the task of solving an illness affecting to him or her based on symptoms that can be found inside organs, and changing the conditions affecting the body.

We have also added some collaborative aspects to the game such as sharing a common goal (to solve problems and issues causing the illnesses of an organism), positive interdependence, and identification with the player.

AudioMUD is associated to spoken text cues. The immersion in this virtual environment is produced by labels that represent places and navigated spaces. These cues include information about current location, navigation possibilities, current personage attributes inside the virtual environment, and information about other players. The player can be familiar with some information about other players and communicate with them through a chat system that let them stay in contact and share information when navigating through the virtual world.

A. AudioMUD Development

AudioMUD was developed using Java SDK 1.5, MatchMaker [9], a collaborative platform which allows the synchronization of a tree with distributed objects, and Festival, a text-to-speech engine.

We developed a server and a client from scratch. The server stores the state of the world in such a way that when a client connects to the server it receives the state of the virtual world at that exact moment. Players can enter and exit the game any time and return later reassuming at the same level where they left the game with the same attributes they had when logged out.

The server and clients were developed by having blind people in mind and later testing them with blind users who provided us relevant feedback to improve their usability. Using this approach, we designed an interface focused on blind people to go further than just reading a screen. The interface presents the text that blind people need for navigating the virtual environment and includes an easy-to-use input interface based on one-keystroke. We defined a virtual environment that facilitates blind players to interact with body organs and other players in an easy and collaborative manner. We did not only focus on totally blind people but also considered people with residual vision. For them, we designed a visual interface presenting big contrast text using blue and yellow colors.

MatchMaker is the platform that maintains all objects pertaining to the virtual world (human body) such as players, illnesses, symptoms, and organ controls. They are synchronized so that the server and clients share the same view of the state of the world. A big number of clients can connect to a server thanks to the abstract layer provided by MatchMaker (see Fig. 2).

Festival acts as a server that translates all text sent from the AudioMUD client into spoken text.

AudioMUD was created by following four stages: 1) design and implementation of the data structure and MatchMaker tree, 2) development of the server, 3) implementation of the client, speak system and GUI for learners with residual vision, and 4) development of the data storage system.

B. AudioMUD World

AudioMUD's world (see Fig. 3) is a representation of the human body, divided into four kingdoms. Each of these kingdoms represents one of four different biological systems:

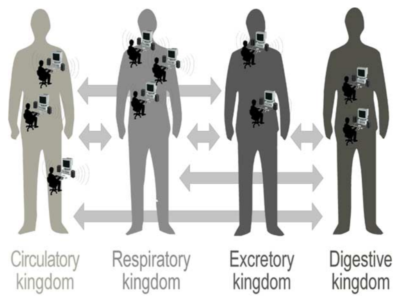

Fig. 3. AudioMUD's world.

circulatory, respiratory, excretory, and digestive kingdom. A kingdom is divided into rooms; each one representing an organ. Inside this world we can also find some tips about symptoms of the body provided by one or more illnesses and organ controls. Each player has own attributes that provide the ability to get some tips about symptoms allowing to control the status of organs and to move through the human body.

C. AudioMUD Architecture

There are three main applications in AudioMUD: a map generator, a server, and a client.

We started designing and developing the server data structure to store data concerning the entire world and its components. This step included the creation of the following classes: World, room, player, attribute, state, illness, symptom, and action. We also included the design and implementation of the MatchMaker tree that can synchronize objects between the server and clients.

Then, we developed the server side of the software that involved the creation of a Server class in charge of accepting connections from clients and interacting with them.

We also created classes that make part of the client side of the software. These classes are client, speech (the class that communicates with the text-to-speech engine), and the GUI class, in charge of creating and manipulating the graphical user interface.

The next stage consisted in developing the classes that store these objects into disk so we can have a server that maintains the state of the world through the time. These classes are Data and ClientData.

The Map Generator consists of a class called MapGen which reads two formatted text files called World.txt and Illness.txt and generates a binary object, representing the World class with the data obtained from the text files.

Finally, we added some extra functionality to the software such as the speaking system, composed by the Message class. We have incorporated three classes in charge of discovering whether there is a server on the LAN or in case of failure to find out this server and ask for the IP location. These classes are Broadcast, BroadClient, and Status.

D. Playing AudioMUD

When the blind learner opens the client an IP server and name are required (if a server is not automatically found on the LAN). Then, the player appears in a random location inside a kingdom of the human body with a random set of attributes. The player can afterward start exploring the kingdom.

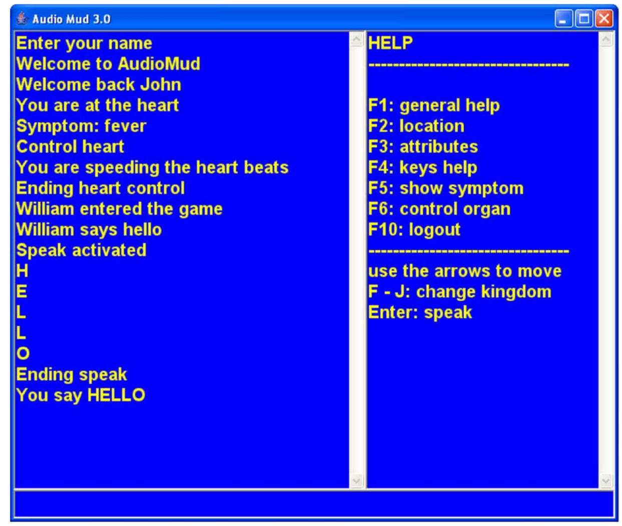

Fig. 4. AudioMUD game in action.

The body can suffer different illnesses through the time. When a user enters to a room and if there is sufficient amount of required attributes, a symptom can be found or an organ can be controlled. With the aid of some tips (symptoms) located during exploration, the illness to be protected from can be identified. With this information, the player can change the status of some organs to finally cope with the illness.

To recover from an illness, the player must share tips with other players because only by knowing all tips he or she can identify the illness. The player has to talk to others because there are some controls that need previous actions to be done in other places. The speaking system included in AudioMUD allows a player to hear through the text-to-speech system what other players write down. Once the illness is discovered and after making all the necessary actions to cope with the illness, a new illness is introduced into the human body.

Blind learners interact with the software by "one keystroke" commands (see Fig. 4). Original MUDs use written commands which were changed in AudioMUD by one keystroke commands in order to facilitate the interaction of blind users with the software. The implemented commands are as follows.

F1—general help: A description of available help and keystrokes needed for specific help are provided by the software. This help is presented as spoken text.

F2—location: The location of the learner is provided at any moment.

F3—attributes: The learner can hear the level reached by each attribute (physiology, anatomy, and energy levels).

F4—keys help: This is a description of the keys used to navigate inside the human body. The use of these keys is explained in more detail at the end of this section.

F5—show symptom: If the player arrives to an organ and listens that, there is a symptom located at that place, a description of that symptom can be listened.

F6—control organ: If the blind learner arrives to an organ and can control it (has the needed attributes), the player listens to a text saying that the organ can be controlled. The player can activate or deactivate the control of the organ.

Once activated, the state of the organ can be changed by the use of up and down arrow keys.

F10—logout: This key is used to quit the game.

ENTER—speak: This key is used to start and finish a conversation. When a user hits the enter key, he or she can start writing and when pressing the enter key again, the written text is spoken to all players connected to the server in that moment.

The navigation keys work as follows: the navigation inside a kingdom is made through arrow keys. Using up and down arrow keys, the player moves vertically inside the human body. Left and right keys are used to move from one side of the body to the other. The movement inside the human body is made in a discrete way. The player can just move from one room to another and there is no movement inside one room.

The F and J keys are used to walk from one kingdom to another but this implies the player has to spend many attributes. This is performed in this way in order to allow a better collaboration environment between players because they have to ask for help to one or more players located in another kingdom rather than going directly to that place.

If a user leaves the game and enters again, he or she is placed in the same room when left, maintaining the same attributes set before leaving the game.

E. Illness Example

The illness introduced in this proof-of-concept example represents a laryngitis produced by an uncontrolled influenza in such a way that follows.

1) In the respiratory kingdom, the player can find the following associated symptoms: fever and decay. The following organ control will help to cope with the illness: expand or contract the bronchi; increase or decrease respiratory frequency at the lung. To do this, the brain has to send specific orders: increase or decrease nasal secretion and ask for more blood cells at the respiratory tube.
2) In the circulatory kingdom, the player can find the following symptoms: muscular pains and migraine. Possible actions are: increase or decrease blood pressure changing the heart pressure; increase or decrease the absorption speed of medicines, changing the heart frequency; increase or decrease the absorption of nutrients to add more blood cells.
3) In the excretory kingdom, the following symptoms can be found: cough and voice problems. Possible actions are: increase or decrease liquid elimination at the kidney; increase or decrease dialysis; verify if there are pathogen organisms in the urine.
4) Finally, in the digestive kingdom the user can access to the following symptoms: nasal secretion and lack of appetite. Possible actions are to inhibit or stimulate the appetite at the stomach.

V. Usability Testing

Participants. Four men and five women with visual impairments with ages ranging from 18 to 31 years old participated in the study. Two facilitators and one usability expert also participated.

Fig. 5. Usability testing of AudioMUD.

Instruments. A usability evaluation questionnaire for blind users was applied. It included features such as software motivation, easiness of playing, and feasibility of sound, and screen questionnaires for experts. We also used heuristic evaluation questionnaires for experts.

Methodology. The study consisted in the following steps.

Step 1) *Introduction to the software*. An explanation about MUDs and the basics of the interface was presented.

Step 2) *Software interaction*. Learners were told to move around the virtual world in AudioMUD, to investigate the interactions they could make, and to explore all capabilities of the software. During this stage, blind learners worked autonomously but they could ask for help if they had difficulties with the interface.

Step 3) *Anecdotic record*. Key data and observations of the child's interaction with the software were registered

Step 4) *Application of usability end-user questionnaires*. Users answered questions asked by special education teachers concerning software motivation, easiness of playing, and feasibility of sound and voices. They were also asked for comments about the overall experience and specific topics such as sound quality, navigation difficulties, and interface design.

Step 5) *Session recording through photography*. Each session was photographed to register the child behavior during interaction.

Step 6) *Protocol reports of the session*. All data from the child's interaction was registered to get comments and suggestions to improve the software navigation.

Step 7) *Design and redesign.* According to the comments and observations made by users and observers during usability testing, the software was improved, redesigned, and some new functions were designed. We evaluated interaction features and audio interface elements to fit the mental model of blind users.

During the development of AudioMUD, we tested different ongoing and final prototypes with blind learners supported by facilitators (see Fig. 5). Two facilitators also interacted with AudioMUD and answered heuristic evaluation questionnaires. All activities were recorded and observed.

Preliminary results. Initially blind learners were not explicitly told about collaborative aspects embedded in the game because we were just evaluating the usability of interface design elements. It was very interesting to realize that without knowing about collaboration techniques that can be developed throughout the interaction with the game, blind users started to share information about their actions between them and design collaborative strategies to solve problems.

The first approach concerning the player's interaction with the virtual world was to answer biology questions encountered in different organs. This was changed later to a more complete interaction with the whole body (the action of changing an organ status) to facilitate the familiarization with collaborative features of the software.

Another attribute developed was the idea of implementing awareness in AudioMUD by giving the necessary information to learners but without saturating them with unnecessary data.

The major issues found as a result of this evaluation were related to sound quality, volume, and speed. End-users proposed the inclusion of a voice control panel that was implemented in later prototypes.

One of the attributes provided to players in the first prototype was the energy. A player used an amount of the limited energy to move from one organ to another, and recovered the energy waiting for a short period of time. Blind people did not like this energy attribute because they had to wait in order to move through the virtual world. This attribute was not really relevant for collaboration; therefore we did not include it in newer versions.

Likewise, initial prototypes considered sighted facilitators to fill into a text box the IP address and name of the server. In later versions of AudioMUD we added a new module that searches for an available server on the local network and asks for the server address only if it was not found at the local network.

Most blind learners did not have any navigation problem and they had no difficulties with the keys selected for input. They also found that biology contents were easy to learn and understand.

One of the functions of AudioMUD that blind users really enjoyed was the ability to speak to other players. This gave them the idea of being in a shared world space.

A request made by blind users was the addition of a repeat key command so they could listen to the last spoken sentence again. This key was implemented and helped them to follow the game sequence in a better way.

They also complained about the low feedback speed mainly when they were writing through the chat system embedded in the game, because any time they pressed a key the letter associated to the key was spoken by the TTS and this process was slow. This feedback is a good option for users who are not good writers but in the case of blind learners who write fast and without making errors, this was not a good feature so a key command was added in order to activate or deactivate this functionality.

VI. Cognitive Testing

We also implemented a preliminary cognitive evaluation. The main purpose was twofold, to analyze the development of collaborative skills and to learn biology concepts by visually impaired learners through the use of a collaborative networked game based on sound.

Fig. 6. Pretest/Posttest group skill results: 1) participation; 2) coordination; 3) leadership, and 4) collaboration.

Participants. Four men and five women with visual impairments with ages ranging from 18 to 31 years old participated in the study. Two special education facilitators also participated.

Instruments. A Likert scale questionnaire evaluating different skills with 32 statements and considering scores from 0 to 4 with a total maximum score of 128. The questionnaire contained four group skills: 1) participation, 2) coordination, 3) leadership, and 4) collaboration.

Methodology. We first applied a pretest, then users solved two cognitive tasks during three sessions of 1.5 h each, and finally we applied the posttest. Cognitive task 1 consisted in a collaborative game distributed in two teams. Learners had to associate the human body organs to their own body systems, answering questions about possible affections and also concerning the four body systems. The objectives of this task were to value individual and peer contribution in a collaborative task, to assign roles in order to achieve goals, tasks, resources, and prizes in the game, and to assist the learning of biology concepts and contents.

Cognitive task 2 consisted in inferring concepts related to the different body systems with the aid of key words to find covert words or concepts related to the human body. This task was implemented in a team contest. The objectives were to establish mechanisms of coordination for collaborative work in order to achieve a goal, and to infer concepts related to the contents of AudioMUD.

Preliminary results. Fig. 6 displays the average percent results obtained by users in each group skills evaluated: 1) participation, 2) coordination, 3) leadership, and 4) collaboration. Participation and coordination skills did not showed pretest/posttest gains while leadership and collaboration skills presented gains, 20% and 10%, respectively. These interesting preliminary results mean that after interacting with AudioMUD learners were able to take the initiative in the game to attain the final goal and get common benefit by using management skills. They also could articulate and organize the group during the game, enhancing collaborative skills to work together, coordinated and with solidarity.

VII. Conclusion and Future Work

This study presents the design, implementation, usability evaluation, and preliminary cognitive evaluation of AudioMUD as proof-of-concept for using audio-based MUDs for learning in blind people. Preliminary results showed that collaboration techniques can be learned by blind people with the use of AudioMUD, the same as the skill for taking initiative and management actions. The next step is to design experiments to include other conceptual and cognitive tasks to observe whether AudioMUD really helps blind users to learn biology concepts. We are also interested in isolating the type of learning that occurs when interacting with AudioMUD.

Finally, one of the problems we have found in developing software based on text-to-speech engines is the quality of the generated voice. We are looking for ways to get better voice qualities that could be accomplished by changing the engine we used or adjusting the tuning to the actual voices.

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Tiago Hassler, photograph and biography not available at the time of publication.