Supporting Collective Learning Experiences in Special Education

Development and Pilot Evaluation of an Interactive Learning Tool for Down Syndrome

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***Abstract*— Down Syndrome (DS) is one of the most common causes of cognitive disability in our society. In DS, cognitive skills are impaired, and learning requires personalized attention and specific special education approaches. In this context, computer mediated learning, and in particular computer games, are promising as potential tools for the personalization of learning and for engaging users in motivating and stimulating learning experiences. In this paper, we present a virtual reality gaming approach to support DS education, with particular emphasis in collective learning in small group settings. The proposed system addresses some of the main limitations in DS such as training of association and composition/decomposition tasks. Here we present the development of the system and results of a pilot study with special education instructors (N=3) and DS participants (N=2). The results show a high degree of acceptance and suggest that our system can be a valuable tool to support both, instructors and DS users, in the learning experience. In addition, our results support the use of integrated computer based interactive board systems with multiple DS users. We find that group settings seem to be more effective at engaging DS participants and encouraging their autonomy and initiative.**

Keywords—human computer interaction; Down syndrome; trisomy 21; learning technologies; interactive board

I. Introduction

Down Syndrome (DS), also known as Trysomi 21, has an incidence of about 1 on 600-1000 births [1], affecting approx. 5 million people worldwide [2] and accounting for about 18% of overall cognitive disabilities. DS is well known for causing learning difficulties, specifically for being a slower process [3]. As a result, DS children do not follow the same development patterns as non-DS children, particularly during the first years of life [4]. In the USA, the direct education and medical cost of life of a person with DS was already estimated around 350.000 dollars in 1996 [5]. This high cost is mostly a consequence of the need of specialized teachers and assistants to provide a more individualized learning. Unlike ordinary children, DS children do not develop spontaneous strategies and therefore problem resolution becomes a very complex task. DS requires more attention and a more directed learning [6]. DS children also present difficulties in aspects such as decision making, action initiation, abstract thinking, and mental calculations among other [3]. However, these deficits are not unique to DS and share several characteristics with other cognitive disabilities, allowing approaches and solutions for DS to generalize to other special education cases [7]. Despite all of the above limitations, DS do not show difficulties in participating in group or social activities [8].

Special educational programs for DS differ in structure, generally by decomposing learning objectives in several intermediate or partial goals to help and ease the development of mental skills such as attention, memory, logic reasoning, as well as task perception and comprehension [7]. In fact, research in special education has led to better practices and improvements that have increased dramatically the quality of life and learning process in people with cognitive disabilities [9]. The activities conventionally performed by DS children are targeted towards their major limitations such as association, selection, classification and naming. Association activities are performed in different ways making use of specific language to facilitate the comprehension of concepts [7]. Conventional games such as puzzles are also useful resources to stimulate attention, perception and visual memory by means of a composition task, while memory games contribute by motivating DS children to resolve association tasks [7]. By performing an abstraction of the features of the different objects in these games (color, size, shape, etc) children are able to compare and classify objects [10].

Nowadays, computational resources are more and more common in the area of education, aiming at stimulating and improving learning in both children and adults [11]. Recent studies show that when children are able to perform traditional tasks in computer-mediated experiences, they are more motivated and more able to sustain attention for longer periods of time [12, 13]. This is also the case for Virtual Reality (VR). VR allows overcoming some of the limitations of traditional approaches, priming the construction of knowledge by the learner while tailoring learning to the individual characteristics of the user [11, 14]. One of the largest advantages of VR is the possibility of presenting complex and abstract concepts with images and sounds. VR technologies have already been used as games for DS children from 3-7 years old to stimulate cognitive skills such as imitation, perception and association, and short term memory [15]. The use of instruction repetition revealed to be particularly beneficial, leading children to attempt resolution of tasks on their own. Another example is an interactive VR environment developed to simulate scenarios for learning about the physical and social worlds [16]. An interesting commercial collaborative approach is the education table e-Blocks (Positivo Corporation, Brazil); a novel multisensory approach for interactive and collaborative learning that received the World Summit Award as the best e-learning solution in 2005. Other approaches for collective learning, targeting in this case small groups of students, use computer-assisted instruction by means of interactive board technologies [17]. More recent approaches exploit the use of tablet technologies for special education pupils [18].

This project is the result of a join initiative with the Madeira Whale Museum (Caniçal, Portugal). The museum's mission is to preserve the history of whale hunting in the island of Madeira as well as to educate, protect and promote activities about sea life and its preservation. In this context, the educational services of the Madeira Whale Museum develop multiple activities and didactic material that are made available to the educational community, with a particular emphasis in children with special education needs such as DS. For the project we are presenting, we developed a VR interactive tool to support associational and relational learning in special education that: builds on motivating gaming experiences, capitalizes on the social skills in DS to support collaborative learning, and uses VR to personalize the learning process.

II. Methods

A. Task selection

The VR tool that we developed was build to be consistent with the Madeira Whale Museum's mission and is intended to be part of the museum's special educational activities, in particular for DS children. Two main learning objectives were addressed with our system: learning associations, and the composition and decomposition of concepts. For this reason, two tasks were selected and implemented: a name association task, and a compositional/relational task on the previously associated names/objects. Both tasks are designed to support the learning and understanding of what the individual objects are, as well as to help understanding their relationship in a more global context. Thus, the association task and the composition/relational task were designed to complement each other to support learning of both individual objects together with their role in a larger context. Building on the marine instructional activities of the Madeira Whale Museum, we selected the study of food chains and ecosystems. These tasks were found to match well the educational mission of the museum as well as to serve as an adequate substrate to implement the association and composition/decomposition tasks. A food chain is the sequence of who eats whom in an ecosystem to obtain nutrition. The organisms in an ecosystem are organized in multiple layers, called trophic layers, depending on the position they hold in a food chain. Thus, these concepts allow us to build an application around the constituents of a food chain and to explore the relationship among them, from primary producers to top predators.

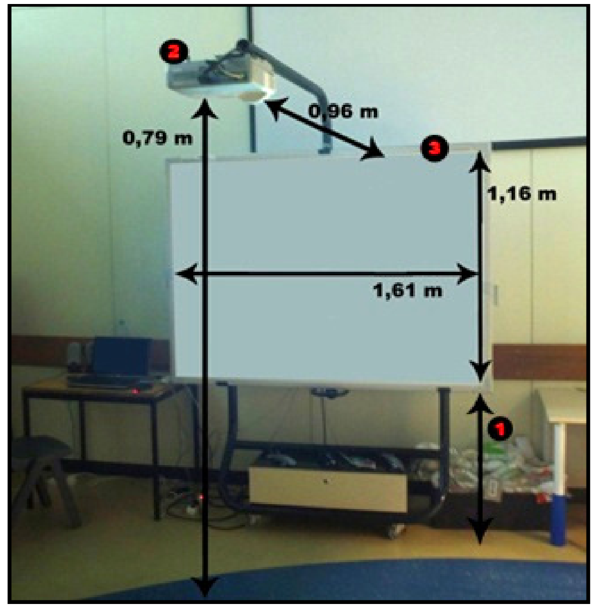

Fig. 1: Interactive board setup used for the VR system (ActivBoard 500 Pro, Promethean, Lancashire, UK). The interactive board has an adjustable height mechanism (1) to use it with both, kids and adults, a video projector (2) and a projection board (3).

B. Implementation

1) Hardware

DS children have been shown to be very communicative and collaborative, particularly in group settings [19]. In addition, interactive boards have been shown to be effective instruments for especial education purposes [17]. Interestingly, interactive boards can support multiple learning experiences such as between instructor and student, among students themselves, or instructor and multiple students. We therefore decided to use this technology because it allows the instructor to integrate multiple students with different characteristics while fostering collaboration in the group and facilitating differential learning (Fig. 1). The used interactive board is the ActivBoard 500 Pro (1.61 x 1.16 m) (Promethean, Lancashire, UK). It is composed of an Epson EMP400W video projector (Seiko Epson Corporation, Nagano, Japan), a projection board, and makes use of a wireless pressure sensitive pen as pointing device. Additionally, the board has an adjustable height mechanism that makes it suitable for usage by both, kids and adults.

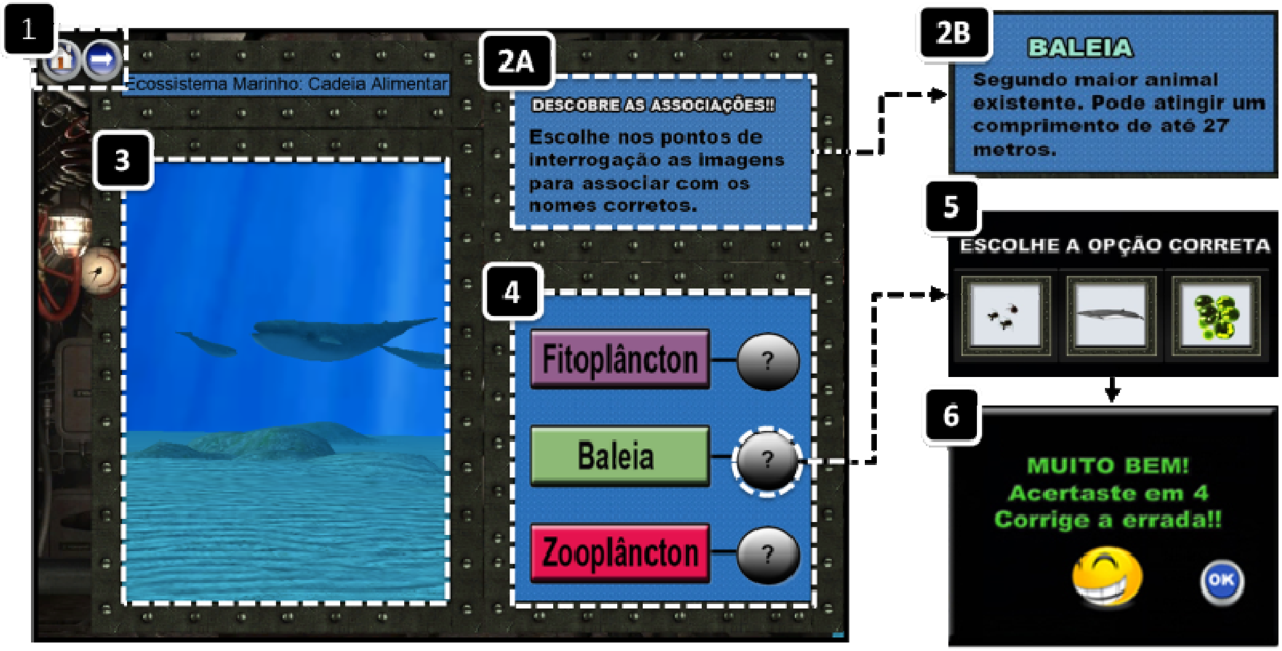

Fig. 2: Basic graphic layout of the interactive VR application. (1) A general navigation menu allows returning to the home screen and to skip through tasks. (2A and 2B) Feedback and information on the game objectives is displayed on the top right quarter. (3) The content of the VR environment is displayed through a large virtual window. (4) The interactive elements of the user interface are displayed on the lower right quarter. Text reads Portuguese for phytoplankton, whale and zooplankton). (5) This panel enables users to solve the different tasks. Portuguese for "Choose the right answer". (6) On task resolution, visual and auditory feedback is used to convey information on performance. Text reads Portuguese for "Very good! You got 4 right. Fix the incorrect one!!".

2) Software

Our system uses a gaming approach to achieve greater engagement in the learning process. The selected task required us to be able to display in real-time a set of marine organisms, their behavior, and their interactions in their natural habitat. The VR environment is therefore designed to serve as the main interactive audio-visual support for the kids to solve the association and composition/relational tasks. We decided to develop a limited set of simulated marine ecosystems that would show the marine environment together with 3D models of the target organisms which were modeled, textured and animated using 3DS Max (Autodesk Inc., San Rafael, California, USA). The modeling and animation process required us to model, texture and rig a total of 7 3D animal models. These models were then imported into the Unity3 game engine (Unity Tecnhologies, San Francisco, USA), a 3D rendering and gaming engine that allowed us to implement the user interface and the mechanics of the game itself. This was performed by means of a combination of Unity C# scripts and shaders that are directly executed on the graphics card. The software development and later evaluation of the system was performed under the Windows operating system.

3) Application

The application simulates a submarine control panel that has a window into the sea, where sea life can be observed in its original habitat. The system is designed to support multiple users at the same time, including children and instructors. For this reason, navigation menus related to the commandment of the system – such as *"jump to"* or *"home screen"* – were consistently placed on the upper left corner of the interactive board were it is accessible to instructors but not to children (Fig. 2, panel 1). All interactive items to be used by children were placed on the lower half of the screen (Fig. 2, panel 4). Interactive elements in this panel are buttons that can be activated using the pen device on the projection screen. The left half of the screen is dedicated to the visualization of the VR marine ecosystem (Fig. 2, panel 3). The upper right space is reserved to deliver feedback and information to both instructors and kids (Fig. 2, panel 2A). When selecting a name button the message displayed on the feedback panel is updated to display information specific to the selected button (Fig. 2, panel 2B). A question mark button is associated to each name button to enable the users to associate the name in that button to the picture of an organism (Fig. 2, panel 5). When the task is completed, feedback on performance is given by means of images and text (Fig. 2, panel 6). All feedback messages are positive and encouraging based on correct choices instead of errors.

Association Task

The game revolves around the topics of food chain and ecosystems, and is structured in two sequential phases. First, the system introduces the different organisms that constitute an ecosystem. Those can be observed through the VR window into the marine ecosystem, which displays the different organisms in their natural habitat when a button name of an organism is selected. This action results in a change of the camera in the VR environment that will display that particular organism in isolation (Fig. 3A, panels 1-5). By selecting different buttons, the user can explore and discover how the organism names relate to their visual appearance and behavior. This process is open ended, and the user can take as long as he/she needs to explore the complete ecosystem. Once the user is able to learn the association, he/she selects the question mark next to each name and subsequently selects the image that corresponds to that name (Fig. 3B). If associations for all organism names have been selected, the system gives feedback about the number of correct associations (Fig. 2, panel 6). Then, the system updates the button panel indicating which associations were correct and which ones were incorrect by showing either the correct matching image or a red cross (Fig. 3C). During this process, users are always allowed to switch back and forth between cameras as many times as needed to complete the task. On completion of all correct name associations, the user advances to the next phase, the composition/decomposition task.

Composition and Decomposition Task

The composition and decomposition task builds around the understanding of the interactions among the organisms of an ecosystem to organize them into trophic levels. This task is solved using the same game mechanics as in the previous task, but this time associating the organism that corresponds to each level of the food chain / pyramid (Fig. 3D). Instead of selecting the button names to visualize each organism, the buttons now show in the virtual environment the interactions among organisms in the selected and neighboring levels. Hence, in order to solve the food chain, users have to first visualize all pairwise interactions between neighboring trophic levels (decomposition) and subsequently organize the organisms within the food chain (composition). Again, the task is solved by associating the images of the organisms to each level by selecting the corresponding question marks. As in the previous task, the user can visit each of the trophic levels as many times as needed (Fig. 3D). An association and a composition task were developed for each of two different marine ecosystems. The first ecosystem consisted of a simplified food chain of 3 organisms, and the second food chain consisted of 5. By default our system starts with the association task for the simpler ecosystem, continuing with the composition task. On completion, the second and more complex food chain is introduced.

4) Experimental Protocol

All user experiments were conducted in the instructional facilities of the Madeira Whale Museum. The main objective of these experimental sessions was to evaluate the suitability

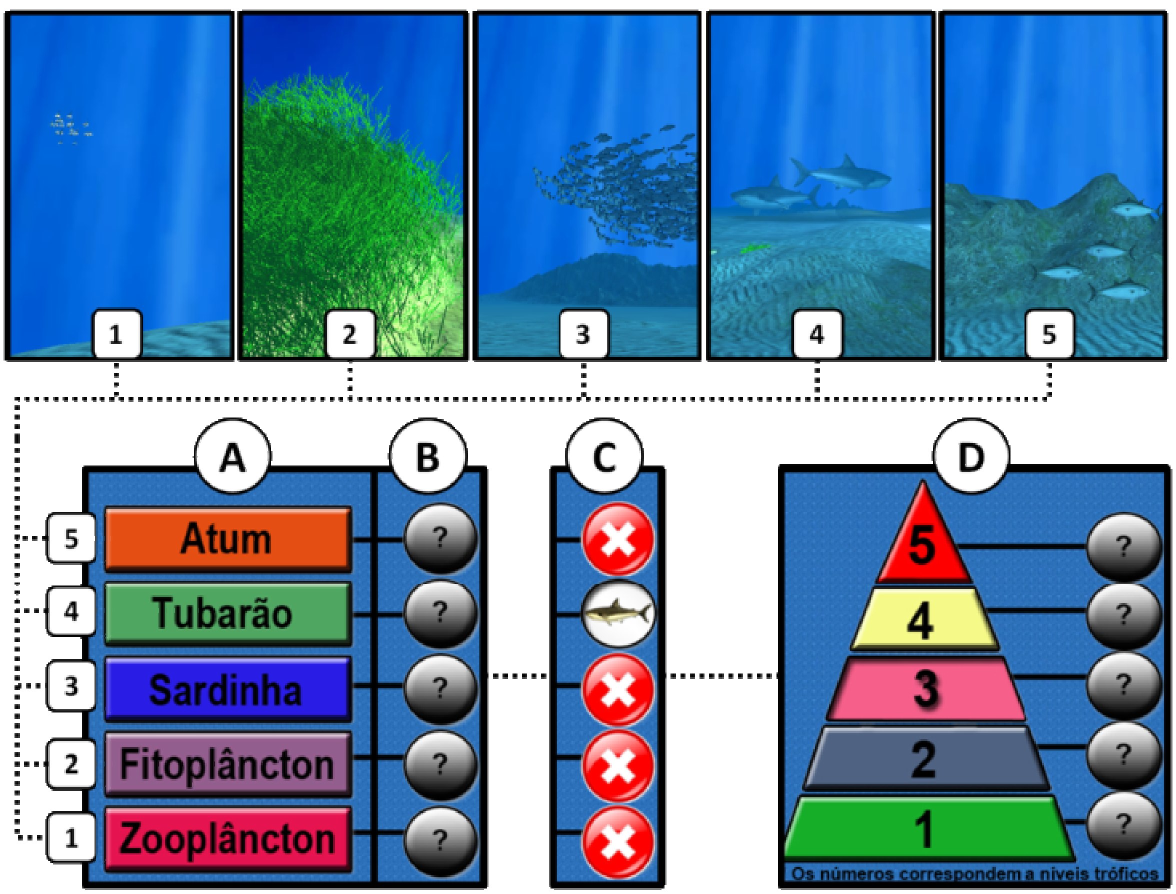

Fig. 3: Visual elements and mechanics of the game. (A) A list of buttons with the name of organisms on them is used to navigate through different camera views (1-5) that display the organisms and their behavior in their natural habitat. (B) A list of question mark buttons associated to each button name allows selecting the corresponding image to each name. (C) If the image associated is correct, the question mark button shows the image; otherwise a red cross indicating wrong association is displayed. (D) Once the naming association task is solved, the user has to solve the food chain of that ecosystem using the same mechanics.

of our approach, usability aspects of the developed system, its effectiveness on our target population, and acceptance by both DS children and instructors. In order to assess the response to our system, we used a dual approach: a behavioral evaluation, followed by questionnaires to both the children and their instructors. The behavioral evaluation was based on observations during the experiment and also on a later analysis of video recordings of the experimental sessions. The analysis of the behavior was based on a grid of evaluation criteria defined beforehand.

Two DS female participants of 22 and 28 years old were recruited to evaluate the system. Both DS users could properly understand the task objectives and how to interact with the interactive board. None of the two DS participants could read or write beyond simple words. Both had little experience with the use of computers (once a week), but had already used an interactive board few times (< 5 times). Informed consent to perform the experiments and to collect and use audiovisual material was obtained. There were two rounds of experiments: a first one with each of the DS participants and an instructor (and 2 other special education instructors as spectators); and a second one were both DS participants collaborated without instructor. Users had never previously used our application, but had previous experience with interactive boards (used < 5 times). An especial education instructor took the role of experimenter and introduced each DS participant with the functioning of our system. While one of the participants was testing the system, the other one was waiting in a contiguous room without being able to participate in or observe the experiment. Researchers were also present at a distance, video recording and taking notes about the experiment and the behavior of both instructor and DS participants. After using our system, a questionnaire was answered by each DS participant. After the completion of the experiment by both participants individually, the instructor repeated the experiment for the third time, this time with both kids simultaneously. After the experiments, the 3 special education instructors that were present were interviewed and answered another questionnaire.

a) Questionnaires and evaluation criteria

A behavioral evaluation grid was designed to assess usability aspects of the system and user performance while interacting with it. The evaluation grid was basically used to count the type and number of user errors, the number of times camera views were used, asses the difficulty of the task and its comprehension, as well as other positive or negative responses to other aspects of the game and system.

Two questionnaires were developed: one for the special education instructors, and another one for the DS participants. The questionnaire for the special education instructors consisted on a series of 15 statements rated on a 5-point Likert scale on the level of agreement or disagreement (1 = full disagreement and 5 = full agreement). This questionnaire addressed 4 basic aspects of the system: adequacy of the interface (including accessibility, clarity and usability aspects); relevance of the tasks and its impact in facilitating

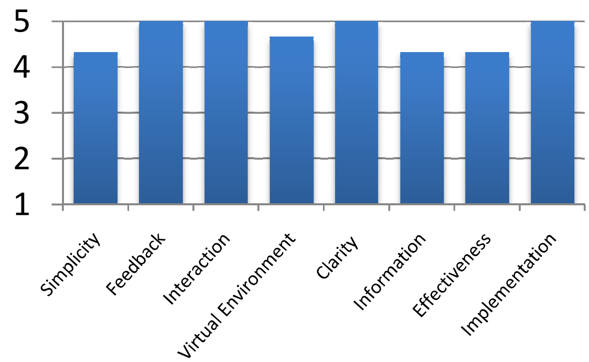

Fig. 4: Aspects and ratings of the developed system that were assessed by special education instructors.

learning and understanding; adequacy of feedback, its impact on motivation, and the overall behavior of the user; and effectiveness of the system as a learning aid tool for DS users. The questionnaires for the DS participants were designed to evaluate different aspects of the application and its use. More concretely, DS participants were asked about: previous experience with computers, computer games and interactive boards; enjoyment of the game-driven learning experience; ease of use and understanding of the game; and a recall test to assess the effectiveness of the learning experience.

III. RESULTS

The experiment was conducted with 3 special education instructors as observers and/or instructors. After the completion of the experiment, instructors and DS participants answered their respective questionnaires. Instructors reported on a 1-5 Likert scale (Fig. 4). The simplicity of use of our system had an average rating of 4.33, meaning that all instructors found it simple or very simple. The type and quality of the feedback delivered by our system obtained a mean value of 5, the highest rate. Instructors reported that the use of smileys and other non-textual information was very appropriate since not all DS children can properly read. Additionally, the instructors reported that the fact that the feedback and pace of our system is determined by the user does allow users to reflect on the problem without creating stress related to the task itself. When asked about the type of interaction used in our system (design of the interface and game mechanics), instructors rated it as being very appropriate for DS (average rating of 5). Similarly, the choice of displaying a VR environment with the organisms together with their behaviors was considered a good support to enable DS children to know the organisms in an ecosystem as well as to understand their role in a food chain (average rating of 4.66). When asked about the clarity of the task, the quality of the information delivered by our system, and the effectiveness of the system, those were rated as 5, 4.33, and 4.33 respectively. Instructors insisted that the appropriateness of these depends very much on the specifics of the target users, since cognitive disabilities vary in DS. Nonetheless, even in

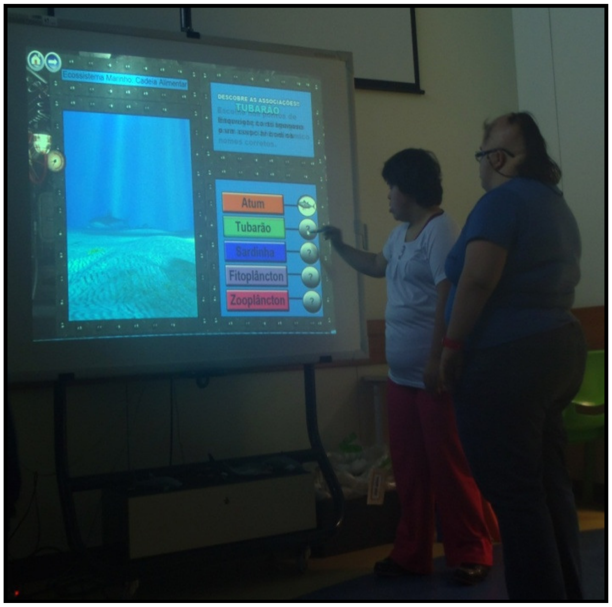

Fig. 5: Experimental session with two DS participants. During this session, one of the DS participants took a leading role and interacted with the board, whereas the second one explained what needed to be done.

the case of our 2 DS participants who were not able to read complex words, it was found very appropriate. Finally, the implementation of the system (choice of software and hardware) was rate as 5.

With respect to the DS participants, they showed no major problems understanding the game or using our system. They reported that the game was easy, they enjoyed the experience, and they learned a lot with it. Only one of them could answer correctly the recall test about the presented food chains. Overall, DS participants could use the system and understand the task, although they required extensive support by the instructor to complete the tasks. However, after the first individual test with the special education instructor, the system was used by both DS participants at the same time (Fig. 5). In this configuration the experience and the behavior of the DS participants was very different. In this setting, they were autonomous and able to complete the task on their own. They developed a collaboration strategy of discussing and explaining to themselves the solutions, requiring almost no support to complete the game.

IV. Conclusions and Discussion

In this paper we presented the development and pilot evaluation of an interactive and VR based approach to support learning in special education. Our system exploits concepts of gaming, VR and an interactive board interface, and is designed to support collective learning experiences with multiple users, in particular for DS. Our system aims at being a learning support rather than substituting the instructor. Two main cognitive competences have been targeted, namely, association and composition/decomposition of elements. Based on the concept of marine ecosystems, our system focuses in the learning of the names, appearance and behavior of individual organisms of an ecosystem, and their later ordering in a food chain. The system was evaluated by 3 special education professionals that reported it to be adequate for special education. Its strongest aspects are the clarity of the tasks, the interaction user-computer, the feedback delivered to support learning, and its implementation. The pilot testing with two DS participants showed it to be engaging and easy to understand. However, it was necessary to have an instructor when the system was used by a single DS participant. Interestingly, when the system was used by two users, a positive collaboration strategy to solve the game emerged. In this condition, users were more independent than when interacting individually with the system. This pilot evaluation is encouraging and indicates that our system can be a powerful tool to support special education instructors. The design of the system allows it to be tailored to the individual needs of the students while also exploiting collaborative learning strategies. However, further evaluation is needed. One of the limitations of the system is the high cost that entails creating and adapting new content to the presented framework. Currently, our system does not provide a general learning framework but a very specific one related exclusively to association and composition training in marine ecosystems. In the future we will investigate how to derive the general working principles of the proposed system and generalize them to a broader context.

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