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Design and Application of an Immersive Virtual Reality System to Enhance Emotional Skills for Children with Autism Spectrum Disorders

Abstract

This paper proposes the design and application of an immersive virtual reality system to improve and train the emotional skills of students with autism spectrum disorders. It has been designed for primary school students between the ages of 7-12 and all participants have a confirmed diagnosis of autism spectrum disorder. The immersive environment allows the student to train and develop different social situations in a structured, visual and continuous manner. The use of a computer vision system to automatically determine the child's emotional state is proposed. This system has been created with two goals in mind, the first to update the social situations, with the student's emotional mood taken into account, and the second to confirm, automatically, if the child's behavior is appropriate in the represented social situation. The results described in this paper show a significant improvement in the children's emotional competences, in comparison with the results obtained until now using earlier virtual reality systems.

Keywords: autism spectrum disorders, virtual reality, emotional skills, social skills, computer vision

1. Introduction

The use of Virtual Reality (VR) as an educational tool for students with an Autism Spectrum Disorder (ASD) is being addressed in different recognized studies with an aim to provide a support tool for the implementation of a series of activities that will help improve the difficulties that the students with ASD have with their social and emotional skills (Parsons, Leonard, & Mitchell 2006; Josman, Ben-Chaim, Friedrich, & Weiss, 2008; Wallace, et al. 2010; Cheng, Chiang, Ye, & Cheng, 2010; Wainer, & Ingersoll, 2011; Kaland, Mortensen & Smith, 2011, DiGennaro, Hayman, Hirst, 2011). The ASD students that participate in this study have a visual and extremely specific way of thinking, a logical but somewhat abstract reasoning and, even though these students are known to be both intelligent and have an excellent memory, they often experience great difficulties when planning executive functions and with their social skills, most noticeably in their emotional incapacity to maintain empathic relationships and to identify such emotions. (Ehrich & Miller, 2009; Volkmar, State, & Klin, 2009, Campatelli, Federico, Apicella, Sicca & Muratori, 2013). All of these deficits lead to a lower comprehension of the rules of communication and to an anticipation of what others feel, do or say, and makes them display an attitude of indifference.

Most current VR environments are visual experiences displayed on a computer screen. However, in Immersive Virtual Reality Systems (IVRS), the user is completely immersed in a computer-generated world, giving them the impression that they have "stepped inside" a synthetic world. These systems offer a controlled and safe three-dimensional representation of real environments that can be used repeatedly. Our aim in this paper consists in designing and applying an IVRS to stimulate the notably visual cognitive processing that characterizes students with ASD for the purpose of improving the student's emotional skills. A large number of strategies used in educational intervention for students with ASD are based on transferring information using visual aids and materials. There is research to support that these students have a tendency towards visual and structured thinking (Lissner, 1992; Gray, 1998; Savner & Smith Myles, 2000; Albrecht, et al 2014). Later works of Grandin (2009) state that visual supports can have an indirect as well as a direct impact on social skills.

A number of authors (see e.g. Blascovich et al., 2002; Wallace, Coleman, & Bailey, 2008) indicated that IVRS can allow an improvement in the stimulation of students with ASD in comparison to the VR-based systems. As indicated in the related works section, several IVRS

have been proposed to enhance the social skills of ASD children. In contrast with previous approaches, the proposed IVRS has been designed and tested specifically for the development of these students' emotional response. Furthermore, a robot with a camera at the end-effector has been incorporated in the above-mentioned IVRS to determine the child's facial expressions at every moment when carrying out the tasks in the virtual environment. The information obtained from the camera at the end of the robot will be used both to evaluate if the child's behavior is appropriate as well as to update the IVRS, as we will explain throughout the paper.

The importance of emotions in social relations is a key element to establish an effective communication between people. Children learn from a young age to develop the capacity to express emotions that allow them to regulate and control their social environment. Through the human face and its emotional expressions we are able to see and interpret the emotional state of another person while we also obtain a great amount of information (Balconi, 2008; Balconi & Carrera, 2008). As mentioned earlier, the goal of this study is to improve the emotional competences in students with ASD. Based on our earlier studies (Lorenzo, Pomares & Lledó, 2013), the IVRS offer the possibility to represent structured and clear visual information, characteristics that adjust well to the cognitive style of students with ASD. Although these earlier studies have not addressed the emotional skills, the immersive system allows students to train and develop new situations and tasks. In the work presented in this paper, the previous IVRS has been improved with an additional sensory system as well as the integration of new properties to train and improve the emotional competences of students with ASD.

This paper will be arranged in the following way: In Section 2 there is a description of previous related works as well as of the specific characteristics that are meant to be stimulated and improved in the students with ASD. In Section 3 we will introduce the main features of the IVRS and the sensory system used. The method and the protocol of tasks will be described in Section 4. Finally, the results and the conclusions will be described in Sections 5 and 6 respectively.

2. Related Works

2.1. The emotional competences in ASD students

This first subsection describes a review about the emotional skills of the ASD students participants in this research. Children with ASD show an emotional development that diverges

from other children and this is interpreted as a lack of empathy to react emotionally to other people's states of mind. The difficulties in children with ASD to establish appropriate emphatic and communicative social relations have been explained with different theories: a) deficits in planning and anticipating tasks and actions and as a consequence, constant repetition (theory of executive dysfunction) (Fisher & Happé, 2005); b) continuous integration and perception of details and a very weak global perspective (theory of central coherence) (Nader-Grobois & Day, 2011; Pellicano, 2010); c) lack of capacity to recognize and interpret other people's state of mind (theory of mind) (Fisher & Happé, 2005; Nader-Grobois & Day, 2011); d) difficulties to express emotionally appropriate behaviors to the presented emotional states of mind (theory of empathy) (Baron-Cohen, 2002; Nader-Grobois & Day, 2011). A great amount of studies such as (Baron-Cohen, 1995; 2000; 2002; 2008; Baron-Cohen et al 2003) indicate a series of aspects that characterize the significant retardation in children with ASD related to the empathic capacity to react emotionally to other people's state of mind:

- Minor joint attention frequency (they don't look at the other person's face and do not even follow their eyes.)
- Less imaginary games and more activities with clear rules.
- A notable reduction in intuitive comprehension that becomes more limited when an explanation is needed.
- Impairment in the capacity to understand the meaning of things and/or predict other people's behavior (incapacity to detect deception) but a high capacity to pay attention to details.
- A significant retardation in the perception and comprehension of emotions and as a consequence, an inappropriate response to other people's emotions.

Baron-Cohen (2008) identifies the empathic capacity as the ability to put yourself in someone else's place, to imagine what the other is thinking and feeling, as well as to understand and to foresee the other person's conduct. In other words, the skill to attribute others with a state of mind and respond with an appropriate emotion. Empathy is attributed with the skill to rapidly and specifically decode the different facial expressions depending on the context, even to identify the most complex states of mind (Sawyer, Williamson & Young, 2012). The lack of empathic capacity is obvious in students with ASD due to the difficulty to recognize the non-verbal expressions and other people's emotions. These children normally focus more on

secondary elements in the face than on the transmitted information (Wallace et al, 2008; Nader-Grobois & Day, 2011). All of these studies support the necessity to continue with projects that teach how to recognize emotions and how to develop ASD children's empathic capacity. To do so, we will use one of the great capacities of the IVRS: the systematization, and the possibility of repeating tasks in diverse contexts. Students with ASD typically exhibit strengths in their visual processing skills, therefore, the mainly visual learning performed in the IVRS helps the student to better understand his/her environment and to acquire the required skills. All these aspects are taken into account in the defined virtual environments.

2.2. ASD and Virtual Reality

This section describes a review about the works that propose the use of VR or IVRS as a tool to improve several deficits shown by children with ASD. Most of these works use VR to check if the child's face adapts to a specific situation as well as to evaluate the child's correct behavior when facing different situations reproduced on the computer. The represented scenes in the VR system are commonly static images and/or animated characters. In this section, we will review the mentioned works and indicate what we have contributed to this study, not only to detect emotional states of mind but also to train and intervene in the development of emotional competences by using the proposed IVRS and the transfer of the learned skills into real contexts.

Considering the studies about VR and facial recognition, there are previous works applicable to ASD that try to identify emotions. For example, the information about facial recognition of the user is also used to improve the social interaction in works like (Ben Ammar, Neji, Alimi, & Gouardères, 2010; Madsen, el Kalioby, Goodwin, & Picard, 2008); while others have presented the possibility to improve facial recognition through monitoring of the eyes, facial expressions or the study of brain images (Harms, Martin, & Wallace, 2010). The works of Tseng & Do, (2010) are also worth mentioning. These works, based on the movie Alice in Wonderland, through the FEW program, intend to detect possible changes in the character throughout the progress of the story. In the same way, Lacava, Rankin, Mahlios, Cook, & Simpson, (2010) propose the Mind Reading system that has a library of emotions. We also want to mention another software, Face IT, with which the user can identify the changes in facial expressions (Tanaka, et al. 2010). Within this context we should highlight the software LIFE is GAME, which can be employed to teach ASD people to recognize facial emotions (Abirached, et

al. 2011). The works of Deriso, Susskind, Krieger, & Bartlett (2012) use the facial recognition CERT library and the emotion system, Mirror. One of the problems with this kind of systems is that the camera has to be placed in front of the child to be able to capture his/her emotions (constraining the child's motions). With the intention to avoid the limitations of always having to place the child straight in front of the camera to be able to detect facial expressions, in this paper we propose the use of a robot with a camera at its end. This will allow the child to move around freely in the IVRS and the robot will do all the necessary movements to make sure that the face is always within its field of view. As indicated before, the computer vision system, described in Section 3, is employed to automatically determine the child's expression. This system will confirm if the child's facial expressions in the IVRS are appropriate and this information will be used, on the one hand, to evaluate the child's development, and on the other, to update the scene represented in the IVRS. One of the major problems when using VR with children with ASD is the lack of contextualization of the emotions and its implementation. However, by using the presented IVRS it is possible to create a context similar to a real one to help the students to learn certain emotions when facing different situations (which will help them learn and afterwards transfer the knowledge into the real world). It will also allow repetition and systematization, as one of its strong assets, which will lead to a reduction of this emotional deficit.

There are previous works such as (Matsentidou & Poullis, 2014; Wallace, et al. 2010) related to the use of IVRS with people with autism. Matsentidou and Poullis (2014) employ an IVRS (VR CAVE) that consists of four HD screens, four projectors and cameras. They investigated whether a VR CAVE environment can be used in an effective way by children with autism, and whether children can benefit from that and apply the knowledge in their real life. Although this system has not yet been tested with ASD people, the system has been designed to represent different unsafe situations where the child must experience it, in order to learn how to act (e.g. crossing the road). Wallace, et al. (2010) explored the responses of ASD adolescents in an immersive "blue room". This room is composed of four screens (three walls and a ceiling) where different animations are projected (street, playground and school corridor scenes). This paper suggests that IVRSs offer the potential to recreate realistic-looking scenes that could form the basis of important social role-play. The IVRSs are also applied for the social interaction development (Beach & Wendt, 2014) and to improve social skills such as teaching pedestrian crossing (Siano, Pellegrino, Casadio, Summa, Garbarino, Rossi, Dall'Agata & Sanguineti, 2015;

Tzanavari, Charalambous, Herakleous & Poullis, 2015). Other works suggest that IVRS can be used to improve the attentional skills of ASD people (Zeng, Fu, Zhao, Swanson, Weitlauf, Warren & Sarkar, 2015). In contrast with previous approaches, the IVRSs proposed in this paper have been developed together with the school teachers and families seeking to improve ASD students' emotional skills. The designed scenes in the IVRS are as close to reality as possible. This reduces the adaptation time and improves the transfer of skills into the real world.

3. Immersive Virtual Reality System

In this section, the different components of the proposed IVRS are described. This system is used to provide the children with visual and interactive learning with the aim to help them acquire the social competences already mentioned. This section shows a description of the components of the IVRS (equipment, virtual environments and other developed software) that recreates different social situations or stories with the objective to train appropriate emotional responses to improve the student's emotional skills.

The IVRS is made up of the elements described in the following subsections: equipment, virtual environments or immersive scenarios and software components.

3.1. Equipment

The different scenes are shown in a system with L-shaped screens called "semi cave" (see Figure 1). One of the screens provides a frontal view of the environment and the other is placed on a platform which allows it to project from below. The components and avatars of the represented virtual scenes can change their behavior depending on the actions and behaviors of the ASD student. For this reason, the face recognition of the student is required in order to detect the student's mood and accordingly update the scenes. To do this, a robot with an eye-in-hand camera system is employed as is shown in Figure 1. The robot used is a 7 DoF Mitsubishi PA-10 robot arm. This robot has an eye-in-hand PHOTONFOCUS MV-D752-160-CL-8 camera installed on its end-effector. The camera also determines the pose of the children. This information is then used to update the point of view shown on the screens. Another important piece of equipment worth of mentioning is the sound system that helps the child to hear different sounds as if they were in a real environment (it is also used to give instructions to the child).

Figure 1. System architecture

3.2. Virtual Environments

A computer with the software Vizard has been used to design the scenes or virtual environments. This software provides an interface that allows the user to write scripts in Python and disposes of a series of virtual reality libraries to adapt the environments. The avatars and their moods were designed using 3ds Max. The tool employed to design the avatars is PeopleMaker. This tool has allowed the design of expressive avatars and the integration of them in the IVRS using Vizard. In Figure 2, two different immersive virtual scenes are represented (a party and a classroom). Using these situations the child can interact with the different avatars and carry out a series of emotion recognition tasks and practice the emotional responses as described in Section 4.

Figure 2. Examples of immersive virtual environments. A birthday party (left) and a classroom (right)

3.3. Software Components

The different software components used in the IVRS can be divided into the following groups:

- Interface. By using this module, the researcher or evaluator can interact with the child and the different components of the IVRS.
- Virtual reality generation module. This module contains the program Vizard where the different immersive environments are designed.
- Data capture module. Provides information about the child's position and orientation within the virtual environment so that the child's point of view can be adjusted to offer a correct display. Our earlier studies (Pomares, Chaumette, & Torres, 2007) are used to calculate this position. This module also determines the child's mood and verifies if it is appropriate for the presented situation. The software FaceDetect (Kueblbeck & Ernest, 2006) and the camera at the end of the robot are used to determine the mood. This software uses an algorithm that generates a numerical value that is employed to identify and quantify the user's four basic expressions: anger, happiness, sadness and surprise.
- VR software application. This software application has been developed with the objective to compare the learning results in the IVRS with the results from a classic VR system (the same scenes can be represented in both systems). In the case of the VR software application, the

moods are captured with a webcam. This last application will be used, as stated in Section 4, with the so-called control group.

4. Method

As mentioned before, the aim of this study is to use the IVRS to train, develop, and improve the deficits in emotional skills shown in students with ASD. The strategic framework proposed for the collection of information about students and their progress employs a mixed methodology (due to the intervention of two disciplinary fields, robotics and technology and psychopedagogy). Therefore, from the technological field a quasi-experimental methodology has been employed and, from the psychopedagogy a qualitative, quantitative and experimental methodology has been used. This method will not only allow us to implement and practice the designed educational intervention but also to analyze possible improvements in the emotional competencies proposed as an object of study in this research through the use of the IVRS.

As background of the present research, the authors worked from 2006 to 2010 with 7-to-12-year-old ASD children. During this initial phase, several social situations where the students had difficulties were identified, that is, they did not have shown an emotional response according to the social situation. Having identified these social situations, the authors proceeded to design the IVRS and its application to improve the emotional skills of these students in the aforementioned situations during the next years. The design and implementation was carried out following the schedule set out in Section 4.3. The investigation has been divided into the following phases:

- Initial phase. The questions/problems were established as a starting point:

  RQ1. Is there a significant difference between IVRS and Desktop VR for the development of emotional competences in students with ASD?

  RQ2. Is there a significant difference between IVRS and Desktop VR with respect to the transfer of the acquired knowledge into a school environment?
- Planning and design phase. Designing of the immersive virtual environments as well as the data collection instrument. These environments should not only allow the identification and recognition of emotions, but also the training and development of appropriate emotional behaviors in students with ASD.

- Implementation phase. The children with ASD carry out a series of previously planned tasks in the IVRS. The IVRS will recreate situations, in the form of social stories, which allows the recognition of expression and emotions as well as the training of appropriate emotional behavior.
- Analysis phase. Study and analysis of the obtained results and their educational implications. Evaluation of the improvement that the IVRSs provide in relation to the deficits in the emotional competences of students with ASD, in comparison to the traditional VR desktop environments.

4.1. Participants

The participants have been chosen according to a purposive non-probability sampling method and following the criteria for primary school students with a ASD diagnosis. The participant sample consists of 40 students (29 boys and 11 girls) from primary schools, between 7 and 12 years old. The students were chosen after interviews with the school psycho-pedagogical services and with the student's tutors. These interviews allowed confirming the family support to the research and verifying if the students' difficulties correspond with those mentioned in Section 2.1. The experimental group of 20 children (14 boys and 6 girls), chosen randomly, will carry out the tasks in the IVRS and a second group, the control group (15 boys and 5 girls), chosen randomly, will carry out the tasks in the VR software application indicated in Section 3.3. All participants have difficulties in the social situations that will be trained using the IVRS or the VR software application and no significant improvements have been noted using traditional therapeutic approaches.

4.2. Instruments

As mentioned before, a structured social situation is represented in the IVRS in which a set of aspects can be controlled: irrelevant information is eliminated, instructions are clearly and explicitly presented, and finally, a visual learning is developed (furthermore, this learning is interactive and close to reality). These aspects help take advantage of the special systematization capacity of this group of students, for which we have designed the following data collection instruments.

4.2.1 Emotional script (ES)

We have established an Emotional Script (ES) as a social script or behavior guideline in which we introduce 10 social situations. As in the Gray social stories (Carol Gray, 1998, 2004) a social situation is presented and the adequate behaviors are presented. However, in the approach proposed in this paper, the user must interact in the IVRS with the individual and continuous support of the evaluator. This allows students to learn the appropriate behavior and apply it in different sessions in the IVRS. These social situations are designed based on real situations where the students have shown difficulties:

1. The student goes to a birthday party.
2. The student wants to play with some children in the park.
3. The student, as every day, stands in line waiting to enter the classroom.
4. The student is listening to a story told by the teacher in class.
5. The student approaches some children playing soccer.
6. The student is going on a field trip with his classmates.
7. The student has the annual medical check-up at school.
8. The student plays hide-and-seek with friends.
9. The student will sit down next to some children that are talking in the patio.
10. The student is working in class and he need to ask for help.

In the designed social scenarios, situations in which students use the emotional behaviors of joy, sadness, anger, fear, surprise, etc. were taken into account. The 20 participants in the experimental group will carry out these situations in the IVRS, following the session planning explained in Section 4.3. The control group will also carry out each and every one of these social situations in the VR software application indicated in Section 3.3. Once the social situation has been introduced to the child (in the IVRS or the VR software), an evaluator will explain the task instructions and the possible behavior guidelines to the child. The guideline is the emotional script and it will be the same for both the children working with the IVRS as for the control group. Having a common emotional script for both groups and following the same structure for all the social situations allows an easier learning for these students (characterized by a visual, mechanical and structured learning), as well as a comparison of the obtained results from both groups. In addition, by using this script, the evaluator can provide the student with models,

explanations and alternatives to solve the mentioned situations. The evaluator will also be responsible for registering the children's behaviors in both groups.

The objective of this instrument is to collect information about:

- The identification of the implicit emotions in the different social stories.
- The training of appropriate emotional responses when facing the introduced social situations.

Phase 1. Identification of the situation and the emotions

In this first phase, the social situation is introduced to the child and the evaluator constantly interacts with the children. The evaluator explains the social situation and asks the child about the components of the situation and about the different characters' emotions (where they are, which situation is being represented, where the children are and how they are feeling (happy, angry, sad, surprised etc.)). During this interaction, students receive permanent support from the evaluator to become familiar with the virtual environment. They do not know that the evaluator carries out a first evaluation of the child during this first phase. Additionally, the information obtained by the evaluators has been employed during the research to create more expressive avatars for ASD children. The evaluator will grade the child's answers, both in the VR application and in the IVRS, with a number from 1 to 6. 1: Does not identify any of the requested situations; 2: Identifies what they are doing; 3: Identifies what they are doing and where they are; 4: Identifies what they are doing, where they are and the implicit emotion in some of the situations; 5: Identifies what they are doing, where they are and the emotions in a regular way; 6: Does not show any difficulties to recognize and identify the introduced situation.

Phase 2. Implementation of the emotional script

Keeping in mind that the goal of this study is not only to identify, but also to develop and train appropriate emotional behaviors that improve the emotional competences of this group of students, we have established a behavior guideline and possible alternatives in the social stories. In the experimental and in the control group it is the evaluator that both gives the directions and registers the behavior. As mentioned earlier, there is an established common emotional script for all the social stories. This script is used in all the sessions in such way that it forms a fixed and mechanical framework that helps the student's learning. The script is as follows:

1. The evaluator describes the situation in a clear and precise manner.

2. Behavior proposals: The evaluator shows the student which behavior would be appropriate.
3. If the behavior performed by the student is appropriate:
   a. The evaluator shows the other avatars' reactions in order to highlight this correct behavior.
   b. The evaluator shows the student what would have happened if the behavior had not been appropriate.
4. If the behavior performed by the student is not appropriate:
   a. The evaluator indicates this by showing the other avatars' reactions.
   b. The evaluator reminds the student which is the appropriate behavior and goes back to step 2.
5. The session ends with one frase to sumarize what the student should learn from this session.

In Table 1, an example of the use of this script in situation 2 is described ("The student wants to play with some children in the park"). In order to show the children interaction in the IVRS, Figure 3 represents a child in the IVRS doing the social story 2.

Table 1. Script for the situation of social story two.

Figure 3. Child interacting with the IVRS

The students' behaviors, while the different social situations take place, will be registered by the evaluator in the categories shown in Tables 2, 3 and 4. In these tables we specify the relevant conduct to be observed dividing them into three sub-categories or dimensions: a) behavior during the presentation and description of the social stories; b) emotional response when carrying out the social stories; c) compliance with the behavior guideline. The evaluator determines the number of times (or frequency as indicated in the results section) where the adequate behaviors indicated in Tables 2, 3 and 4 are observed. This record has been carried out throughout the 4 planned sessions for each of the social stories, as indicated in Section 4.3.

Table 2. *The evaluator's record of the categories corresponding to:*
a) Behavior during the presentation and description of the social stories.

Table 3. *The evaluator's record of the categories corresponding to:*
b) Emotional response when carrying out the social stories.

Table 4. *The evaluator's record of the categories corresponding to:*

c) Compliance with the behavior guideline.

4.2.2. Data collection using computer vision.

As mentioned in Section 3, the proposed IVRS uses a computer vision system, capable of automatically determining the child's expression while the social stories take place. In the case of the control group we have used a fixed camera facing the child's face and in the case of the IVRS we have used a camera placed on the robot's end-effector. This computer vision system is used so that the avatars that appear in the virtual scenes react according to the child's expressions. However, this system is used simultaneously to register the number of times that the child's behavior or facial expressions do not correspond with the social situation. Therefore, the computer vision system is employed to automatically register the number of times when students perform inadequate behaviors or the facial expression does not correspond with the social situation. This number of inadequate behaviors is called here as a score. This value is also used as an evaluation criterion. The following score categories are used: Category 0: null score (all behaviors were appropriate); Category 1: scores from 1 to 3; Category 2: scores from 4 to 6; Category 3: scores from 7 to 9; Category 4: scores from 10 to 12; Category 5: scores from 13 to 15; Category 6: scores over 15.

4.2.3. Initial interview and throughout the intervention process of the social stories.

In order to determine if the proposed IVRS allows improving the deficits in emotional skills of these students, it is necessary to evaluate the generalization and application of the knowledge acquired in the virtual environments to other real contexts, such as a school environment. For this purpose it is necessary to use a data collection instrument in the real classroom. For this, we have interviewed the students' tutoring teachers. These interviews were held on a monthly basis with the intention of doing a close follow-up of the emotional responses given in the social situations represented in the virtual environment. The tutoring teacher writes a monthly evaluation of each child with a number from 1 to 6, with 1 being: the child still does not identify what the other children are doing and how they feel and they do not follow any behavioral guideline; 2: the child starts to identify and understand what the others are doing and how they feel even though they still do not follow any of the guidelines; 3: identifies the

emotions and follows a few of the guidelines; 4: identifies the emotions and follows several of the guidelines; 5: identifies the emotions and follows the guidelines regularly; 6: Does not show any difficulty to identify the emotions and to follow the guidelines in the presented situation.

4.3. Design and Procedure

This section describes the procedure carried out during this research. The study begins in the academic year 2006/2007 with a group of children, selected from schools in the province of Alicante (Spain). These schools had students with ASD and special education teachers. During that year we established a list of situations to develop a set of social skills, with which the students with ASD have shown difficulties (this list later became the Emotional Script). During that year we also created several questionnaires to determine the student's development throughout the year in a quantitative way. These questionnaires measure the student's development while they perform the above-mentioned list of tasks (see Section 4.2.3). These evaluations were used with other students with ASD during the following two academic years. The number of participating students during these three years varied between 17 and 24. The information collected during these three years was the starting point to create the virtual environments and the emotional script. The implementation process of the instruments mentioned in Section 4.2 took place during the 2011/2012 school year. The students became familiar on an individual basis with the virtual environment in September 2011 and the sessions with data collection instruments started in October 2011. The timeline is presented in Table 5. The individual sessions lasted 35 minutes. There were four monthly sessions, held in the morning and in the afternoon, outside the regular school schedule. At the beginning of the research, the interviews with the tutoring teachers were scheduled on the last day of each month and a member of the research team went to the school to learn more about the student's learning development and about possible changes or adaptations.

Table 5. Timeline. Tasks implemented during each month

5.-Results

This section presents the results obtained during the application of the method described in the previous section. In this section, the term "study group" is employed when referring to the

children that have used the IVRS and the term "control group" when referring to the children that have used the VR software application. The statistical significance is evaluated with a t-test (p-value), considering as statistically significant the estimates of the parameters with p-value < 0.05 (in this section, p-value = 0 is considered when lower than 10^{-5}).

Figure 4 presents the results obtained during the process of identifying the virtual environment (first phase of the emotional script), for both the control group and the study group. To work out this figure we have calculated the average grade (see Section 4.2.1, Phase 1) obtained by all the children over the 40 sessions (as stated earlier, each social story has been carried out 4 times). This figure represents the average and standard deviation of the grades obtained for each session. In this last figure we can see that the average grades obtained by the study group become higher as the number of sessions increase. Furthermore, analyzing the average, standard deviation and confidence interval for the parameters represented in Figure 4, the values obtained by the study group are: 5.2, 0.4, and [4.6, 5.4]; and the values obtained by the control group are: 4.5, 0.14, [4.43, 4.7]. The final average grades for the study group (5.4) and for the control group (4.7) are significantly different from each other (p-value = 0.03). Additionally, at the end of the study, the average grades of the study group and the control group showed a very statistical significant difference; the mean scores in the study group increased by 0.9 points (p-value = 0.00001) compared to only 0.1 points in the control group (p-value = 0.37). All these data reveal that the training helps the child to adapt to the virtual environment and improves the identification in the IVRS more than in the traditional VR desktop software application.

Figure 4. Identification process for both participating groups during the presentation of the social stories.

Figure 5.a presents the average frequency of behaviors obtained by all the children in the study group during the second phase of the emotional script (execution of the emotional script) classified in the three subcategories or dimensions indicated in Section 4.2.1: a) Behavior during the presentation and description of the social stories; b) Emotional response when carrying out the social stories; c) Compliance with the behavior guideline. To obtain this "average frequency" we have calculated the number of adequate behaviors (frequency) indicated in Tables 4, 5 and 6 that have been registered by the evaluator while the social story is presented in the IVRS. Tables 4, 5 and 6 represent a set of appropriate behaviors that would be desirable for the children to

exhibit. While the emotional script is carried out in the IVRS, the evaluator registers the number of these adequate behaviors (frequency). The average frequency (and corresponding standard deviations) obtained by all the children is the value indicated in Figure 5.a. We have divided this figure in such way that the reader can see the average frequency from the first, the second, the third and the fourth time the children carry out all the social stories. The information corresponding to the control group is indicated in Figure 5.b. Analyzing the average frequencies represented in Figure 5 for session 1, an average value for the frequencies and standard deviation of 8.5 and 4.1 respectively is obtained for the study group. The corresponding values in session 4 are 14 and 2.9 respectively. Additionally, an average value for the frequencies and standard deviation of 7.6 and 4.5 respectively is obtained for the control group in session 1. The corresponding values in session 4 are 10.5 and 3 respectively. From the results we can observe that, even though the number of adequate behaviors is similar in the first session, as the training moves forward, the average frequencies increase significantly in the immersive environment. In order to answer the RQ1, in the next paragraph the statistical significance is evaluated depending on the three categories represented in Figure 5.

Firstly, the results obtained for the category a), behavior during the presentation and description of the social stories, are studied. At the end of the research, the average frequencies of the study group increased by 2.4 points (p-value = 0.00002) compared to only 0.2 points in the control group (p-value = 0.47). A statistical very significant difference is obtained between both groups (p-value = 0). With respect emotional response, when carrying out the social stories (category b) the average frequencies of the study group increased by 4.4 points compared to 2.3 points for the control group. However, the significance of both values is very different. A p-value of 0 is obtained for the study group and a p-value of 0.031 for the control group. A statistical significant difference is obtained between both groups (p-value = 0.002). Finally, the results for category c), compliance with the behavior guideline, are considered. In this case, at the end of the study, the average frequencies of the study group increased by 9.4 points (p-value = 0) compared to 6.4 points in the control group (p-value = 0.00033). A statistical significant difference is obtained between both groups (p-value = 0.011).

To summarize and to confirm the obtained results, Figure 6 shows the evolution of the registered adequate behaviors (frequency) throughout the 40 sessions. The results confirm that even though the students in the desktop environment obtain higher frequencies of adequate

behaviors in the initial sessions, the students that carry out the social stories in the immersive environment, with training and practice, show significant improvements related to the emotional behaviors and the compliance with the guidelines. At the last session, the average frequencies of the study group increased by 9 points and only 3 points in the control group with respect to the first session. A statistical very significant difference is obtained between the last average frequency for both groups (p-value = 0.0001).

Figure 5. Analysis of the frequency record of adequate behaviors a) In the immersive environment b) In the desktop environment.

Figure 6. Analysis of the evolution of the adequate behaviors in the emotional script throughout the student's 40 sessions, both in the immersive and desktop environment.

In Figure 7, the average scores obtained by all children in both groups, using the computer vision system are presented (this figure also shows the standard deviations). The computer vision system is employed to automatically register inadequate behaviors and the scores have been calculated with the criteria indicated in Section 4.2.2. All the children (study group and control group) show some difficulties to identify the emotions in the first sessions and a great number of inadequate behaviors (score) are detected by the computer vision system (in the first session an average score of 30 and 28 are obtained in the study group and control group respectively). However, the scores clearly decrease with the number of sessions (in the last session an average score of 7 and 14 is obtained in the study group and control group respectively). The final average scores are significantly different from each other (p-value = 0). Analyzing the average, standard deviation and confidence interval for the parameters represented in Figure 7, the values obtained by the study group are: 16.3, 6.5, and [13.1, 19.5]; and the values obtained by the control group are: 22.2, 4.1, [20.8, 23.5]. Regarding the RQ1, the emotional competences in the IVRS related to the represented social situations seem to be improved according to the information provided by the computer vision system. All these data indicate that both groups reduce their inadequate behaviors in the IVRS. However, the training helps the children to adapt to the virtual environment and improves their behavior in the IVRS more than in the traditional desktop application.

Figure 7. Analysis of the average scores obtained using the computer vision system.

In Figure 8, the results obtained from the evaluations answered by the tutoring teachers at the schools during this research are presented (see Section 4.2.3). As mentioned before, this evaluation is carried out by the tutoring teachers on a monthly basis and allows us to confirm the transfer of behaviors from the virtual environment into the real world (RQ2). Analyzing the average, standard deviation and confidence interval of the values represented in Figure 8, the values obtained by the study group are: 4, 1, and [2.8, 5.1]; and the values obtained by the control group are: 3.4, 0.4, [2.9, 3.9]. The grades have shown more significant values in the study group, related to the knowledge of emotional situations and their existence in the school environment. In Figure 8, the empirical results reveal an increase of the average scores from the beginning to the end of the implementation process of the emotional scripts (10 months) when the IVRS is employed. At the beginning, the study group obtains an average grade of 3, while the control group obtains a value of 3.1 (these average values are obtained during the first month). The statistical significance of the average grades in the interviews are different for both groups. For the control group, an average grade of 4 (p-value = 0.02) is obtained at the end of the implementation of the emotional scripts (improvement of 0.4 units). However, in the study group an average grade of 4.9 (p-value = 0) is obtained at the end (improvement of 1.9 units). The final average grades for both groups are significantly different from each other (p-value = 0.00187). As indicated in Section 4.3, we carried out interviews during the three academic years 2006-2009, with the goal to learn more about the ASD student's development in the school environment, carrying out the social situations of the Emotional Script. These students had special education support (the IVRS is not applied) and showed an improvement from 0.1 to 0.7. This means that the emotional skills in the real school environment have been improved. Therefore, the skills trained in the IVRS are correctly transferred to the real world and the students have shown a better progress than in previous years when the IVRS was not used.

Figure 8. Evaluations answered by the tutoring teachers at the schools during this research.

6.-Conclusions

The results of this study show a significant presence of more appropriate emotional behaviors in the immersive environments in comparison with the use of desktop VR applications.

The immersive environments offer a high degree of interactivity with the user and consequently the possibility of further developing the imagination and learning through various roles that occur in the represented social situations. Another interesting aspect is the fact that the emotional behaviors in the real school environment have improved during the study in the children that participated in the IVRS. This aspect indicates that it is possible to transfer and generalize the acquired skills from the virtual environment to real situations. In the same way, one of the aspects that we also consider interesting in the study is that the results confirm the general evolution in the students throughout all the sessions. We have verified higher grades in the resolution of emotional responses in the immersive environment than in the desktop environment, even though the grades in both environments did not show any significant differences at the beginning of the study.

Looking at the results, the IVRS is a useful tool in the acquisition and development of the emotional competences in students with ASD. The IVRS help to develop and improve the emotional competences of students with ASD not only by identifying more or less complex facial expressions, but also by interacting in different situations and understanding the emotions implied in these social situations. To do so, it is necessary to design school and social situations that are as real as possible (with elements known by the students), with behavior guidelines to systematize the responses and the support of the computer vision system to interact and to collect information. A possible improvement for future studies is to continue widening the range of emotions and tasks so that they become more complex both in the IVRS as in the school context.

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Figure Captions

Observations and guidelines for the evaluator	Directions and reinforcements for the students
1. The evaluator describes the situation indicating where the children are.	The evaluator indicates that the child should approach the other children and show an interest in playing with them.
2. If the child goes away	The other avatars try to capture the child's attention. The evaluator indicates the appropriate behavior.
3. If the child approaches the others but with and inappropriate expression.	The other avatars also change their expression. The evaluator indicates which the proper expression is by showing an example.
4. If the child approaches the other with an appropriate expression.	The evaluator reinforces this behavior by showing the other children's expressions and offers him/her to play in the IVRS.
5. The evaluator ends the session by reminding the learnt information.	

Table 1. Script for the situation of social story two.

Categories	Session 1	Session 2	Session 3	Session 4
They show interest for what is being presented to them				
They understand what is being presented to them.				
They pay attention to the things that are being described.				
They show interest in doing what is being explained to them.				

Table 2. The evaluator's record of the categories corresponding to the behavior during the presentation and description of the social stories.

Categories	Session 1	Session 2	Session 3	Session 4
They identify where the social story or situation occurs.				
They look at the people that appear in the story.				
They know what the people that appear are doing.				
They ask questions about what they are seeing.				
Their expression shows what is happening in the story.				
They answer the questions that are being made.				
They follow the indicated guidelines.				
They show implicit emotional expressions in the social story through their answers.				
They don’t follow the indications literally.				
They realize that the children are pleased and happy.				
They realize that the children are angry.				
They are surprised by the stories that they see.				
They realize that there are children that are surprised by something.				
At some point of the task, they ask what is going on with the children.				

Table 3. The evaluator’s record of the categories corresponding to the emotional response when carrying out the social stories.

Categories	Session 1	Session 2	Session 3	Session 4
The student followed the teacher's guidelines.				
The behaviours are reinforced with the help of the other avatars.				
The student applies the alternatives given by the evaluator.				
The student explains how he/she should act.				

Table 4. The evaluator's record of the categories corresponding to the compliance with the behavior guideline

IVRS Group		Control Group. Desktop environment	
Month	**Social situations**	**Month**	**Social situations**
October	1,2,3,4	*October*	1,2,3,4
November	5,6,7,8	November	5,6,7,8
December	9,10,11,12	December	9,10,11,12
January	3,4,5,6	January	3,4,5,6
February	7,8,9,10	February	7,8,9,10
March	1,2,3,4	March	1,2,3,4
April	5,6,7,8	April	5,6,7,8
May	9,10,1,2	May	9,10,1,2
June	3,4,5,6	June	3,4,5,6
July	7,8,9,10	July	7,8,9,10

Table 5. Timeline. Tasks implemented during each month.

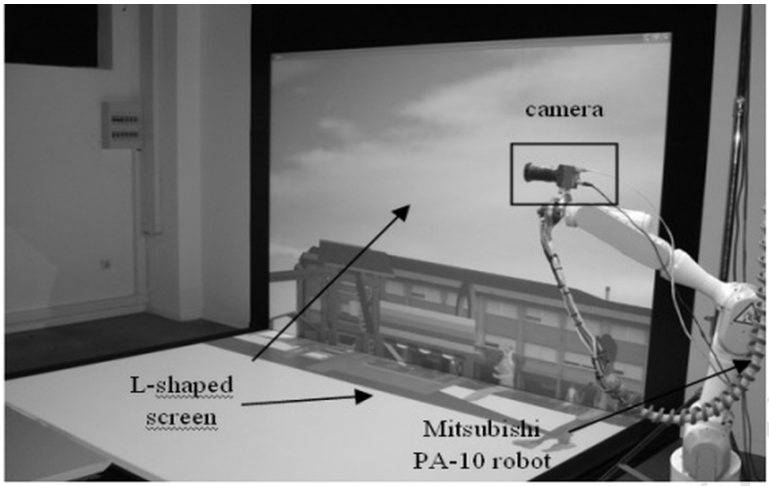


Figure 1. System architecture

Figure 2. Examples of immersive virtual environments. A birthday party (left) and a classroom (right)

Figure 3. Child interacting with the IVRS

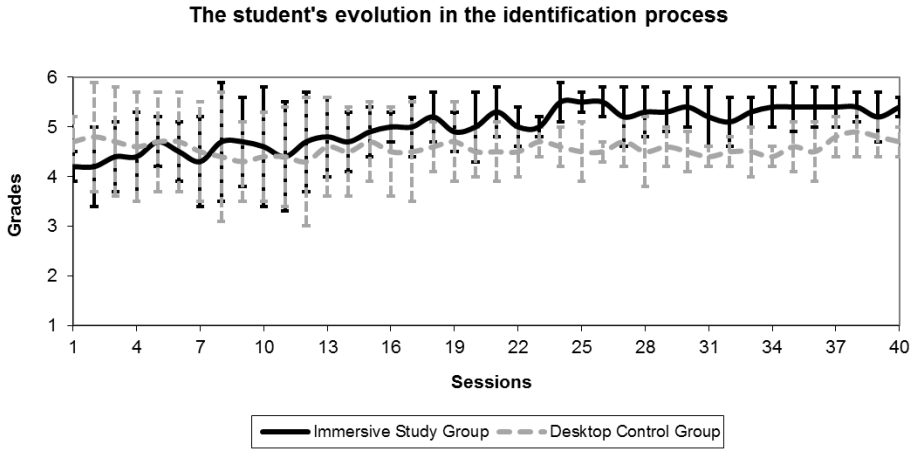
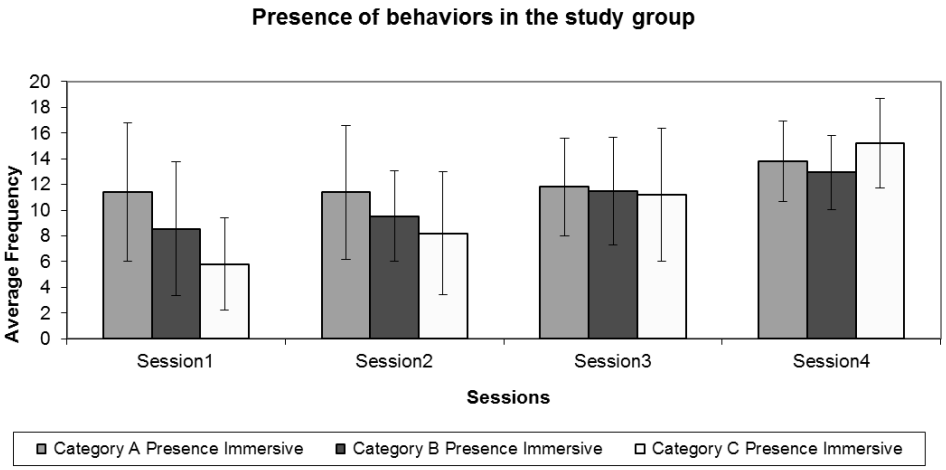
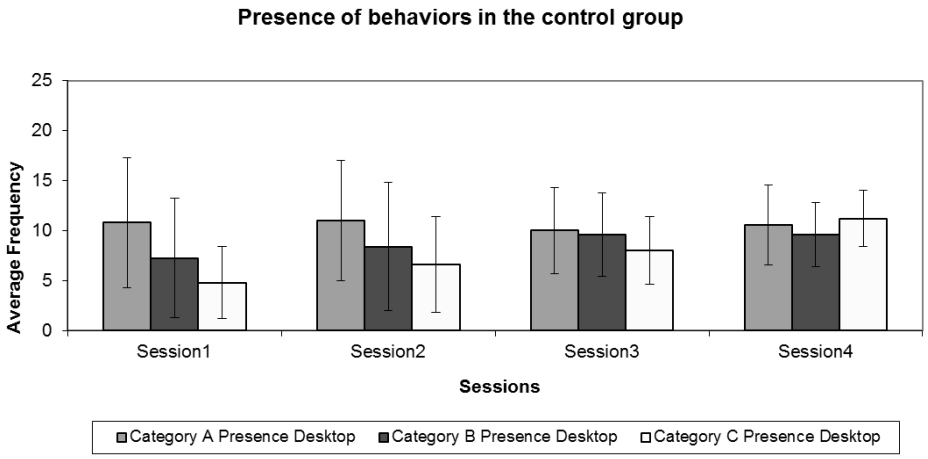


Figure 4. Identification process for both participating groups during the presentation of the social stories.



a)



b)

Figure 5. Analysis of the frequency record of adequate behaviors a) In the immersive environment b) In the VR desktop software application.

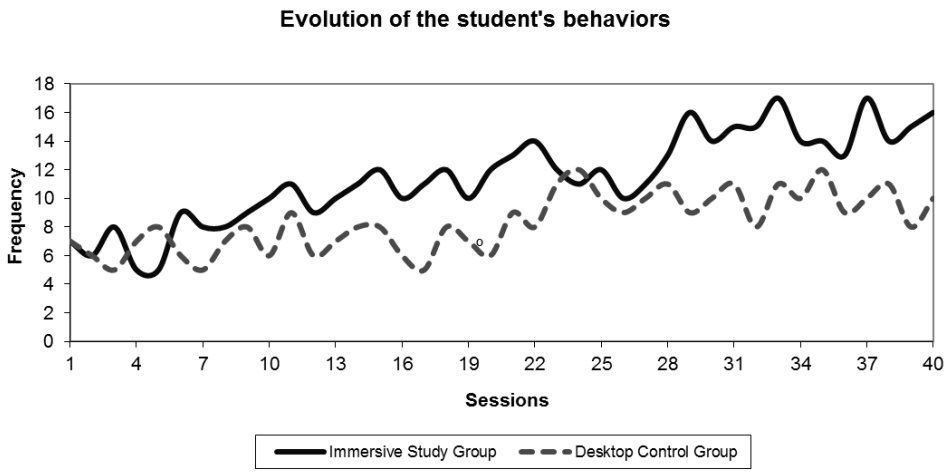


Figure 6. Analysis of the evolution of the adequate behaviors in the emotional script throughout the student's 40 sessions, both in the immersive and desktop environment.

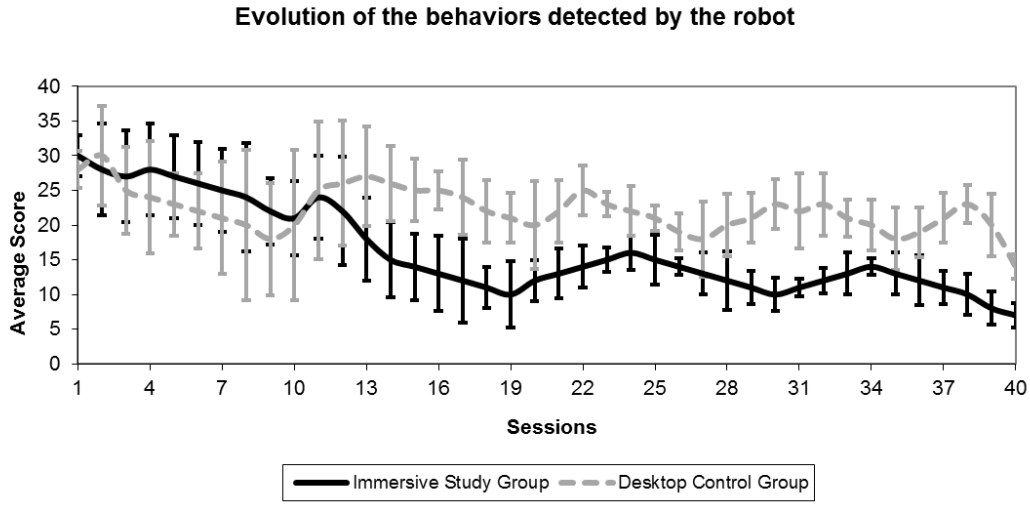


Figure 7. Analysis of the average scores obtained using the computer vision system.

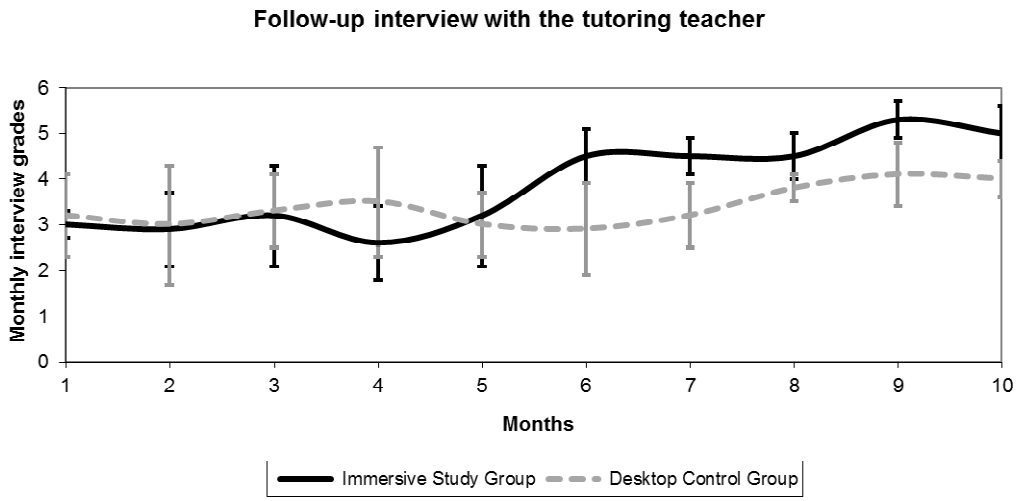


Figure 8. Evaluations answered by the tutoring teachers at the schools during this research.

HIGHLIGHTS

Virtual reality to improve the emotional skills of ASD students.
Immersive virtual reality system to create social situations where the students can practice their emotional responses.
Design and implementation of protocols to evaluate the students' emotional response.
Identify, develop and train appropriate emotional behaviors of ASD students.
Immersive virtual reality system to create social situations to improve their emotional skills