Educ Inf Technol (2019) 24:127–151
https://doi.org/10.1007/s10639-018-9766-7

The application of immersive virtual reality for students with ASD: A review between 1990–2017

Gonzalo Lorenzo[1] **· Asunción Lledó**[1] **·**
Graciela Arráez-Vera[1] **· Alejandro Lorenzo-Lledó**[2]

Received: 9 March 2018 / Accepted: 22 June 2018 / Published online: 29 June 2018

Abstract We live in a society where Technology has an important position in our diary activities. Everybody wants to have the last device to be in contact with his family and friends. Additionally, these took are being applied in other fields such as Education. One of these tools is: Virtual reality that can respond the need of our students. It allows the designer an important control of the system that can be useful for students with Autism Spectrum Disorder. These students can use Virtual Reality as a support to practice social situation that can be generalized in real environments. Therefore, our research provides a state-of-the-art review of what studies have applied Immersive Virtual Reality to students with Autism Spectrum Disorder. The sample of study has been 12 papers in the period 1996–2017. To analyse these research, it has been proposed these variables: participants' features, research questions, instrument, type of activities, results, and limitations. These study variables have been chosen because they are the most repeated in all research using the experimental method. According to the results gathered: it has been worked with small sample, without control group and interactive activities. Moreover, the vast majority of the studies are focused on social skills.

✉ Gonzalo Lorenzo
glledo@ua.es

Asunción Lledó
asuncion.lledo@gcloud.ua.es

Graciela Arráez-Vera
graciela.arraez@ua.es

Alejandro Lorenzo-Lledó
alejandro.lorenzo@ua.es

1 Department of Development Psychology and Teaching, University of Alicante, Carretera San Vicente del Raspeig s/n - 03690 San Vicente del Raspeig, Alicante, Spain

2 Department of General and Specific Didactics, University of Alicante, Alicante, Spain

Keywords Immersive virtual reality · ASD · Review · Technologies · Intervention

1 Introduction

It is possible to find a large number of research papers where virtual reality (see e.g. Parsons et al. 2006; DiGennaro et al. 2011) or an immersive virtual reality (see e.g. Wallace et al. 2010; Strickland et al. 1996) are applied to the education of students with special educational needs. Virtual Reality (VR) is created by personal computers that allow the user to walk along virtual environments using commercial software (Johnson et al. 1998). Furthermore, Blascovich et al. (2002); Baileson et al. (2008) defined VR as a simulation of true real worlds with a high degree of authenticity. Additionally this tool allows the designer in order to obtain more information about the way in which these learners respond, interpret and interact with the real world. This feature could be useful for students with especial needs such as students with Autism Spectrum Disorders. It is due to the possibility to adapt environments to their needs. According to Terzi (2005), these students have different learning rates because of their individuals' limitations or disabilities. In contrast, Norwich (2006) conclude that special needs of these children are produced by the limitation of the schooling system.

Moreover, these children are highly enthusiastic about the use of computer-assisted technologies, which can become a powerful educational tool (Chen and Bernard-Opitz 1993; Moore and Calvert 2000; Parsons and Mitchell 2002, Schmidt and Schmidt (2008). In addition to this, Standen and Brown (2006) explain that this instrument allows students to learn from their mistakes without suffering effects produced by the real world. It is a useful feature because these students have problems to perform different stimulus. Later, Goodwin (2008) affirmed that this tool could provide an educational tool to improve certain social tasks. Therefore, we can observe how technology can help students with ASD.

To sum up, the present study has as its aim to create a systematic and thematic review providing a state-of-art about what studies have worked with IVR and students with ASD. To obtain the objective we have established the following research questions.

What are type of research questions used in these studies?
What are the instrument used working with students with ASD?
Which are the areas studied in this research?
Which are the most important limitations to work with students with ASD and IVR in social situation outside the school?
What are the features of the activities shown?
What are the most important results?

1.1 Virtual reality and ASD

In our research, the characterisation of ASD students begins taking up one of the definitions of autism provided by Strickland (1997), in whose opinion, this is a complex developmental disorder characterised by a severe deterioration of the social, communicative and behavioural life. In some cases, according to other authors (Dautenhahn 2000; Lord et al. 2000; Robins et al. 2005), autism shows a certain degree of intellectual disability. It usually appears during the first years of a child's life –especially until the age of three (Tzanavari et al. 2015). Additionally, DSM-V (2013) establish the general term called Autism Spectrum Disorder, which is defined by the alteration in communication and social interaction, patterns of behaviour, restricted interests and activities and a significant deterioration of activity in the context of society, work.

However, Baron-Cohen (1995, 2000, 2002, 2008); Baron-Cohen et al. (2003) focus their research in other important area of students with ASD: emotions. For these authors, students with ASD present a significant delay in the perception and understanding of emotions, as well as an inadequate response before them. Moreover, they have a deterioration in the ability to understanding the meaning of things and/or predict the behaviour of other people. Furthermore, these children try to focus on secondary elements in the face than on transmitted information (Nader-Grosbois and Day 2011; Wallace et al. 2008).

Taking as a reference the previous features, Parsons (2016) fix two reasons to apply VR to students with ASD: first, "as a way of creating synthetic but realistic social scenarios in order to provide supportive contexts for learning and intervention that help participants in transferring knowledge and skills to the real world". Secondly, Parsons (2016) argues it is a way of providing authentic and well controlled context in which social responding. In the same way, there are some promising results with regard to showing changes or improvements in participants' responses after a period of use, and some evidence of learning new skills and knowledge that later are applied to the real world (Hopkins et al. 2011; Jarrold et al. 2013; Ke and Im 2013; Mineo et al. 2009; Schmidt et al. 2012).

1.2 Immersive virtual reality and ASD

Strickland's work (1996) is seminal in this area and provides the starting point for the search. This work uses realism in the designed environment as an element to achieve a better generalization. Furthermore, the scene is more believable and a better transfer of skills from the immersive environment to the real world. For this reason, we choose IVR in comparison to VR. In the same way, authors such as Blascovich et al. 2002, Wallace et al. (2008) indicate that IVR allows an improvement in the stimulation of students with ASD in comparison to the VR-based systems. In addition, Wallace et al. (2010), show that IVR environments produce environments that share some similarities with the real world, thereby offering greater potential for generalization of learning. Additionally, Baileson et al. (2008) analyse two basic characteristics that justify why IVR has to be used with ASD students: Firstly, it allows tracking all the movements of the user (position, orientation, facial expression); secondly, an important control of the system is provided to the users. These two aspects produce that IVR is chosen to work with students with ASD. Similarly, Kandalaft et al. (2012) indicate that environments with IVR can be adapted to the student's need in real time. Nevertheless, this situation cannot be obtained with VR.

2 Method

2.1 Design

A system and thematic review is utilized because we want to know the different variables that characterize our investigation. In order to achieve the aim of our research, we decided to follow the steps suggested by Rosa et al. (1996) which are:

- Information location and selection. At the beginning, it is needed to clarify what type of source is worked. Furthermore, we should stablish where can find this information. Finally, it is important to determine search criteria. For example, keywords could be used. This process will be explained in more detailed in the procedure section.
- Manipulation and classification of documentary information. In this step, we should create a list of variables that will allow us to classify the information. According to Rosa et al. (1996) these elements will be: title, year of publication, keywords, topic, area, authorship, institution, type of document, pages, journal where the document is published, and quartile of the journal. Finally, language and country are the last variables.
- Analysis of documentary data. In the end, it is fixed a list of bibliometric indicators to study the documentary data. According to Rosa et al. (1996) the elements will be: number of citations per year of publication, number of articles per year; number of producing countries and language of publication, categories and areas of the Web of Science as well as the quality of journals. As with these variables, it is important to analyze the most productive authors.

2.2 Instrument

These study variables have been chosen because in a thematic analysis, we need to focus on the relationship between content and context (Elo and Kyngäs 2008; Hsieh and Shannon 2005). It allows to adapt the content to the different context of the students. According to Krippendorff (1980), content analysis is a research method for making replicable and valid inferences from data to their context, with the purpose of providing knowledge, new insights, a representation of facts and a practical guide to action. For authors such as Hsieh and Shannon (2005) the aim is to develop a complete understanding of the context, thus failing to identify key categories.

Additionally, Elo and Kyngäs (2008) explain that the aim is to attain a condensed and broad description of the phenomenon and the outcome of the analysis were concepts or categories describing it. Moreover, the purpose of those concepts or categories is to build up a model, conceptual system, conceptual map or categories (Kyngas & Vanhanen 1999). Taking as a reference the previous research, we have stablished two categories that relate content and context (Elo and Kyngäs 2008; Hsieh and Shannon 2005). Furthermore, we have achieved different subcategories or variables according to Polit & Beck, (2004). These authors fixed a deductive process to obtain subcategories or variables.

Content:

Worked area. It is focused on the specific content of ASD students that the authors want to work
Intervention activities. This variable recognize the features of the activities generated during the implementation of VR
Methodology. This variable is focused on the process produced to explain research questions and objectives
Improvements. This variable try to show what type of development has suffered the student
Research questions. It is focused on the research problem that is trying to be solved with this study

Context:

Participants' features. This variable is targeted on the main characteristics of the students. Moreover, we want to know the number of participants.
Instrument. It is focused on the type of tool that has been used for gathering information.
Limitations. It is focused on the problems appeared during the intervention process and results.

2.3 Procedure

The way in which the information was obtained is summarized in Fig. 1.

Taking as a reference Fig. 1, we have described the diverse phases.

Phase 1 It has been used Autism Spectrum Disorder and Virtual reality as a keyword for searching. These two words were selected because Virtual Reality and ASD are concepts that are more global and include Immersive Virtual Reality, Autism, and Asperger.

Phase 2 It has been chosen the period 1996–2017, because in 1996 appeared the starting point of applying IVR to ASD students (Strickland et al. 1996). Previously, the different researches were generated using virtual reality. Secondly, age limitation was not established, because we want to know which age areas have been worked. Thirdly, papers in English have been put in the review because accordingly with Lorenzo et al. (2016a, b), this language is the most used. Moreover, paper with the VR desktop presentation were deleted due to the improvement with this instrument was lower than IVR Lorenzo et al. (2016a, b). According to the Research domain: Science Technology and Social Technology were selected because these two areas are related to Technology and ASD students. In contrast, we have chosen these web of Science categories: Computer Science, Psychology, Social Issues, Behavioral Science, Pediatrics, Engineering, and IVR applications with ASD students Educational Research. The reason to select them is that these areas talk about how to apply technology with students with ASD. Excluded articles were theoretical studies,

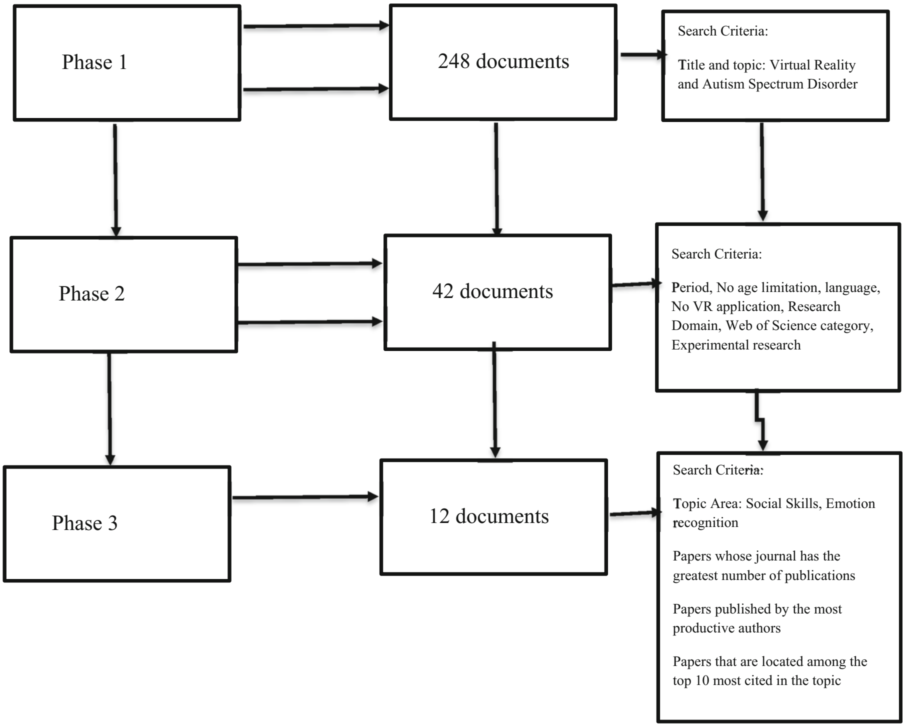

Fig. 1 Procedure process

empirical studies, case studies, preliminary studies and repeated studies. As a result, we only select experimental research.

Phase 3 We have tried to focus on research that work social skills and emotion recognition. These criteria were chosen because accordingly, to APA (2013), these are the most common areas where ASD students have problems, but our research tries to add new knowledge focusing on different sub-areas like gestures. Moreover, it has been obtain papers whose journal have the greatest number of publications according to ISI web of Knowledge. Furthermore, it has been focused on papers written by the most productive authors such as Sarah Parsons. Finally, we wanted to target on papers that were located among the top 10 most cited in the VR and ASD thematic area".

2.4 Data analysis

Data analysis was focused on two very important blocks: Thematic analysis and quantitative analysis of the information associated with the articles. In order to obtain information about data downloaded from the ISI web of Knowledge, it was chosen SPSS 23. For the thematic analysis of the articles, we have used a list of variables and categories explained in section 2.2.

3 Results

This section will show the results obtained from the thematic analysis of the articles. Tables 1, 2, 3, and 4 show the information according to the different thematic variables explained in method section. Tables 5 and 6 are also added to justify the quality of the articles that have been used in the research. Finally, Fig.2 illustrates the relationship between the applications of RV and the different research questions.

3.1 According to research questions and objectives

The results show a clear evolution in the proposed research questions, authors such as Strickland et al. (1996), focus on two important research questions: Firstly, how VR equipment can be tolerated by ASD students and secondly how ASD students respond to the computer-generated world. Similarly, Wallace et al. (2010) show similar research questions focused on ecological validity of IVE to represent social situation and social judgements made by ASD students about the social situation in IVE.

In the same way, Lorenzo et al. (2013) tries to study some important aspects: Firstly, they create a protocol to help students with ASD in social situations. Secondly, if IVR would be useful to transfer knowledge from one situation to another. In contrast, Cai et al. (2013) fix their research question on how ASD students can learn no-verbal communication using gestures.

Regarding with transfer social skills learned from IVE to the real world, Beach and Wendt (2014) suggest in their research question that maybe ASD students could transfer social skills learned from IVE to the real world. After that, they consider on their main question that maybe students with ASD could maintain their social interaction skills by practicing them in a virtual immersive environment. In addition to this, Matsentidou and Poullis (2014) wanted to emphasize on convincing that Immersive Virtual Reality (IVR) is a useful instrument to improve social skills of students with ASD. Similarly, Tzanavari et al. (2015) explain in their objectives how students with ASD could tolerate IVR equipment. Furthermore, Tzanavari et al. (2015) try to measure the effectiveness of IVR as a learning tool when they showed research question. However, Cheng et al. (2015) add the possibility to work with HDM (Head Mounted Display) devices in the same line as Strickland et al. (1996). Also, Newbutt et al. (2016) study about acceptance of VRHMD (Virtual Reality Head Mounted Display), among ASD students, whether they might be able to use it in a meaningful way. Furthermore, Newbutt et al. (2016) pose on their research question the possibility to measure of HDM devices as a learning tool to improve emotional skills. Finally, Horace et al. (2016) show similar research questions focus on how IVR can be used for improved emotional skills and if IVR is better than desktop presentation of Virtual Reality to improve these skills.

Taking as a reference the previous research, it has been observed how in the investigations studied, the great majority tries to verify the viability of this tool to learn social skills and on the other hand to analyze if they produce improvements and transfer these skills to the real world. Other research questions were not raised because the IVR is considered as a tool to help social interaction. According to APA (2013) it is one of the problems of students with ASD.

Table 1 Immersive Virtual Reality Research during period 1996–2013

Reference	Research Questions	Area of Study	Participants	Instruments	Immersive Activities	Results
Strickland et al. (1996).	Can Children with Autism tolerate VR equipment? Can Children with Autism respond to the computer-generated world in a meaningful way?	Diary life activities	Two ASD Students (7–9 years old). Authors do not use control group.	The computer used a Pro-Vision fully integrated VR System, HDM device and 3D Mouse	The students should learn how to cross-virtual street. After that, they apply new skills in other real environments.	The two children accepted virtual helmet. The children responded similarly to three different street scenes. Both children used the 3D Mouse.
Wallace et al. (2010)	Can an IVE accurately simulate ecologically valid social situations? How ASD students made social judgements about a specific scene within the VE?	Social Skills (Opinion about a social situation)	10 children with ASD (12–16 years old) and 14 typically developing adolescents all aged 12–16 years old (control group).	Presence Questionnaire and Blue Room (IVRS a cube)	In a immersive virtual reality the user should observe some actions in different scenarios for example a Residential street, School playground, School Corridor	The children with ASD reported similar levels of presence to their TD peers and no negative sensory experience. Although TD adolescents rated the socially desirable character as more socially attractive than the undesirable character,adolescents with ASD rated the two characters as equally socially attractive
Lorenzo, G., Pomares, J., Lledó, A. (2013).	Can IVEs support the acquisition of knowledge; improve social skills and the performance of school tasks of students with Asperger syndrome? Can the learning implemented in the IVEs be transferred to the real school environment?	Social skills and how to act in social situations at school.	17–24 participants control group.10 ASD students in primary school (8–11).10 ASD students in secondary school (12–15)	TEVISA (protocol).-Interviews during the implementation of TEVISA protocol. PIAV Protocol. IVRSystem (LShape)	Executive Functions in the School Environment. Task to support social skills of ASD students. Children interact with the environment without devices	The students improved their executive functions and social skills. Both groups presented difficulties at the beginning of the implementation of PIAV and TEVISA but they disapeared.
Cai et al. (2013)	How ASD students can learn nonverbally communication through gesturing using a Virtual Dolphinarium?	Nonverbally communication	The initial study involved a random selection of 15 ASD participants from a cohort of 32. Their age ranged from 6 to 17 years old.	An Immersive Room, 3D Screen spanned 320°, Kinect of gesture recognition and a tracking system from movements of users.	Six task and two test. The test were TONI-3 and GARS and the task for example identifying parts of a dolphin, shape traced on a palm, Geometric shape copying, copy-drawing of a dolphin, dolphin maze, name writing and sentence copying	In this study, 15 participants demonstrated different levels of interest to interact with the virtual pink dolphins. Eight male participants had no problems with wearing 3-D glasses and they showed strong interest with enthusiasm and volunteering. Only 4 participants refused to cooperate and were unable to learn.

3.2 According to the area of study

Strickland's work (1996) was seminal in this area and so provided the starting point for the search. These authors have focused their study in diary life activities area, for instance the students had to learn how to cross-virtual street. After that, they have applied new skills in other real environments.

In contrast, Wallace et al. (2010) focus their efforts on a specific aspect of social situation; presence situation. Sometimes students with ASD have problems to obtain information about a real or simulated simulation. In the same way, Lorenzo et al. (2013) establishes a protocol to interact in social situations. In like manner, Cain et al. (2013) has worked nonverbal communication-using gesture; it is a new area studied on IVR.

In recent research Beach and Wendt (2014), focus their area of study on social skills as most of the previous research but the students solve the social situation without protocols.

Nonetheless, Matsentidou and Poullis (2014); Tzanavari et al. (2015) analyse diary life activities as area of study. It can be observed how the different authors do not analyse which the most important activities that students suffer.

In the same way, Cheng et al. (2015) work on social skills but they try to create a systematic methodology that would be useful for students with ASD. In addition to this, Newbutt et al. (2016) attempt that students with ASD worked in a collaborative way using different immersive virtual environments but inside social skills. Recently, research has focused on emotional skills, in particular how to act in emotional situations (Horace et al. 2016).

Based on the previous research, three global areas have been studied in IVE; social skills, emotional skills and nonverbal communication. Some of these areas had been studied in VR but they are studied in IVR due to its features.

3.3 According to the number of participants

Our findings show that most of the research works carried out have shaped their sample with a control group (made up of typical development students) and an experimental group of ASD students to which the immersive virtual system has been applied. Sample composition is changed in terms of both student age and regarding its size.

It can be checked that some works shape the participants' sample with a quite small experimental group of 2 to 6 students (Strickland et al. 1996; Beach and Wendt 2014; Tzanavari et al. 2015; Cheng et al. 2015) with ages comprised between 7 and 18 years. In the same way Cai et al. (2013) work with an experimental group with ages between 6 and 17 years, but the size of the sample has been 15 students.

The remaining papers opt for a control group to which the immersive environment has not applied, and which include between 12 and 20 students with ages going from 6 to 16 years. In the same experiment, an experimental group of ASD students to which the immersive environment is applied, and which is formed by 10 to 33 students with ages comprised between 6 and 16 years (Wallace et al. 2010; Cai et al. 2013; Horace et al. 2016). It stands out amongst the results obtained that the paper by Matsentidou and Poullis (2014) considers an undetermined number of the experimental group with 9-to-

Table 2 Immersive Virtual Reality Research in 2014

Reference	Research Questions	Area of Study	Participants	Instruments	Immersive Activities	Results
Beach and Wendt (2014)	Can students with ASD transfer and maintain skills learned in a virtual scenario to a real-life scenario? Can students with ASD alter their social interaction skills by practicing them in a virtual immersive environment?	Social Skills and how to solve problems in social situations.	Two ASD students between 15 and 18 years old	The participants used a developing virtual reality head-mounted display to engage themselves in a fully immersive environment	Different virtual reality situations: Local Hospital, library, park bench, high school. Children interact with the environment using devices.	One of the participants was able to maintain conversation without redirecting it to his specific interests. Both participants said they felt less stress when engaging in conversation after practicing in the simulator. Participant Two maintained eye contact throughout the scenarios consistently, and increased eye contact in his real-life scenarios
Matsentidou and Poullis (2014)	Can virtual reality technologies, and in particular the aforementioned application, be effectively involved in enhancing the social skills and behaviours of children? Can the immersive visualization application be considered as a new and innovative method of intervention?	Diary Life Activities.	Twelve children (9–10 years old, control group). Unknown number of ASD students	EON Reality iCube VR Cave Environment with 3D glasses and Xbox Controller for interaction	Children must work in Scenario "Lost in city". They will carry out different task to complete the final, which is cross the street.	Children learned easily to use and interact with the system and devices without problems. Also, completed the sessions with signs of improvement between the different trials. Children showed samples of excitement, they laugh and smile during and after the completion of the session and gave us to understand that they enjoy the whole experience.

Table 3 Immersive virtual reality research in 2015

Reference	Research questions	Area of Study	Participants	Instruments	Immersive activities	Results
Tzanavari et al. (2015)	Which are the reactions of ASD students in an immersive virtual environment? How can we measure its learning effectiveness with respect to safe pedestrian crossing?	Diary Life Activi-ties.	Six Boys, all were diagnosed with ASD (8–11 years old)	The experiments took place in a four projections screens Virtual Reality System (4 infrared camera Vicon System), Xbox controller can be used for interaction	Each child had four trails attempts to cross the pedestrian crossing in the VR CAVE following the correct procedure as explained to them. Observations were recorded throughout on data sheets	One of the participants was able to maintain conversation without redirecting it to his specific interests. Both participants said they felt less stress when engaging in conversation after practicing in the simulator. Participant Two maintained eye contact throughout the scenarios consistently, and increased eye contact in his real-life scenarios
Cheng et al. (2015)	Investigate the effectiveness of a three-dimensional social understand-ing system with a head-mounted display to improve social understand-ing and skills in three children with ASD.	Social Skills and how to solve social problems.	Three students diagnosed with ASD (10–-13 years old)	A virtual HMD glasses, a workstation laptop, a joystick to interact with the environment.	The user interact in two different scenarios: a bus stop and a classroom. The researchers work with the pupils using a systematic methodology.	The results indicate that participants' social understanding and skills improved following their use of the system. The three teachers reported that the 3D-SU system provided visual stimuli and helpful assistance to their students in developing their social understanding and skills

Table 4 Immersive Virtual Reality Research in 2016–2017

Reference	Research questions	Area of study	Participants	Instruments	Immersive Activities	Results
Newbutt et al. (2016).	Investigate the willingness and acceptance of VRHMD, among ASD students, whether they might be able to use it in a meaningful way. Present a series of 3D immersive experiences within the VRT to measure the immersion and other experiences of a VR-HMD by users with ASD.	Social Skills and how to solve social situations.	29 individuals diagnoses with ASD (22–42 years old)	An Oculus RiftTM head-mounted display, headphones, an Xbox 360TM controller, laptop computer.	The participants work in two phases different VR scenarios. Phase I: Virtual Café, Virtual Cinema, Virtual Safari. Phase II: An Apollo 11, a Tuscan House	The majority of the participants reported an enjoyable experience, high levels of presence and were likely to use HDMs again. Our findings from behavioral observations and self-reported questionnaires revealed that people with ASD generally accepted the HMD and were willing to complete the tasks associated with VR scenarios in full.
Lorenzo, G., Lledó, A., Pomares, J., Roig, R. (2016)	Is there a significant difference between IVRS and Desktop VR for the development of emotional competences in students with ASD? Is there a significant difference between IVRS and Desktop VR with respect to the transfer of the acquired knowledge into a school environment?	Emotion recognition and how to act in emotion social situations	20 ASD students (experimental group), 20 TD students (control group). Participants of both group are between 7 and 12 years old.	Semi-Cave IVRSystem. Emotional Script. Avatars and assistant to modify incorrect behaviour of the participants	Phase I. Identification of the situation and the emotions. Phase II. Implementation of the emotional script. All the activities were made in different virtual reality scenario. Children have natural interaction	The results of this study show a significant presence of more appropriate emotional behaviours in the immersive environments in comparison of VR desktop application. The emotional behaviours have improved in real school during the study, because of IVRSystem.
Horace et al. (2016)	Can ASD students to understand internal emotions, express their	Social Skills and how to	20 children for control group (6 to 9 years old). 33 children	Four-side CAVE-like immersive VR Environment with head tracking for perspective	The user interact in six different virtual environments:	After training completion, children show significant improvements in three major

Table 4 (continued)

Reference	Research questions	Area of study	Participants	Instruments	Immersive Activities	Results
	thoughts, and feeling in the different situations using IVR? Can IVR be used by ASD students to develop empathy and generalise the knowledge into the real situations?	act in social situations.	with ASD between 6 and 11 years old.	adjustment. (Xbox game controller, for user to interact with the environment via body gestures and communication with the trainer). The author use a questionnaire for collect some aspects of the interaction.	Preparation of going to school, social occasions, virtual reality library, tuck shop, the last two scenarios are a review. The interaction is using devices	designed aspects including emotion recognition, affective expression and social reciprocity. There was no significant difference in the Faces Test. For affective expression, there was a significant difference in the score before training. In terms of emotion recognition, there was a significant difference in the Eyes Test scores before training

Table 5 Top ten Most Cited Articles on Virtual Reality and ASD

Referencia	Citations	Average number of citations
Strickland, D., Marcus, L., Mesibov, B., and Hogan, K. (1996). Brief Report: Two case study using virtual reality as a learning tool for autistic children. *Journal of Autism and Developmental Disorders, 26*(6), 651–659.	87	8
Wilkinson, N., Rebecca, A., Goh, P., & Dion, H. (2008). Online video game for mental health concern: A review. *International Journal of social Psychiatry, 54*(4), 370–382.	61	5.55
Mineo, B., Ziegler, W., & Gill, S., et al. (2009). Engagement with Electronic Screen media among students with Autism Spectrum Disorders, *Journal of Autism and Developmental Disorders, 39*(1), 172–187.	53	5.30
Strickland, D. (1997).Virtual reality for the treatment of autism. *Virtual Reality in Neuro-Psycho-Phsyology, 44*(1) 81–86.	38	1.73
Wallace, S., Parsons, S., Westbury, A., et al. (2010).Sense of presence and atypical social judgment in immersive virtual environments. Responses of adolescents with Autism Spectrum Disorders. *Autism, 14*(3), 199–213.	32	3.53
Cai, Y., Noel, C., Thalman, D., et al. (2013). Design and development of a virtual Dolphinarium for Children with Autism. IEEE transactions on Neural Systems and rehabilitation Engineering, 21(2), 208–217	25	4.17
Valmaggia, L., Leila, L., Kempton, M., et al. (2016). Virtual reality in the psychological treatment for mental health problems: A systematic review of recent evidence. *Psychiatry Research, 236*(1), 189–195.	24	8
Greffou, S., Bertone, A., Hahler, E. (2012). Postural hypo-reactivity in autism is contingent on developmental and visual environments: A fully immersive virtual reality study. *Journal of Autism and Developmental Disorders, 42*(6), 961–970.	16	2.29
Rajendran, G. (2013). Virtual environments: a developmental psychopathological approach. *Journal of Computer Assisted Learning, 29*(4), 334–347.	14	2.33
Lorenzo, G., Pomares, J., & Lledó, A. (2013). Inclusion of immersive virtual learning enviroments and visual control systems to support the learning of students with Asperger Syndrome. *Computers & Education, 62* (1), 88–101	14	2.33
Lorenzo, G., Lledó, A., Pomares, J., & Roig, R. (2016). Design and application of an immersive virtual reality system to enhance emotional skills for children with Autism Spectrum disorders. *Computers & Education, 62* (1), 88–101	10	3.33

10-year-old students, whereas Newbutt et al. (2016) worked with the highest samples, both in size and regarding participants' ages, which ranged between 22 and 42 years. It is also worth highlighting that the largest sample of participants −33– can be found in Horace et al. (2016).

In this way, one of the big problems that comes from working with students with ASD is the size of the sample. All the investigations analyzed have small sample sizes and therefore there are consistency problems in their results. For example, there are studies with only two students that have not used a control group. Moreover, it has been analyzed that there is no study using adults with ASD. In the same way, it has been observed that all the participants had basic social skills, as a consequence, it has been easy to obtain an improvement in these areas.

Table 6 Number of citations and impact of the Journal

Reference	Citations	Impact of the Journal and quartile
Strickland, D., Marcus, L., Mesibov, B., and Hogan, K. (1996). Brief Report: Two case study using virtual reality as a learning tool for autistic children. *Journal of Autism and Developmental Disorders, 26*(6), 651–659.	87	3.321,Q1
Wallace, S., Parsons, S., Westbury, A., et al. (2010).Sense of presence and atypical social judgment in immersive virtual environments. Responses of adolescents with Autism Spectrum Disorders. *Autism, 14*(3), 199–213.	32	3.684, Q1
Cai, Y., Noel, C., Thalman, D., et al. (2013). Design and development of a virtual Dolphinarium for Children with Autism. IEEE transactions on Neural Systems and rehabilitation Engineering, 21(2), 208–217	25	3.410,Q1
Lorenzo, G., Pomares, J., & Lledó, A. (2013). Inclusion of immersive virtual learning enviroments and visual control systems to support the learning of students with Asperger Syndrome. *Computers & Education, 62* (1), 88–101	14	3.819,Q1
Lorenzo, G., Lledó, A., Pomares, J., & Roig, R. (2016). Design and application of an immersive virtual reality system to enhance emotional skills for children with Autism Spectrum disorders. *Computers & Education, 62* (1), 88–101	10	3.819,Q1
Newbutt, N., Sung, C., Kuo, H., Leahy, M., Lin, C., & Tong, B. (2016). Brief Report: A pilot study of a virtual reality Headset in Autism Population. *Journal of Autism of Developmental Disorder, 46*(9), 3166–3176.	4	3.321,Q1
Cheng, Y., Huang, C., & Yang, C. (2015). Using a 3D Immersive Virtual Environment System to Enhance Social Understanding and Social Skills for Children with Autism Spectrum Disorders. Focus on Autism and Other Developmental Disabilities, 30(4), 222–236.	4	0.732,Q3
Horace, H., Wong, S., Chan, D., Byrne, J., Li, C., Yuan, V., Lau, K., & Wong, J. (2016). Virtual reality enable training for social adaptation in inclusive education settings for school-aged children with Autism Spectrum Disorders (ASD). In S. Cheung, L. Kwok, J. Shang, A. Wang, K. Kwan (Eds.), *Blended Learning: Aligning Theory with Practices* (pp. 94–102). Beijing, China: Springer International Publishing	4	0,40, Q4
Matsentidou, S., & Poullis, C. (2014). Immersive visualizations in a VR cave environment for the training and enhancement of social skills for children with autism. *In 9th International conference on computer vision theory and applications* (pp. 230–236). New York, USA: Springer.	4	–
Tzanavari, A., Charalambous, N., Herakleous, K., & Poullis, C. (2015). Effectiveness of and immersive virtual environments (CAVE) for teaching pedestrian crossing to children with PDD-NOS. In *Proceedings of 15th international conference on advanced learning technologies* (pp. 423–427). Hualien, China: IEEE Xplore.	3	–
Beach, J., & Wendt, J. (2014). Social interaction development through immersive virtual environments. *In Proceedings of the international conference on education technologies and computers* (pp. 1–8). Lodz, Poland: Lodz University of Technology.	0	–

3.4 According to the instrument

The earliest works (Strickland et al. 1996) use "a rudimentary HDM device (headset containing two small video screens, one suspended in front of each eye) and a laptop to

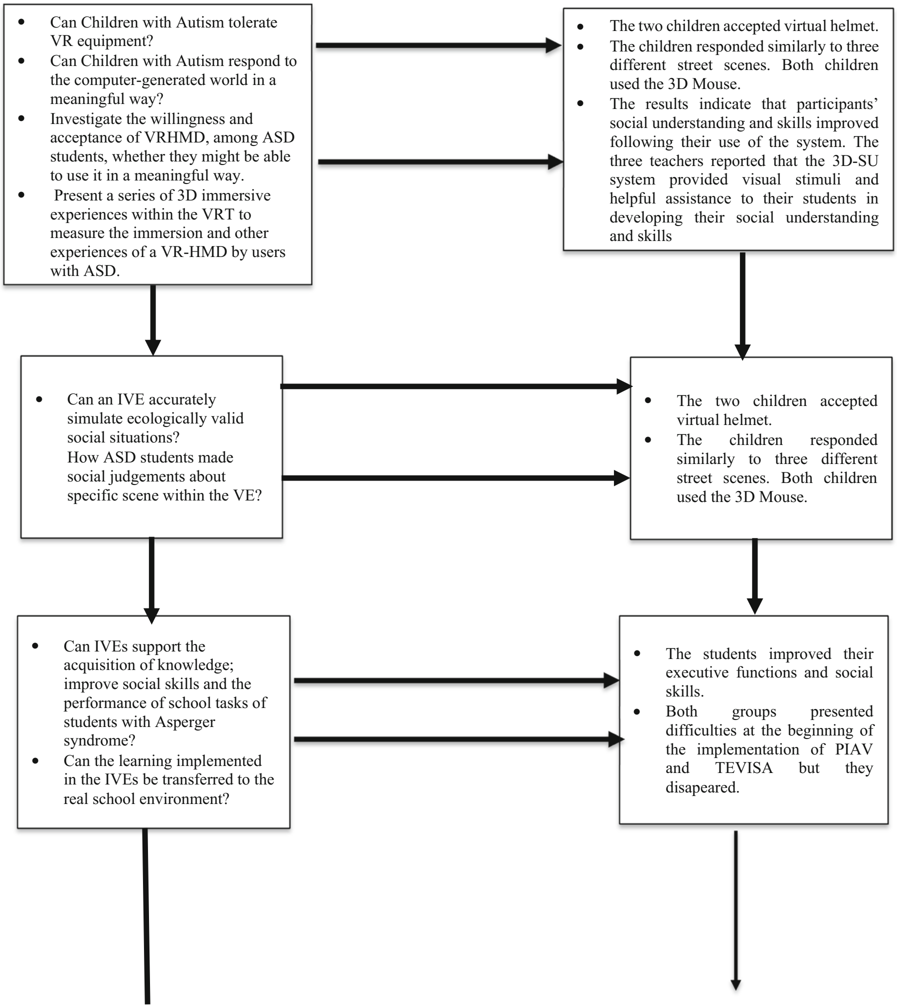

Fig. 2 Relationship between VR Applications and research questions

create a working environment". In the same way, Beach and Wendt (2014) used HDM device along with the design of environments by means of the Second life platform. They try to assess interaction, social awareness and sensory commitment.

Along these same lines, a suggestion is made to use HDM devices –together with a laptop (like before) – but with a joystick in order to be able to interact with the environment (Cheng et al. 2015). For the authors there are two scenarios, both are presented on virtual HMD and a workstation laptop. This device relied on arrow keys or a joystick, to immerse themselves in the VEs without distraction.

It can be seen in the results that, following this same approach, a tendency exists to use smaller and simple equipment, which can favour a certain level of portability; thus making it unnecessary to take the children to a specific place, which may cause problems of integration with the other classmates (Newbutt et al. 2016). They use HDM device called

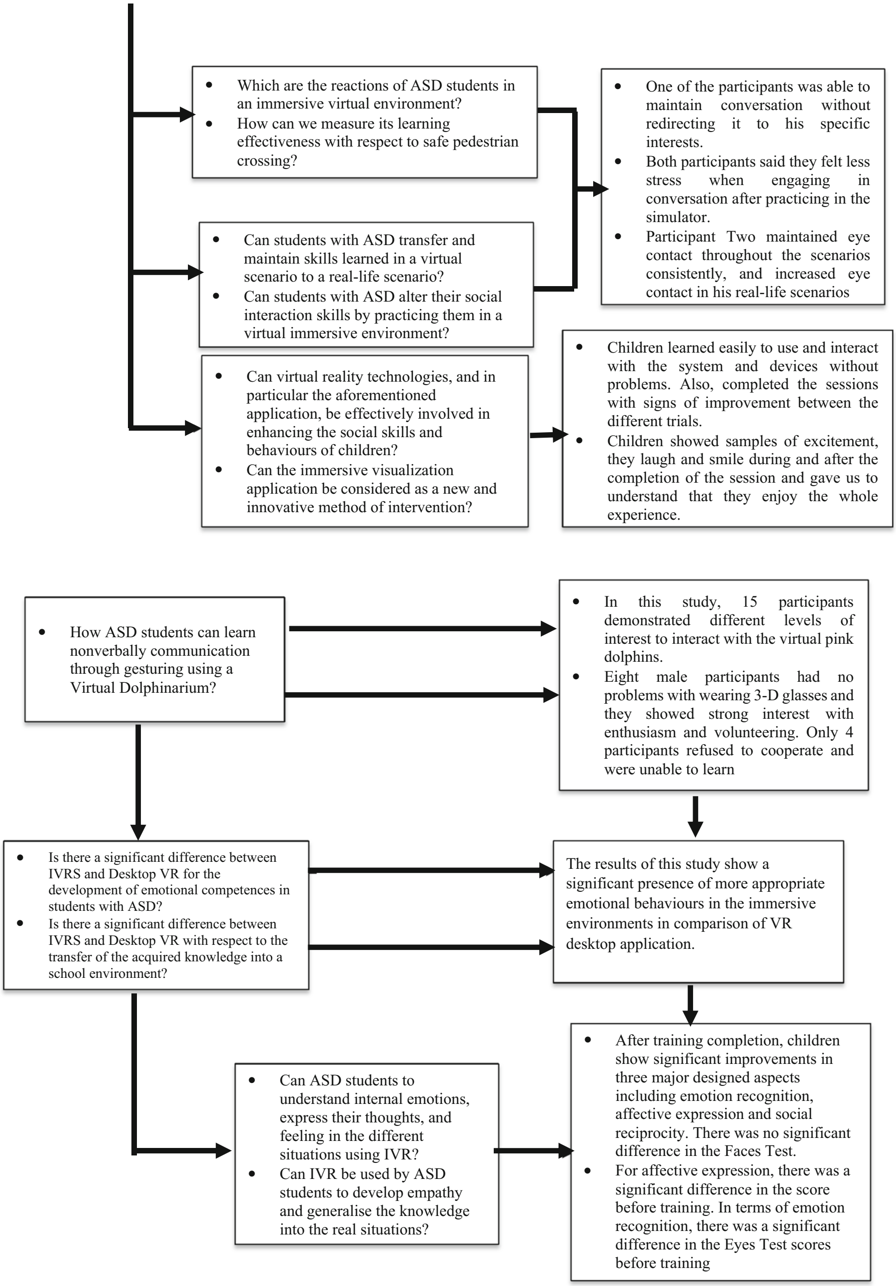

Fig. 2 (continued)

Oculus RiftTM, a laptop, an Xbox360TM controller, and a pair of headphones. The participants' instructors have recorded and analysed the reactions to the use of HDM devices. Accordingly to Newbutt et al. (2016) after 1 week, post-experimental session, a follow-up survey has been used to gather information.

Nevertheless, one of the most widely utilised systems is the CAVE system –with four cameras, which permit to detect each user's position and adapt the environment to their point of view (Wallace et al. 2010). These authors adopt a presence questionnaire with the aim of determining the immersion feeling, and disadvantages of virtual environments. Moreover, they use the ITC-SoPI (The Independent Television Commission-Sense of Presence Inventory) developed by Lessiter et al. (2001) and a social questionnaire thanks to which participants are able to express if they feel happy when the avatars come closer. Wallace et al. (2010) used a Blue Room that works by animations being projected onto the walls and ceilings of a screened space. Hence why the EON Reality iCube VR with 3D glasses and an Xbox controller (http://www.microsoft.com/accessories/es-es/d/xbox-360-controller-for-windows) has been used so that the participant or the educator could interact and navigate in the environment (Matsentidou and Poullis (2014).

Continuing with the application of the CAVE system, Cai et al. (2013) use an Immersive Room with the latest immersive graphics and software. A spherical 3-D Screen to display images from five projectors, which are ceiling mounted. Microsoft Kinect for gesturing recognition; moreover, a tracking system has been installed to capture viewer's motions in terms of position and orientation changes.

In the same way of some of the previous research, Tzanavari et al. (2015) has worked with CAVE system. It is created with two projection screens, four computers so that the screens can be controlled, a pair of 3D stereoscopic glasses and four cameras to determine the position, as well as the Xbox to monitor navigation and interaction.

More works that are recent have also taken up the CAVE system (Horace et al. 2016), though with two workstations and the controller by means of the Xbox360, along with the point of view update depending on the movements performed by the user. Along the same lines of the previous cases, questionnaires are utilised that the child has to fill in. They serve to measure specific variables such as attention, the maintenance of the look and the recognition of social situations, amongst others. All the children have completed the Raven Progressive Test, a nonverbal test of analytic intelligence. Parents had to filled form the Childhood Autism Spectrum Test to assess the quality of life in children.

Our findings confirm the importance of several new instruments and systems utilised, insofar as they increase users' interactivity. An example can be found in the immersive system with a software composed of several modules: an interface module; a module for Immersive Virtual Reality generalization; object virtualization and data capture module, and finally, a decision module (Lorenzo et al. 2013).

Some works include quite expensive and hard-to-maintain equipment (the virtual reality room devices). However, they also promote the use of an HDM device along with a laptop to achieve a certain level of immersion at a lower cost. This tools allow a great adaptation to the diversity of features that students with Autism Spectrum Disorders can present. Additionally, this devices should achieve the interaction as natural as possible with the environment.

3.5 According to the methodology and intervention activities

The different authors have decided to work with two different methodologies: Firstly, the implementation of intervention in visual environments trough case studies and with a very small sample of participants (Strickland et al. 1996; Beach and Wendt 2014; Tzanavari et al. 2015; Cheng et al. 2015). Secondly, most works bet on an experimental methodology with a control group formed by students without ASD and an experimental group of students with ASD (Wallace et al. 2010; Matsentidou and Poullis 2014; Horace et al. 2016).

According to the intervention activities, Strickland et al. (1996), propose on a virtual street, different colored cars moving. The children are asked about the car or follow images created by a hand-controlled five bottoms. The authors are able to modify the different variables of the situation.

In the same way, Wallace et al. (2010) create activities that are more passive. For example, a residential street scene with a duration of 64 s that begins at the end of the street and finishes when two pedestrians are about to cross the road.

With respect to school environments Lorenzo et al. (2013); Lorenzo et al. (2016a, b) focuses their virtual activities in school environments. Firstly a classroom where some avatars interact with the students. When the student makes a mistake, the evaluator and the avatar explain the correct option. Secondly, in Lorenzo et al. (2016a, b) it uses a social story where the user can interact with ten social situations inside and outside the school environment.

In contrast, other authors are focused on social activities out of the virtual school environment. For example, Cai et al. (2013) propose six different tasks to their student relationship with the interaction of a dolphin. This type of activities allows the students transfer the knowledge acquired to the social situation.

Analysing the different type of activities showed by the authors, Matsentidou and Poullis (2014) put the user in a city; he is lost and needs to train recognition and follow-up, as well as avoiding the movement of cars inside the virtual street scene. However, this task has more interaction because the user has to find the 'crossing button" and pressed it. At the end of the investigation, the student has to cross the street without help.

Similarly, Beach and Wendt (2014) show no-school environments with difficult social situation that could be solved by the participants. For example, Beach and Wendt (2014) work with a van protected by an aggressive-looking student.

In recent researches, activities designed by Tzanavari et al. (2015) has similar features with Matsentidou and Poullis (2014), Strickland et al. (1996) because the aim is to learn to cross a pedestrian street. However, in Tzanavari et al. (2015) task appear with various complexity levels.

For Tzanavari et al. (2015), "Each child has four attempts to cross a pedestrian crossing following the evaluator's instructions. Each one of the proposed activities has a summative nature, in such a way that the child is able to cross the street after completing those activities".

Continuing with no-school environments Cheng et al. (2015) work with a bus stop environment. It has to be observed after which 24 social issues or questions are shown to the children while simultaneously recording their behaviours and reactions to them. A system is used to read the knowledge produced by the user.

In like manner, Horace et al. (2016) design different scenarios some of them are school environment. In this first activity participant must prepare all the equipment for going to school in the early morning. The user can receive visual cue with a checklist. This type of support produces an improvement in executive function. In another task, Horace et al. (2016) simulate a library. The aim of this effort has been to teach how to stand in queue and pay with the right amount of money.

Finally, Newbutt et al. (2016), work with different environments. For instance, a virtual cinema where you have to choose which film to see, a café where you have to sit facing someone else, and a safari where you have to drive a jeep.

In the same way, all the designed activities could be divided in two groups, school environment (Wallace et al. (2010, Lorenzo et al. 2013, Lorenzo et al. 2016a, b, Newbutt et al. 2016), and no-school environments for the rest of research. Moreover, most of the intervention activities in virtual scenarios work with some work-assessment-questionnaire. It is needed to be filled in by the students. The exception can be found in the works of (Lorenzo et al. 2013, Lorenzo et al. 2016a, b). In this research authors propose a protocol of action for the students in the different situations. In addition to this, it would be very interesting to expand the range of social situations that the TEA child would face.

3.6 According to the improvements and limitations found

Strickland's work (1996) has been seminal in this area and so provides the starting point for the search. For these authors, children do not show problems interacting with HMD however, they showed generalization problems. Moreover, some difficulties to understand the image as in interactive tool were observed.

Later, Wallace et al. (2010) have talked about improvements such as the capacity to attract them so that they could feel involved in the IVE. Moreover, this type of environment can be adapted to the students need. In contrast, some limitations appeared relationship with the stress that the users suffer when they observe the situations. Moreover, the size sample was an enormous problem such as Hernandez et al. (2009); Lahiri et al. (2011); Cassidy et al. (2015).

In the same way, the immersive virtual environments allow not only the planning of tasks but also become comfortable with them. Furthermore, the repetition has produced improvement in executive function and social skills. (Lorenzo et al. 2013; Lorenzo et al. 2016a, b). Furthermore, evidence is found of a significant presence of suitable emotional behaviours in immersive environments, more than in desktop ones, even improving in real environments (Lorenzo et al. 2016a, b).

Accordingly, to the previous research, Cai et al. (2013) show that students with ASD acquire different nonverbal gestures to interact in social situation using Virtual Dolphinarium. However, some limitation appeared in their research. For example, calibration is required for each participant to have gesture recognition. Another problem were small simple size, it appeared on research like Strickland et al. (1996), Self et al. (2007), Mitchell et al. (2007), Wallace et al. (2010),

With respect to the improvement in students with ASD, Beach and Wendt (2014) have explained that they are able to show a moderate progress in their weakest areas. Thus, one of the participants could have a conversation without redirecting it towards his interests. The second user is able to maintain a fixed gaze during the conversation in real situation. To sum up, all the participants were less stressful when they finished the intervention. In addition to Beach and Wendt (2014), Matsentidou and Poullis (2014) affirm that participants easily learned to use and interact with the system and the devices without any difficulties worthy of mention.

Similarly, to some of the works analysed Tzanavari et al. (2015) have problems in terms of checking the extent to which learning has been generalised to the real environments. For this purpose, it was necessary to use a guide/parent who could stay near the child at the time when the activity was about to be performed.

With regard to simple size, Cheng et al. (2015) suffer the same problems of Tzanavari et al. (2015); the lack of real scenarios to practice what they have learned prevented both the generalization and the achievement of better results. What's more, support teacher helps the students to obtain information about what type of behaviours have been learnt in the real situations.

Finally, Newbutt et al. (2016) add new problems to the previous work. For these authors, one of the greatest problems faced in this research lay in the need to generate an independent system, which did not suffer the errors generated by students when answering the questionnaire. In contrast, the vast majority of the students has been satisfied about the intervention and how their social skills had been improved.

Similarly, it can be concluded that students with ASD has improved their skills because of realism and the structuring of immersive virtual reality. Moreover, these students learn to repeat situations. In contrast, the vast majority of the study has the same problems: sample size, generalization of knowledge to another context and real world. To achieve a correct generalization, it would be necessary to cover many contexts which is one of the limitations of this research.

4 Discussion and conclusions

Based on the point that IVR is a support and learning tool for students with ASD, it has been possible for us to verify that all the works examined focus their intervention on virtual image with more rudimentary devices –and more expensive– or other more simple and portable ones.

In the same way, these researches performed mostly adopted an experimental methodology: a control group with typical students; and an experimental group with students diagnosed with ASD. Didehbani et al. (2016) conclude that a control group design will help us to determine whether improvements on this measure are truly due to the intervention or practice.

The sample used used to be small in most cases: between 2 and 33 students from the compulsory educational stage. Some author such as Cheng et al. (2015); Newbutt et al. (2016); Didehbani et al. (2016) analyse this aspect concluding that small samples produce limited generalization of the findings and they don't know whether it is possible to extend to real environments.

Two clearly distinct strands: the utilisation of HDM devices along with a laptop to achieve a high level of immersion (Strickland et al. 1996; Beach and Wendt 2014; Cheng et al. 2015; Newbutt et al. 2016) for the purpose of avoiding the high cost of the equipment in one case. In contrast the others (Wallace et al. 2010; Cai et al., 2013: Lorenzo et al. 2013; Matsentidou and Poullis 2014; Tzanavari et al. 2015; Lorenzo et al. 2016a, b; Horace et al. 2016) advocate using the classical immersive virtual reality together with the glasses so as to achieve a higher level of immersion It can be concluded that HDM devices are emerging because they expand the field of view, are lightweight and small, and can present interactive spaces (Cheng et al. 2015). The two instruments used allow a great adaptation to the diversity of characteristics that students with Autism Spectrum Disorders can present. Although the most important thing would be to get devices that, allow the interaction as natural as possible with the environment.

With respect to area of study, the vast majority of research focus on social skills and emotional skills, which are the most common. They try to show different methods to learn how to learn in social or emotion situation and if VR is a useful tool to work with students with ASD. For example, emotional skills (Lorenzo et al. 2016a, b; Horace et al. (2016), social skills (Matsentidou and Poullis 2014; Tzanavari et al. 2015). In contrast, Cai et al. (2013) used immersive virtual reality to learn nonverbal communication. These problems, according to APA (2013), are the most important deficits in students with Autism Spectrum Disorders.

Intervention activities are defined by two clearly differentiated approaches: observation tasks; and immersion tasks in the most recent works. Scenarios refer in most cases to school situations and everyday situations. The feeling of immersion has been satisfactory to both of them, and children did not have major problems when carrying out the tasks. Only one of the researches proposes the use of protocols of action for ASD students. Due to its structuring and clarity, this tool along with the virtual reality would provide great advances in their abilities.

Overall, it can be concluded that students with ASD has improved their skills because of realism and the structuring of immersive virtual reality. Moreover, these students learn by repeating situations. In contrast, the vast majority of studies have the same problems: sample size, generalization of knowledge to another context and real world. To achieve a correct generalization, it would be necessary to cover a large number of contexts which is one of the limitations of these researches.

In like manner, this study could be useful to establish a new protocol to work with students with ASD and virtual reality. Firstly, it would be interesting to know the objectives and research questions. The main problem in this situation is to transfer skills learned from virtual environments to real ones. After that, it has to be selected the area of study. The vast majority of the research has focused on social skills and emotional skills.

The third step in our protocol it would be targeted on participants. One important aspect in this step the size of the sample. Big samples produce better results related to the transfer of skills from virtual to real world. Moreover, it would be preferred participants with slightly problems on social and emotional skills. Additionally, it can be observed that IVR don't produce improvement in students with deep communication problems.

The fourth step in our protocol is related to the type of instrument. If we wanted to work in the classroom, it would be chosen HDM devices. However, if we worked with big samples and different variables we would prefer IVR rooms like Blue Room (Wallace et al. 2010).

Taking as a reference the previous step, on the second-to-last step, it is important to pick methodology and intervention activities. The observational methodology is suitable for activities where the user does not interact with the environments. However, an experimental methodology is adequate to the task where the user interacts with the environment. Finally, we need to take into account the improvements and limitations that the previous selection can produce in our research.

Compliance with ethical standards:

Conflict of interest The authors declare that they have no conflict of interest.

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