Education and Information Technologies (2023) 28:9557–9605
https://doi.org/10.1007/s10639-022-11545-z

Designing virtual reality tools for students with Autism Spectrum Disorder: A systematic review

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Received: 31 August 2022 / Accepted: 16 December 2022 / Published online: 12 January 2023

Abstract

Nowadays, technology plays a fundamental role in the development of daily life activities. In this regard, there is an increase in disciplines that have used technologies, with educational fields standing out above all. Within education, there are a series of emerging technologies that are increasingly implemented in the classroom. Emerging technologies are also well aligned to autistic students and their specific learning and cognitive preferences. Therefore, the aim of this review is to carry out a systematic and thematic review on the application of Virtual reality (VR) in teaching and learning environments for autistic students during the period 1996–2021. Our analysis located a sample of 38 documents obtained from the WEB of Science and Scopus based on following Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidance. Our results highlight that much of the research was focused on areas of emotional recognition and social skills development. In addition, we found that when activities were interactive and realistic within the VR environments, the acceptance of this tool was improved for this specific population.

Keywords Virtual reality · Systematic review · Technology · Autism Spectrum Disorders · Bibliometrics

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1 Introduction

Within the wide range of people included under the Special Educational Needs umbrella, autism is a group that is increasing. This condition, according to De Luca et al. (2021), has an estimated worldwide incidence of approximately 1%, while other research has indicated that one of 44 of all 8-year-olds have autism (Maenner et al., 2021). The APA (2013) indicates that autistic individuals need support related to challenges in the social, communicative, and behavioral domains. According to Schmidt et al. (2021a, b), difficulties in the social, communicative, and behavioral domains can lead to issues with adaptive skills. These skills consist of the ability to respond to the demands of the environment. Similarly, Moon and Ke (2021) state that autistic students manifest some difficulties in the process of identifying variable social cues in the different contexts they face. In this regard, Newbutt et al. (2020) suggest that autistic people are impacted by the way people relate to the environment through perception, communication, and interaction. Moreover, Lorenzo et al. (2016) claim that autistic students are characterized as having visual preferences and extremely specific learning needs in addition to logical but somewhat abstract reasoning. It is this preference for visual learning that has fostered the use of new emerging technologies such as Virtual Reality by researchers and autistic groups (Lorenzo et al., 2016).

Virtual reality (VR) can be defined as a digital simulation of a three-dimensional environment (Mosher et al., 2021). For Mosher and colleagues, these environments allow a user to physically interact with the technology in a way that creates an atmosphere that resembles the real world. In addition to this, Mak and Zhao (2020) explain that VR allows the user to feel a sense of immersion with the environment. Moreover, users receive feedback from the environment through image, sound, and tactile manipulation. Consequently, VR allows autistic students to practice interactions and behaviors from a realistic environment avoiding overexposure and undesirable sensory and social inputs (Bradley & Newbutt, 2018; Didehbani et al., 2016). In addition, VR can provide an opportunity for autistic students to learning in a safe and predictable manner; without implications of real-world consequences. As such, Bozgeyikli et al. (2018) outline some of the features that enhance the use of VR for autistic people, including: predictability, customizable task complexity; control; realism; immersion; automation of feedback, assessment, reinforcement. Based on the potential of VR for use with/by autistic students, research projects have been developed in a range of areas and for a range of outcomes/benefits. For example, traveling by bus and participating in a coffee shop (Mitchell et al., 2007), emotion recognition (Lorenzo et al., 2016), practicing public speaking (Jarrold et al., 2013), learning social competence (Wang et al., 2017), calming a friend who had lost a pet, or a brief conversation with classmates (Didehbani et al., 2016), feeling of presence in a place (Wallace et al., 2010), and crossing a road safely (Strickland et al., 1996).

Previous systematic reviews and research have been conducted in this area (i.e. Mesa-Gresa et al., 2018). Mesa-Gresa and colleagues analyzed a total of 31 papers through an evidence-based systematic review including clinical and technical databases on the effectiveness of VR-based interventions when used with autistic groups. The results highlighted that the average sample size is 20 (autistic participants), and the average age of the participants is between 8–14 years old. In addition, social and emotional skills were the most researched/focused areas. One of the limitations of this study is the absence of an educational focus. In another study Bradley and Newbutt (2018) conducted a systematic review on the use of head-mounted display (HMD) devices with autistic students over the period 1990–2018. They only located six papers that met their criteria (autism, education, HMDs). The results indicated an absence of control groups in comparing the findings in addition to a lack of details related to ethical and safety practices. In the same sense, there is an absence of methodologies that enable follow-up in real environments such as schools in addition to including autistic people in the research. Along similar lines of enquiry, Glaser and Schmidt (2021) implemented a systematic review to better understand the present design characteristics of virtual reality (VR) systems designed as training tools for individuals with autism. Their results show that most of the interventions have been developed with desktop VR. This has led the authors to conclude that VR is not being fully exploited or used in ways researchers have previously proposed. Similarly, the environments analyzed were fictitious and did not match real situations. The average age of the participants was between 0–9 years. Most recently, in the work of Dechsling et al. (2021), 49 documents were located and analyzed. These focused on the use of virtual reality and augmented reality technology in social skills interventions for autistic individuals. The results indicate that the average number of participants was 13, with desktop VR being the most used. Social interaction and attention were areas that received the most research.

With respect to previous research, here we propose several advancements to what has gone before. Firstly, we have extended the study period from 1996–2021. This will result in a larger number of documents being obtained, and the representativeness of the results should be greater. Secondly, we also included conference papers, so that emerging topics in the area of our study can be detected. This aspect is not included, for example, in the works of Bradley and Newbutt (2018) or Glaser and Schmidt (2021). Thirdly, none of the previous research has analyzed the instrument that is most suitable for assessing the improvements that occur in autistic students after the application of VR. This question is fundamental if we are to determine and incorporate this tool in educational settings. Another of the strengths, is that in this study, unlike others such as those of (Mesa-Gresa et al., 2018), the subject matter is exclusive; to this end, the documents have been filtered by the categories Education and Educational Research and the category Education Science Discipline. In addition, an inclusion criterion has been included so that only documents that work on VR in education are analysed. In line with the contributions of this review, the search terminology used is exclusively VR, unlike the works of (Mesa-Gresa et al., 2018) or Dechsling et al. (2021), which use search terms related to augmented reality. Another study variable that has not been included in previous research has been the type of activity. In other words, what are the characteristics of the activity that autistic students are going to carry out. Only Glaser and Schmidt (2021) have some similarities since they analyse the objectives of the activities.

Despite the growth and rapid development of virtual reality applied to autistic children, very little is known about the type of technologies being used/applied in schools, what the focus of these technologies are, how these technologies are measured (instruments used), or the key findings from work in this area to date. As a result of these gaps in knowledge, the field remains unable to provide clear guidance to the autistic community, or a range of stakeholders (i.e., teachers, parents) on the best way(s) to utilize VR and HMD-based materials in educational settings. Based on the gaps in this field, the key aim of this study is to conduct a systematic and thematic review on the application of VR in teaching and learning environments of autistic students during the period 1996–2021. A series of research questions were established to guide our enquiry and systematic review.

1. What type of virtual reality has been used most frequently in research with autistic students?
2. What are the research objectives that have been most often worked on for implementing virtual reality for autistic students?
3. What type of instrument has been the most employed by researchers in their interventions for autistic students?
4. What are the characteristics of the activities designed for the intervention of autistic students using VR?
5. What have been the most frequent results achieved in the implementation of VR for autistic students?

2 Method

2.1 Approach

To address the research questions, it was decided to implement a systematic and thematic review (STR). There are several reasons that justify the use of this methodology. Firstly, it should be noted that STR makes it possible to synthesize a large amount of information and the identification of areas in which new research can be developed that incorporate methodologies to improve the field of study (Dakduk & González, 2018) Secondly, it allows a quantitative and qualitative approach (Crompton et al., 2021). These authors state that with this methodology it is possible to develop a study by thematic variables and by number of documents. Finally, Cook et al. (1995) suggest that the bias introduced by the researcher in a STR can be eliminated by developing a critical appraisal, synthesis of all relevant studies on a topic, and systematic collection. Beltran (2005) argues that the use of STR is justified because it reveals contradictions in the different studies in aspects, such as results or methodologies. This author concludes that one of the fundamental reasons for using STR is to offer an analysis of the existing evidence on a topic based on a methodical and systematic analysis so that a research question can be answered.

2.2 Instrument

Next, the variables selected for the study are justified and defined. Based on Elo and Kyngäs (2008), Krippendorff (1980), Weber (1990), it was decided to choose two types of variables for the thematic analysis: content and context. The aim of the content variables is to obtain a condensed and accurate description of the phenomenon to be studied, and the result of the analysis are concepts or categories that describe the phenomenon (Elo & Kyngäs, 2008).In this line, content variables seek to classify large amounts of text into an efficient number of categories representing similar meanings Whereas context variables are defined as those aspects that need to be considered to adapt the described phenomenon to different contexts (Elo & Kyngäs, 2008). Therefore, the context variables aims to provide knowledge, new insights, a representation of facts and a practical guide for action. The content and context variables used in the study are defined below.

Content
Objectives: the purpose of the research.
Results: The most frequent findings
Type of activity: The nature of the activity developed.
Context
Type of virtual reality: Type of device used in the support of the autistic person/group.
Type of instrument: Tool used to collect information on the evolution of the autistic student.

2.3 Procedure

The first phase of this systematic review involves the development of research questions. For this purpose, the target population of the study was autistic students currently attending an educational stage. Next, the type of support is addressed along with the length, location, and type. In our case we are interested in educational support that took place at the school. Subsequently, reference is made to the comparison where the authors choose the type of interventions to be compared.

For the second and third phases of the systematic review, the following aspects are developed: first, it is necessary to establish the research protocol avoiding bias together with the inclusion and exclusion criteria. Subsequently, the databases are selected, and the search is carried out based on the established criteria and the elimination of those documents that have not been adjusted to the research questions. As for the research protocol, it was decided to extract all available information from the documents such as authors, abstract, title, institution, country, source, origin of the source and references included in the documents. All this knowledge was stored in excel files generated by Scopus and WOS. In addition, a visual review of the documents was carried out to avoid the appearance of publications that did not deal exactly with the subject matter of the study. In the research protocol phase, the following criteria for inclusion and exclusion of documents were established in Table 1. Inclusion and exclusion criteria can be according to Cardona-Arias et al. (2017) of two types: conceptual or related to the research topic, while the second type are linked to operational considerations. For these authors, within the first type, criteria such as temporal delimitation, population characteristics, type of study and area worked on are included. According to Cardona-Arias et al. (2017), the second type may consider the filters of the sources consulted. In this sense, Connelly (2020) assures that the inclusion criteria help researchers to determine whether or not an article should be included in the review sample. The importance of exclusion criteria lies in avoiding the influence of variables in the study. Also, for Connelly (2020), strict inclusion criteria can improve the internal validity of the study. However, too many exclusion criteria can lead to problems in the generalization of the studies obtained. Therefore, it was decided to extract all available information from the documents such as authors, abstract, title, institution, country, source, origin of the source and references included in the documents. All this knowledge was stored in excel files generated by Scopus and WOS. In addition, a visual review of the documents was carried out to avoid the appearance of publications that did not deal exactly with the subject matter of the study.

After establishing the inclusion and exclusion criteria in addition to the research protocol, the search for documents was executed using the keywords determined by the authors. The words were selected from the UNESCO and ERIC Thesauri. These tools collect the most used terms in the most prestigious articles in the field (Haas et al., 2020). We chose terms used in DSM-IV and DSM-V because this would allow us to obtain a larger number of documents. In this way, the terms were

("Autism" or "Autism Spectrum Disorders" or "High functioning autism" or "Asperger" or "ASD" or “Autistic”) AND ("Immersive virtual reality" or "Head Mounted display" or " IVR"or "virtual reality")

The filtering of the documents was carried out with the use of the PRISMA methodology (Page & Moher, 2017). As articulated in Fig. 1, the first phase is called identification, the indicated keywords were applied, and a total n = 1322

Table 1 Inclusion and exclusión criteria

Inclusion Criteria	Exclusion Criteria
IC1: Period 1996–2021	EX1: Presence of duplicate documents
IC2: Web of Science Core Collection Categories. Education and Educational Research, Education Science Disciplines. Scopus. Social Science and Computer Science	EX2: No access to documents
IC3: Language: English and Spanish	EX3: Exclusion of documents of type Letter, Book Chapter, Editorial Material and News Item
IC4: Type of study: Interventions	EX4: Type of technology
IC5: Thematic of virtual reality in education	EX5: Age of participants. The participants had a mental age greater than 18 years were excluded

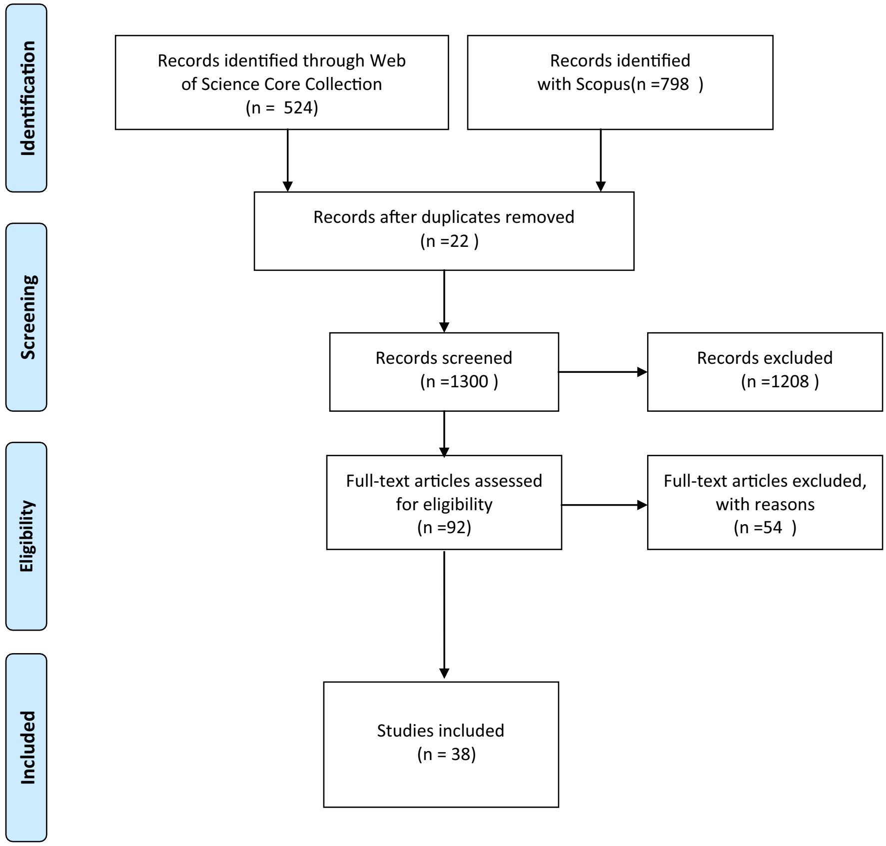

Fig. 1 Flowchart according to the PRISMA statement

documents were identified. The second phase, known as "Screening," inclusion criteria IC1,2,3, and exclusion criteria EX1,2,3 were applied (details in Table 1). This part of the study was developed collaboratively by the different authors of the article. Therefore, each one of them shared the information of each article based on the data of the abstract and the deep reading of the complete article. The third phase of the study, named Eligibility, considers the thematic criteria for the study of the documents. For this reason, inclusion criteria 4 and 5 were applied, in addition to exclusion criteria 4 and 5. The last phase called "included" specifies the final sample size n = 38 documents representing 2.87% of the initial sample of documents. As a summary, Fig. 1 shows the document filtering flow in the various phases of the PRISMA methodology.

To complete the fourth phase of the systematic review, the following points were extracted from the studies and added to an excel spreadsheet: Title of the article, type of virtual reality used and the device, objective of the research, type of instrument, type of activity, results. The spreadsheet was completed by two independent researchers of the team. At the end of the process, they checked the differences obtained and were able to eliminate bias. This also helped to increase internal validity.

In the fifth phase of the systematic review, the items of the CONSORT statement (Moher et al., 2001) were followed to assess the quality of the review documents. Although some of the variables were not targeted by the study, we considered some quality criteria such as "Interventions for each group with sufficient detail to allow replication including how and when they were actually administered" (Moher et al., 2001, p. 1193). Another item considered was "A table showing the baseline demographic and clinical characteristics for each group" (Moher et al., 2001, p, 1192). Therefore, all the items of the CONSORT statement (Moher et al., 2001) were analyzed and the documents were given quality scores. In the sixth phase of the systematic review, the data analysis was implemented as indicated in Sect. 2.3. By way of a summary, Table 2 synthesizes the 38 documents that make up the sample. Table 3 shows the documents that the previous research has in common with the one presented by the authors.

2.4 Data analysis

To study of the documents obtained, two types of analysis were applied. On the one hand, a qualitative analysis was developed to qualitatively describe the phenomenon of interest based on the selected content and context variables. This is shown in Table 2. The process followed for the qualitative analysis was based on Cavanagh (1997), Elo and Kyngäs (2008), McCain (1988) and Polit and Beck (2004). First, the preparation phase was developed, in which the units of analysis or study variables were selected. Thus, it was decided what was to be analyzed and in what detail. This process was based on a theoretical review of the subject under study. Second, a categorization matrix was prepared, and the data were coded according to the established units of analysis. Third, the data obtained were reviewed and coded to establish correspondence with the units of analysis or variables contemplated. On the other hand, a quantitative analysis has been carried out to numerically study the chosen phenomenon by means of the frequency of occurrence of each of the variables previously studied in the qualitative analysis.

3 Results

3.1 The type of virtual reality

Our findings show that 52.63% (n = 20) of the included studies used desktop virtual reality. Research by Lorenzo et al. (2016) was noteworthy because it compares the use of VR and Immersive Virtual Reality (IVR) to determine how autistic students learn emotions. Immersive virtual reality was implemented in 42.10% (n = 16) of the studies, with the HMD device being the most widely used for IVR work (n = 10). Within this group we highlight the work of Schmidt et al. (2021a, b), the reason being that they employed spherical video in HMD devices. This allowed the research

Table 2 Description of the documents according to the variables

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Building an online educational platform to promote creative and affective thinking in special education. Tu et al. (2021)	VR Desktop	To evaluate the capabilities of an online learning platform designed to assist students with Asperger Syndrome in social and emotional development	Ekman test. NEPSY-II measures of auditory attention Narratives were recorded from the tests, transcribed, and evaluated by blinded experts on a 6-point Likert scale before and after training	The test involved projecting a series of black-and-white photographs of adults displaying the expressions of these basic emotions: happiness, sadness, fear, surprise, anger, and disgust. In the Affect Recognition task, children were given a series of colored photographs of a child's face in three different tasks. In the	The online platform elicits improvements in social skills. Similarly, there was an increase in affect recognition skills, social attribution skills and analytical reasoning skills
Evaluation of a spherical video-based virtual reality intervention designed to teach adaptive skills for adults with autism: a preliminary report. Schmidt et al. (2021a, b)	IVR. HMD. video-based virtual reality (SVVR)	This paper presents the design, implementation, and formative evaluation of a spherical video-based virtual reality (SVVR) mobile app designed for adults with autism	Interview structures and survey methods for experts. In addition, a participant observation and survey were implemented. In this way, feedback from designers and users was collected	Four tasks of (1) determining where to go to catch the shuttle, (2) walking to the shuttle stop, (3) checking a university app to determine when the shuttle will arrive, and (4) getting onto the shuttle	The field notebook notes suggest that users reported a positive experience. In this regard, participants quickly learned to use the system

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Evaluation of the Use of Real-time 3D Graphics to Augment Therapeutic Music Sessions for Young People on the Autism Spectrum. McGowan et al. (2021)	IVR. AR	The present research evaluates the effectiveness of Cyma Sense, a real-time 3D visualisation application developed by the authors, as a means of improving the communicative behaviours of autistic participants through the addition of a visual modality within therapeutic music sessions	Videorecording, Interview with Parents and The Checklist of Communicative Responses/Acts Score Sheet (CRASS),	The sessions were customised for each participant; however, a general set of structured activities were as follows: (1) Directed activity – The tutor began sessions with an introductory welcome and interaction with a chime bar. He would continue with personalised interaction with each participant's chosen instruments and/or voice. At the end of the sessions, conclusory activities included simple breathing and stretching exercises. (2) Free activity – The music tutor would identify favoured instruments for each participant and encourage them to initiate interaction during the sessions	the study has provided quantitative evidence that the use of Cyma Sense resulted in an increase in communicative behaviours for the majority of the autistic participants
Automatic assessment of cognitive and emotional states in virtual reality-based flexibility training for four adolescents with autism. Moon et al. (2020)	Desktop VR	The design and implementation of an automatic system to track cognitive and emotional states of individuals with ASD during flexibility enhancement training	Automatic system that is trained from a random sample of the recorded study session data	These 3D-simulation design problems aim to foster the development of domain-specific representational competence—flexibility in representing and solving the science- and math-related problems of forces and Newton's laws of motion	The results conclude that the designed autonomic system can detect the cognitive and emotional states of learners with ASD during their VR-based interactive learning activities

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
An immersive virtual reality educational intervention on people with autism spectrum disorders (ASD) for the development of communication skills and problem solving. Herrero and Lorenzo (2020)	IVR. HMD	The main objective of this intervention is to address communication problems verbal and social communication, including ToM, empathy, and emotional regulation for the ASD population	All sessions are videotaped, and the researchers fill out a questionnaire about the student's performance on the assigned tasks. Similarly, the researchers interviewed family members and therapists, and filled out a questionnaire, before and after the intervention	The first scene has an introductory nature and is mainly devoted to introducing the context and facilitate the user relationship with the avatars he/she will interact with later on. The main educational goals of these initial sessions involve practice and improvement of verbal and non-verbal communication skills, joint attention, and ToM. The second VR setting takes place in the garden of the same virtual environment	The experimental group presents optimal levels of adaptation to the RV. Similarly, an improvement in social memory is developed. Increases in empathy and emotional regulation also occur, although not in the expected values
Virtual Reality Based Joint Attention Task Platform for Children with Autism Jyoti and Lahiri (2020)	Vrdesktop	Develop a task platform using VR for attention work based on a hierarchical set of prompts	The Social Responsiveness Scales (SRS) and Social Communication Questionnaire (SCQ) were administered to obtain an estimate of autism measures An additional scale was used in this research study, namely the Childhood Joint Attention Assessment Rating Scale (C-JARS hereafter)	The experimenter narrated that there will be virtual characters who will introduce themselves and ask the participant to find the object/objects that he/she is interested in. Also, the experimenter asked the participant to think the virtual characters as peers	The results of the study indicate that the system has been able to estimate the attention level of children with ASD and their performance on tasks. In addition, to be able to establish an individualized presentation of tasks based on their needs

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Design of a Physiology-based Adaptive Virtual Reality Driving Platform for Individuals with ASD. Bian et al. (2019)	Vrdesktop	We present the development of a novel closed-loop adaptive Virtual Reality (VR) driving simulator for individuals with ASD that can infer one's engagement based on his/her physiological responses and adapts driving task difficulty based on engagement level in real-time	A questionnaire evaluating participant responses to the system was designed using a 5-point Likert scale. Sensors for in this study, three physiological signals, photoplethysmogram (PPG), galvanic skin response (GSR), and respiration (RSP)	At the start of the session, physiological sensors were placed on the participant's body by an experienced researcher. Participants watched a tutorial video that discussed basic traffic rules as well as manipulation of the driving interface. After the tutorial, the participant was asked to remain calm and relaxed for 3 min	Twenty of 23 participants completed the driving task, and performance data as well as physiological data were properly recorded for offline analysis. All participants who completed the study reported positive experiences with the system
Effects of Virtual Reality Properties on User Experience of Individuals with Autism Bozgeyikli et al. (2018)	IVR = HMD + CAVE	To explore effects of five attributes of user interfaces designed for VR on user experience of high-functioning individuals with Autism Spectrum Disorder (HFASD): instruction methods, visual fidelity, view zoom, clutter, and motion	Surveys included questions about user experience, presence, motion sickness, and user comments. The user experience questions were adopted from the Loewenthal's core elements of the gaming experience questionnaire. The presence questions were adopted from the Witmer, and Singer's presence questionnaire and the motion sickness questions were adopted from the questionnaire of Gianaros	. In this experiment, the users' goal was to inspect moving boxes on two conveyor belts the users stood still at the center of the tracked area and touched the virtual boxes that had defects on them in the form of black spots (diameters of 3–5 cm). When selected, the boxes were highlighted in magenta to provide real-time feedback	Results of the study indicated that it would be better to use animated instructions and avoid verbal instructions, use low visual fidelity and normal view zoom, and use no clutter and no motion in VR training applications (especially with a focus of warehouse or vocational tasks) targeting individuals with high-functioning ASD
Virtual collaborative gaming as social skills training for high-functioning autistic children Ke and Moon (2018)	Vrdesktop	To build a 3D virtual playground that affords competition-themed social gaming, role-play gaming and design-themed architectural gaming among high-functioning autistic (HFA) children	Data were collected via screen recording and observation of participants' gaming actions and reactions. We conducted a behavioural analysis with the recorded social interaction performance of participants in the virtual gaming sessions	, we constructed a 3D virtual world that simulates a variety of real-world locales, such as the township, a school, parks and resorts, restaurants, and stores. It also portrays novel, fantasy locales, such as an underwater world and a historical western town	Role-playing games promote social interaction performance in a comprehensive way. In the category of competitively themed social games, the chess game seems to promote negotiation and cognitive flexibility better than self-identity expression, while the sports game shows the opposite pattern

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Outcomes for design and learning when teenagers with autism codesign a serious game: A pilot study Bossavit and Parsons (2018)	Vrdesktop	This paper is a pilot study that explores and analyses an academic-based educational game that was co-designed with and for young people with ASD. The serious game aims to help the players learn Geography-specific knowledge and integrates several strategic features	Video Coding. Additionally, the students completed the Intrinsic Motivation Inventory (IMI). Regarding enjoyment, the participants completed the Scenario Experience Feedback Questionnaire (SEFQ), which has previously been used with children on the autism spectrum	The game is a turn-taking one where users aim to win a new country by answering a question related to that country (see Fig. 1). The questions are classified by categories and are selected randomly (e.g., people and rivers)	The results show that participants enjoyed the game feeling in control of the environment. They also increased knowledge and social interaction
Learning through VR gaming with virtual pink dolphins for children with ASD Lu et al. (2018)	Vrdesktop	This paper will describe our effort on virtual pink dolphins to assist children with ASD in their learning, at the same time, to avoid the use of physical pink dolphins which is a species endangered	The survey was conducted for the children (EG) who have experience playing with the virtual pink dolphins before	In the game, the children will be dolphin trainers giving directions to the pink dolphins to perform tricks. By mirroring an avatar on the screen, their hand movements will be picked up by the motion sensing input device. pon executing the set correctly, the dolphin will perform a trick. The wrong gesture will trigger a prompt displaying "Follow me!" with a buzzer sound	Results shows that the game has a positive effect in the helping children with ASD learn to follow directions from the avatar and give directions to the dolphins

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Vocational Rehabilitation of Individuals with Autism Spectrum Disorder with Virtual Reality Bozgeyikli et al. (2017)	IVR. HMD	Designing a VR system to train vocational skills in students with ASD	To evaluate trainee performance based on the system parameters, a custom scoring algorithm was implemented These surveys were designed as modified versions of Loewenthal's core elements of the gaming experience questionnaire	There are several modules to work with. The first one is the cleaning module where they learn to use the cleaning instruments. The second is the shelving module to learn how to organize orders and deliveries. The third is the environmental awareness module, where they learn how to keep a computer in the supermarket. The fourth module to learn how to load in the back of the truck. The fifth would be the module to control the money in the cash register and the last module focused on social skills	The follow-up surveys indicated improvement in individuals with ASD in all the skills trained. As found to provide effective training for individuals with ASD by the professional job trainers, we believe that our VR4VR system provides an alternative training tool for improving vocational skills of individuals with ASD
Design of Immersive Virtual Reality System to Improve Communication Skills in Individuals with Autism Halabi et al. (2017)	HMD/CAVE/Vr	This paper presents an interactive scenario-based VR system developed to improve the communications skills of autistic children. The system utilizes speech recognition to provide natural interaction and role-play and turn-taking to evaluate and verify the effectiveness of the immersive environment on the social performance of autistic children	A questionnaire is used to measure user satisfaction and another to analyze the level of immersion	We start the scenario by virtually auto-navigating from outside the school environment into the school and entering the classroom through the corridor. The class-room environment is the main setting where the conversation development task takes place. A virtual teacher avatar in the classroom stands with two other virtual student avatars in front of the chalkboard	The results of tests conducted verify that the developed system is an effective tool for improving the communication skills of autistic children. Although the results indicate that the impact on virtually all the participants was positive, there are certain limitations when considering these results in general for all high-functioning children with ASD

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Visuospatial attention in children with autism spectrum disorder: A comparison between 2-D and 3-D environments Ip et al. (2018)	IVR. HMD	This study examined the use of 3-D VR technology as an assessment tool in ASD children, and further compared its use to two-dimensional (2-D) tasks. Additionally, we aimed to examine attentional network functioning in ASD children	Raven's coloured progressive matrices test (CPM). Children's colour trails test (CCTT). Child version of the attentional network test (ANT-C)	Each game consisted of six blocks (five trials in each block). Both Bubble Poking and Balloon Poking programs required the participants to perform an arm elevation to burst the bubble/balloon stimuli as soon as they reached the black line on the screen. A simple movement pattern (overhead arm elevation) was chosen to minimize possible confounding variables such as motor clumsiness, poor motor planning, and inadequate physical endurance. Moving targets were used as it required good temporal-spatial capabilities of motor control	The current study has provided evidence for the successful application of VR technology as an assessment tool for a sample of ASD preschool children and has also provided a novel perspective into the understanding of visuospatial processing and attention

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Teaching Process for Children with Autism in Virtual Reality Environments. Naranjo et al. (2017)	IVR. HMD	This paper presents the implementation of 3D virtual environments applied to the teaching–learning process for children with autism	Two field notebooks	The interaction between the patient and the virtual environment is done through a humanoid robot that allows to be manipulated—controlled—with ease, in order to provide the inputs to the virtual environment. The development of the virtual environment should allow the interaction between the robot and an avatar. The avatar can be selected according to the interest of the patient to be treated. In the virtual environment, the movements of the avatar are executed according to the emotions of the patient, which are captured by means of a vision sensor. Virtual Environment:	The users improve the social relationship with other people in a controlled environment
Virtual reality based collaborative design by children with high-functioning autism: design-based flexibility, identity, and norm construction. Ke & Lee (2016)	Vrdesktop	To assess the process and potential impact of collaborative architectural design and construction in an Open Simulator-based virtual reality (VR) on the social skills development of children with high-functioning autism (HFA)	Recording of interaction and analysis of behaviour	Collaboratively the various participants must complete the construction of a virtual neighborhood. This comprised a hospital, two school buildings, a restaurant, a beach house, and a greenhouse	Participating children demonstrated a sustained level of engagement in the collaborative design task and fulfilled the targeted design goal

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Virtual-Reality-Based Social Interaction Training for Children with High-Functioning Autism Ke and Im (2013)	Vrdesktop	To examine the implementation and potential effect of a virtual-reality-based (VR-based) social interaction program on the interaction and communication performance of children with AS/HFA	Each participant was observed and videotaped during baseline and intervention sessions. Frequency data were collected on each target social interaction behavior. Rate per hour or session was reported	In Task 1, a target child, when spending his or her first day at the virtual school, got to meet with a peer student in the school lobby. In Task 2, the target child would need to order lunch in the school cafeteria, take a seat at a café table, respond to the interactions initiated by peers sitting around the same table, and maintain interactions with others who came to the table. In Task 3, the target child would attend birthday parties, with alternated roles of a guest and the party host	The study findings indicated that participants demonstrated improved performance of responding and interaction maintaining during intervention sessions and increased facial expression an gesture

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Inclusion of immersive virtual learning environments and visual control systems to support the learning of students with Asperger syndrome. Lorenzo et al. (2013)	IVR. CAVE	is the inclusion of virtual environments in the educational context as a support tool in the educational intervention of students with Asperger syndrome	Supportive tasks protocol (TEVISA). Interviews with school teachers during the implementation of the TEVISA protocol tasks. Instructional protocol of avatars (PIAV)	The student has to face two blocks of tasks: Block I. Executive functions in school learning.: At home, the student has to plan the next day's work by checking the class timetable and the work to be done. Situations in the classroom in which the pupil has to ask the teacher when he/she does not understand an explanation well. Another example of an activity would be when the child has to address other classmates in the playground. As for Block II, which is centred on social skills. Some examples are: In the classroom, the pupil reads a text and then answers questions. The teacher is absent from the classroom, or the pupil has to ask the teacher for a missing material to complete a task	The results indicate an improvement in social skills and executive functions

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Virtual environments for social skills training: comments from two adolescents with autistic spectrum disorder. Parsons et al. (2006)	Vrdesktop	This paper adopts a qualitative case-study approach to report observations of, and comments from, two adolescent boys with ASDs, gathered during a series of sessions using a virtual café and bus environment	Videorecording and take notes	2. VE familiarization: Navigation with a joystick through 'training' VEs showing open and confined space (outside and inside a virtual building, respectively), and interaction with objects using the mouse 4. Café VE: With four levels of difficulty, from a scene with no queue in a quiet cafe with lots of empty tables, to a scene showing a long queue in a noisy café where users needed to 'ask' if they could sit with someone (by clicking on the speech bubble icon on the screen) 5. Bus VE: With five levels of difficulty, from a scene with no queue for a quiet bus, to one with a long queue on a busy, noisy bus with no available seats.6. Café and bus VE: Both VEs, across all levels of difficulty, used in the same way as sessions 4 and 5, lasting approximately 40–50 min (there was less discussion during this session compared to the first time through)	Generally, there was a very positive response to the VEs from the users and evidence that they had remembered social knowledge gained during their VE sessions

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Design and application of an immersive virtual reality system to enhance emotional skills for children with autism spectrum disorders. Lorenzo et al. (2016)	IVR. CAVE	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	Computer Vision-System, Emotional Script, Record Book	4.2.1.1. Phase 1. Identification of the situation and the emotions 4.2.1.2. Phase 2. Implementation of the emotional script 4.2.2. Data collection using computer vision 4.2.3. Initial interview and throughout the intervention process of the social stories	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
Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach. Ip et al. (2018)	IVR. Half-Cave	This paper presents a virtual reality enabled program for enhancing emotional and social adaptation skills for children with ASD	Raven's Progressive Matrices (RPM) Childhood Autism Spectrum Test (CAST) Faces Test Eyes Test to test for emotion recognition and Psychoeducational Profile, Third Edition (PEP-3) for emotion expression, regulation, and social reciprocity. (Schopler et al., 2004). (ABAS-II)	The child has to face four scenarios. In the first one, all the morning routines for going to school are recreated. In the second scenario, he has to get on the bus to go to school. In the third scene the child must follow the rules for being in the library in silence. While in the fourth scene the child must interact in the store to buy the snacks that the school has	The results showed that the 28-session training improved emotion expression, emotion regulation and social interaction substantially
Understanding how adolescents with autism respond to facial expressions in virtual reality environments. Bekele et al. (2013)	Vr. Desktop	an innovative VR-based facial emotional expression presentation system was developed that allows monitoring of eye gaze and physiological signals related to emotion identification to explore new efficient therapeutic paradigms	Automatic system	The VR-based facial emotional understanding system presented a total of 28 trials corresponding to the 7 emotional expressions with each expression having 4 levels. Each trial was 30–45 s long. For the first 25–40 s, the character narrated a lip-synced context story that was linked to the emotional expression that followed for the next 5 s	Results indicated interesting differences in performance regarding identification of certain emotions as well as differences in how individuals with ASD often processed emotions

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
The AS interactive project: Single-user and collaborative virtual environments for people with high-functioning autistic spectrum disorders (Rutten et al., 2003)	Vr. Desktop	Its aim was to research and develop VEs to allow adolescents and adults with ASDs to practice and enhance their social skills	Video Recording and questions about situation	The task for participants in this study was to find an appropriate place to sit downing the café SVE. All participants were seen five times in one month. All participants were shown video clips of café s and buses and asked where they would sit and why. Half of the participants received two VE sessions after the first showing of video clips, the other half after being shown the second set of clips. All participants were shown video clips for a third time	The main conclusions from this study show that people with ASD can learn rules about social skills from VEsessions, and that they can generalize this knowledge to another medium
Blending human and artificial intelligence to support autistic children's social communication skills. Porayska-Pornsta et al. (2018)	Vr. Desktop	To assess the educational efficacy of a learning environment in which children diagnosed with Autism Spectrum Conditions (ASC) engage in social interactions with an artificially intelligent (AI) virtual agent and where a human practitioner acts in support of the interactions	Video recording Social Communication Questionnaire (SCQ) and British Picture Vocabulary Scales (BPVS)	Children's interactions with ECHOES are structured around 12 learning activities that focus on social communication and, in particular, on the following: (1) joint attention:and (2) symbolic use: a child's understanding of meaning expressed through conventional gestures, words, and sentences, and their ability to use non-verbal means and vocalizations to share intentions	Our results show that as some of the children with ASC progress through the ECHOES environment (from beginning, middle and end), they seem to show corresponding numerical increases in initiations of joint-attentional behaviours to both the virtual character and the human practitioner

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Personalisation and automation in a virtual conversation skills tutor for children with autism. Milne et al. (2018)	Vr. Desktop	This research combines these ideas and investigates the use of autonomous virtual humans for teaching and facilitating practice of basic social skills in the areas of greeting, conversation skills, listening and turn taking	Vineland-II and automatic system	The Whiteboard contains support for displaying a wide range of activity types including the previously mentioned concept maps, along with drag and drop sorting activities, interactive role-plays performed by the virtual characters, support for Social StoryTM style activities, and display of multimedia such as videos. Utilising a wide range of activity types is intended to increase both user engagement and the chances of users generalizing the skills learned in the Social Tutor to novel contexts and real-world situations	A major motivator for the use of autonomous tutoring systems is the capacity to present content and lesson sequences tailored to individual learners' needs

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Immersive virtual reality in improving communication skills in children with Autism (Halabi et al., 2017)	IVR (HMD-CAVE)/VR desktop/No immersion	This paper presents a virtual reality solution to reduce the gap experience by autistic children due to their inability to establish a communication. An interactive scenario-based system that uses role-play and turn-taking technique was implemented to evaluate and verify the effectiveness of immersive environment on the social performance of an autistic child	Automatic system and parameters	1.Auto-Navigation: The user automatically navigates through the virtual environment (outside the school to inside the classroom through the corridor) 2. Welcome and Introduction: Virtual teacher character introduces self and virtual student avatars 3.Virtual teacher greets one student avatar in the VE first and receives the response 4.The teacher then greets the next virtual student in the VE and gets similar verbal and non-verbal response 5. The user gets the final turn where the virtual teacher avatar greets the user (customized using the name of the user within the teacher's speech); and the teacher expects a response from the user. 6.Voice and Action Monitoring: The user's voice and physical motion is continually tracked to record a response and its corresponding time to respond. 7.Task Completion: The virtual environment displays text labels that show the amount of time the user has taken to respond to the task assigned	The results of the comparative usability study discussed above shows the effective-ness of the system contributing to improvement of the autistic user's communication skills

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Evaluation of a spherical video-based virtual reality intervention designed to teach adaptive skills for adults with autism: a preliminary report. Schmidt et al. (2021a, b)	IVR. HMD	The aim of this study was to extend the literature on the use of VR with individuals with ASD by presenting the design, implementation, and formative evaluation of a spherical video-based virtual reality (SVVR) mobile app. Using Design Based Research methods, we conducted a formative evaluation to investigate the SVVR app from the perspectives of (1) user experience, (2) feasibility, (3) relevance, and (4) usability for adults with ASD	Social Responsiveness Scale (SRS; Constantino et al., 2003) Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 2007) Behavior Rating Inventory of Executive Function (BRIEF; Gioia & Isquith, 2011)	four tasks of (1) determining where to go to catch the shuttle, (2) walking to the shuttle stop, (3) checking a university app to determine when the shuttle will arrive, and (4) getting onto the shuttle	Results from our usage test suggest that participants had a largely positive user experience. No participants quit, all participants completed all tasks, and several participants indicated a desire to use the Virtuoso SVVR app again

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Virtual Reality–Based Social Skills Training for Children with Autism Spectrum Disorder. Ke et al. (2020)	Vr. Desktop	Therefore, the purpose of this study is to investigate the implementation of a VR-based learning environment in supporting social skills training via a packet of naturalistic, personally meaningful learning activities	The Social Communication Questionnaire (SCQ; Rutter et al., 2003) and Social Skills Questionnaire (SSQ; Spence, 1995) were used as supplementary measures of the participants' social and communication competence before and after the training program	. It encompassed a variety of play- and design-oriented social interaction tasks situated in VR-simulated everyday social scenes such as a neighborhood, a school, amusement parks, other public facilities (e.g., restaurants and shops), or story scenes (e.g., an underwater lab and a Western town). These social interaction tasks were organized into four types: virtual schooling (i.e., social skills instruction and practice), social role-playing in familiar and novel tasks, artifact design (to fulfill individual or group needs), and social gaming that allows or requires social interactions	The study findings suggest the feasibility of using an open-source, desktop VR platform to support situated, play- and design-oriented training of multifaceted social skills with children with ASD

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Utilizing social virtual reality robot (V2R) for music education to children with high-functioning autism Shahab et al. (2022)	IVR. HMD	we evaluated the feasibility of conducting virtual music education programs with automatic assessment system for children with autism at treatment/research centers without the need to purchase a robot, resulting in the possibility of offering schedules on a larger scale and at a lower cost	performing the Stambak Rhythmic Structures Reproduction Test (Fig. 5) to assess the children's musical skills (Gardner, 1971), and 3) Early Social Communication Scales (ESCS). Second, four questionnaires, the 1) Autism Social Skills Profile (ASSP) (Bellini and Peters, 2008), 2) Gilliam Autism Rating Scale (GARS) (Gilliam, 1995), 3) Autism Checklist (Corbett et al., 2008), and 4) Parenting Stress Index-Short Form (PSI-SF) (Abidin, 1990). Video recording	In the present study, a virtual reality classroom was designed for musical rehabilitation and treatment of children with autism, this music class consists of two virtual humanoid robots with the Iranian names Nima and Sina and virtual musical instruments (a xylophone and a drum). The Nima robot was used to teach and play different notes and rhythms on the xylophone	.The positive results observed in this initial study promise that virtual reality technology would be effective in the rehabilitation of children with autism spectrum disorders. The results of this study showed that the ability of children to play musical phrases during the second half of the sessions was significantly different from the first half of the sessions
An exploration of using virtual reality to assess the sensory abnormalities in children with autism spectrum disorder. Koirala et al. (2019)	VR. Desktop	Therefore, in this study, we investigated the feasibility of using VR to assess the difference in sensory processing between children with ASD and TD children	Video recording and sensory questionnaires completed by parents/guardians (e.g., the Short Sensory Profile (SSP) for children aged 3–10 years) or the children with ASD themselves (e.g., the Adolescent/Adult Sensory Profile (AASP) for people aged 11 and older)	The user could feel preprogramed "heaviness" of ball. When the ball was pushed against the path, the participant would feel resistance that stopped the ball from passing through the paths. If the ball was slid against the paths, the participant could also feel preprogramed friction, i.e., the texture of the paths	Results shows the ASD group performed relatively better than the TD group when the virtual ball was heavy, given the same level of friction

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Impact of mainstream classroom setting on attention of children with autism spectrum disorder: an eye-tracking study. Banire et al. (2021)	Vr. Desktop	This study aims to explore the attentional behaviors of children with ASD in a virtual reality simulated classroom	Automatic System and CAST	The child will be confronted with the following situations where the time spent looking at each of the stimuli must be measured. (1) board; (2) a teacher; (3) a front desk with stationery; (4) 'Student 1'; (5) 'Student 2'; (6) 'Ceiling Light 3'; (7) 'Ceiling Light 2'; (8) 'Window 2'; (9) notice board; (10) 'Ceiling Light 1'; (11) 'Student 3'; (12) 'Student 4'; (13) 'Student 5'; (14) and 'Window 1'	Our findings showed that children with ASD are quick to give attention to externally imposed stimuli, such as an instruction to identify the letter X in a VR-CPT attention test
Learning impacts of using data glove and stereoscopic projection with virtual environment for enhancing the social etiquettes in autistic spectrum conditions. Cheng et al. (2014)	IVR. Google Cardboard	The purpose of this study is to investigate the performance of using data glove cooperated with stereoscopic projection to assist the impairment of social etiquettes for children with ASCs	The measure of "social etiquettes checklist (SEC)" was developed to determine the change in understandings of social etiquettes skills for each participant. Questionnaire	The intervention was designed to increase appropriate social etiquettes behavior. Prior to the intervention of the 3DVP system guidance, the participants equipped with 3Dglasses and data glove by the instructor. The researcher explained how to operate the 3DVP system and gave the participants the opportunity to familiar the system. The participants could listen the questions with speaking sounds in reading the text	The primitive results are encouraged; (a) the score of each participant shows considerable increased in the intervention stage after operating the 3DVP system; (b) the usage of data glove was acceptable for these participants with ASCs, and they could use the data glove to grab and interact the virtual objects and virtual characters;

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Investigating the usability and learner experience of a virtual reality adaptive skills intervention for adults with autism spectrum disorder. Schmidt and Glaser (2021)	IVR. HMD	A proof-of-concept adaptive skills intervention for adults on the autism spectrum was developed to promote safe and appropriate utilization of public transportation	Field notes Unstructured, post-usage testing interviews Screen, webcam, and audio recordings Structured expert interviews The adjectival ease of use scale was administered to participant testers, (Bangor et al., 2009)	Specific learning objectives state that learners will be able to: 1.Identify that it is time for shuttle training using their daily schedule, 2.Plan a route from their workspace to the shuttle stop using a map, 3.Follow the planned route from their workspace to the shuttle stop, 4.Check current shuttle location using mobile app,	Results suggest a largely positive learner experience and that the intervention is feasible and relevant to the unique needs of the target population. Implications are presented from the perspective of Roger's adoption characteristics
Inclusion of third-person perspective in CAVE-like immersive 3D virtual reality role-playing games for social reciprocity training of children with an autism spectrum disorder. Tsai et al. (2021)	IVR. CAVE	The present study aimed to improve the ability of children with autism to recognize emotions correctly. We used our third-person perspective role-playing game (TPP-RPG) method to teach social skills and help develop an improved understanding of the six basic emotions	SST Questionnaire	The child is presented with a variety of situations in which he has to interact. There are a total of six scenes where the child will have to associate an emotion with a situation. The first one is angry because a boy has broken his toy car. The second one is happiness because the child has a new friend. The third is to express fear because his mother had gone shopping and it had taken her a long time. The fourth is happiness as his mother has cooked him his favourite meal. The fifth is surprised as someone appears in an unexpected place in an old alley	In particular, the system led to observable and moderate changes in the ability of the three children involved to recognize and understand the facial expressions and body language of the real and virtual interlocutors with which they were involved in the study

Table 2 (continued)

Reference	VR and Type of VR	Objective	Instrument	Activities	Results
Can you help me move this over there? Training children with ASD to joint action through tangible interaction and virtual agent. Girault et al. (2021)	Vr. Desktop	we present the design of a tangible and virtual interactive system for the training of children with autism spectrum disorder (ASD) in performing joint actions	Video recording	To do the activity, the actions to be carried out are raising the box on the floor to the table; slide the stool next to the table; taking the box from the table and placing it on the stool. picking up the box on the stool and placing it on the floor	. Preliminary feedback from a field training study showed encouraging results given the great diversity of the population
Asperger's and virtual reality. Frolli et al. (2021)	Vr. Desktop	In this study we compare two types of intervention to enhance social skills: a traditional emotional training, performed individually with the therapist (group 1), and an emotional training achieved via the usage of VR (group 2)	WISC-IV (Wechsler Intelligence Scale for Children) [23], ADOS 2—Module 3 (Autism Diagnostic Observation Schedule) [24], K-SADS-5 [25]	In the first part of the activities the children had to identify the primary emotions from a series of photographs. In the second activity, they visualised scenes where these emotions could be applied with VR	Our study showed that the acquisition times for the recognition of primary emotions were the same in both groups that had used different modes of intervention
Exploring learning supports in virtual reality-based flexibility training for adolescents with autism. Moon and Ke (2021)	Vr. Desktop	This study examined how using learning support promoted ASD adolescents' cognitive flexibility	We employed a systematic behavior analysis with the video recordings of participants' actions and reactions during training	The task was designed to be aligned with the middle-school physics and math content and practice standards. It requires ASD adolescents to actively represent and apply the concept of Newtonian physics (o define different design variables	We found a total of 8 statistically significant behavior transitions from learning support to target competencies

Table 3 Articles in common between the different reviews

Reference. Our study	Bradley and Newbutt (2018)	Mesa-Gresa et al. (2018)	Glaser and Schmidt (2021)	Deschsling et al. (2021)
Tu et al. (2021)	Adjorlu et al. (2017)	Manju et al. (2018)	Bian et al. (2013)	Amaral et al. (2018)
Schmidt et al. (2021a, b)	Cheng et al. (2015)	Taryadi and Kurniawan (2018)	Strickland et al. (2013)	Babu and Lahiri (2020),
McGowan et al. (2021)	Mundy et al. (2016)	Adjorlu et al. (2017)	Simões et al. (2018)	Beach and Wendt (2016)
Moon et al. (2020)	Newbutt et el. (2016)	Lamash et al. (2017)	Dixon et al. (2019)	Bernardini et al. (2014)
Herrero and Lorenzo (2020)	Strickland et al. (1996)	Bekele et al. (2016)	X	X
Jyoti and Lahiri (2019)		Chen et al. (2016)	Schmidt et al. (2019)	Burke et al. (2018)
Bian et al. (2019)		Didehbani et al. (2016)	Yuan and Ip (2018)	Burke et al. (2020)
Bozgeyikli et al. (2018)		Ip et al. (2016)	Chen et al. (2019)	Cheng et al. (2015),
Ke and Moon (2018)		Wade et al. (2016)	Babu et al. (2018)	Cheng et al. (2010),
Bossavit and Parsons (2018)		Ke and Lee (2015)	Maskey et al. (2014)	Cheng and Huang. (2012),
Lu et al. (2018)		Cheng et al. (2015)	Maskey et al. (2019a)	Cheng and Ye (2010)
Bozgeyikli et al. (2017)	X	Kim et al. (2015)	X	Crowell et al. (2019),
Halabi et al. (2017)		Parsons (2015)	Self et al. (2007)	X
Ip et al. (2017)		Bai et al. (2015)	Maskey et al. (2019b)	Didehbani et al. (2016),
Naranjo et al. (2017)		Bekele et al. (2014)	Maskey et al. (2019c)	Kandalaft et al. (2013),
Ke and Lee (2016)		Escobedo et al. (2014)	Wade et al. (2016)	X
Ke and Im (2013)		X	X	X
Lorenzo et al. (2013)		X	X	X
Parsons et al. (2006)		Maskey et al. (2014)	Zhang et al. (2017)	Ke and Moon (2018)
Lorenzo et al. (2016)		X	X	X
Ip et al. (2018)		X	X	X
Bekele et al. (2013)		X	Wade et al. (2017)	Malinverni et al. (2017),
Rutten et al. (2003)		Stitcher et al. (2014)	Meindl et al. (2019)	Milne et al. (2010)
Porayska-Pornsta et al. (2018)		Bernardini et al. (2013)	Cheng et al. (2015)	Moon and Ke (2019),
Milne et al. (2018)		Cai et al. (2013)	Kandalaft et al. (2013)	Parsons (2015),
(Halabi et al. 2017)		Finkelstein et al. (2016)	Didehbani et al. (2016)	Ravindran et al. (2019)

Table 3 (continued)

Reference. Our study	Bradley and Newbutt (2018)	Mesa-Gresa et al. (2018)	Glaser and Schmidt (2021)	Deschsling et al. (2021)
		Modugumudi et al. (2013)	Ke et al. (2015)	Serret et al. (2014),
Ke et al. (2020)		Wang and Reid (2013)	Zhao et al. (2018)	X
Shahab et al. (2022)		Alcorn et al. (2011)	Volioti et al. (2016)	Smith et al. (2014)
Koirala et al. (2019)		Milne et al. (2010)	Wang et al. (2017)	Stichter et al. (2014)
Banire et al. (2021)			Wang et al. (2016)	Strickland et al. (2013)
Cheng et al. (2014)			Stichter et al. (2014)	Trepagnier et al. (2011)
Schmidt and Glaser (2021)			Schmidt et al. (2012)	Tsai et al. (2020)
Tsai et al. (2021)			Schmidt et al. (2014)	Uzuegbunam et al. (2018)
Giraud et al. (2021)				Ward and Esposito. (2019)
Frolli et al. (2021)			Laffey et al. (2014)	Wang et al. (2017)
Moon et al. (2020)			Laffey et al. (2012)	White et al. (2016)
				Yang et al. (2017, 2018)
				Zhang et al. (2018a, b),
				Zhao et al. (2018)

team and autistic groups to interact with the content and context of the environment via their head movements. Similarly, research by Lorenzo et al. (2013) pioneered the use of Cave Automatic Virtual Environment (CAVE) for VR interaction. There is also a study where both technologies are combined and another study in which the type of virtual reality technology used was not specified (5% of studies, n = 2).

3.2 The objective of the research.

The analysis of the objectives set shows great variability. In 18.42% (n = 7) of the publications, the objective was to develop/teach on social skills. Research by Ke et al. (2020) can be highlighted as one of those aimed at supporting social skills. This publication is characterized by working with everyday scenes such as the neighborhood, school, amusement park or fairytale scenes. In addition, the authors organize the tasks into four types: virtual teaching, social role-playing, environment design and social games. Ip et al. (2018) suggests the creation of a virtual reality programme to improve social and emotional skills. With this objective in mind, six learning scenarios are designed and developed, one of which focuses on the control of emotions and relaxation strategies, four of which work on social situations. The last of the scenarios consolidates generalization. In addition to this, the identification, interpretation, and emotional response was another of the objectives in 13.15% (n = 5) of the investigations. Within this topic, we should point out the work of Herrero and Lorenzo (2020). These authors analyze whether IVR produces improvements in learning and recognition of emotions. Studies aimed at the design, implementation, and evaluation of a VR system to help autistic students represented 10.52% (n = 4) of the studies. Tu et al. (2021) developed an online platform using desktop virtual reality to teach children with Asperger's adaptability and flexibility in addition to the integration of social and emotional development. After finalizing the design, they implemented a pilot study. In 7.89% (n = 3) of the included studies, symbolic play was proposed as one of the objectives. More specifically, Ke and Moon's (2018) mixed-methods and multi-case research examine the association between game tasks, environmental features, and game-based social interaction using VR. To test whether VR is a facilitator of symbolic play. Finally, there are other objectives that have appeared in this study, such as communication skills (5.2%, n = 2), attention (5.2%, n = 2), social interaction (5.2%, n = 2) and motor skills. Jyoti and Lahiri (2020) work on attention by designing a desktop VR-based platform with a hierarchical queuing protocol (using eyes, head turns, finger pointing, etc.). This platform adapts to individualized performance and autonomously increases the level of cues on demand. Similarly, one of the research that aims to work on communication and social skills is Rutten et al. (2003). These authors use desktop virtual reality environments to foster social communication and interaction. More specifically, it focuses on various situations that can be encountered in a cafeteria.

3.3 The instruments used in the research/support program

About the evaluation instruments, 42.10% (n = 16) of the studies used questionnaires. In the case of Jyoti and Lahiri (2020) a series of standardized questionnaires are used such as the social responsive scale (SRS) and the Social Communication Questionnaire (SCQ). Next, the combination of video recording and questionnaires are found in 15.78% (n = 6) of the studies. In research by Herrero and Lorenzo (2020), the sessions are recorded for subsequent analysis, while before and after the intervention, the study used a questionnaire they developed to determine the improvements of autistic students after working with VR. In relation to this, automatic evaluation systems appear in 13.15% (n = 5) of the studies. For example, Bozgeyikli et al. (2017), utilized an algorithm to automatically evaluate student performance across tasks based on a set of parameters. These included the completion time, the number of prompts and the number of incorrect actions. In doing so, a more personalized response to the students was achieved. Another element of evaluation is qualitative analysis of videos. 7.89% (n = 3) of the publications included this form of evaluation. Of note is the research of Ke and Moon (2018) who developed a behavioral analysis of children during interaction games taking verbal initiation, nonverbal initiation, and interpersonal negotiation to resolve a conflict as parameters. This highlights that there are also other types of combinations of instruments such as interview and questionnaire or video recording, interview, and questionnaire. In both cases they appear in 2.1% (n = 1) of the studies. Within this extensive group of papers is the research of McGowan et al. (2021), where video recording is used during the sessions. An interview with parents is also conducted to find out what changes their children have experienced. Throughout the intervention it is necessary to fill in the CRASS (communicative responses/acts score sheet) questionnaire.

3.4 According to the type of activity

In the studies analyzed, the results were as follows. In 5.26% of the studies (n = 2) the desktop VR user identified a series of images associated with an emotion. However, they did not have to apply it to a social situation. In this case, the work of Tu et al. (2021) stands out, which uses desktop virtual reality to design an online platform for working on social skills in autistic students. In 13.15% of the publications (n = 5), identification and recognition activities are proposed, as in the previous case, but associated with social interaction. In this way, the child can learn what would be the consequence of expressing that emotion in a given situation. The work of Lorenzo et al. (2016) stands out, where, by means of a script, the child can learn how to act when expressing a certain emotion, both for him or herself and for the interlocutor. Within this group of work, it is worth highlighting that more than 70% of the publications have used the IVR in its HMD or CAVE modality. The use of desktop virtual reality was a minority.

There are other types of activities with non-social content that have also been developed. For example, presenting the child with a series of bubbles to be popped. Another case is the possibility of guiding a ball along a path. It is also possible to use a driving simulator (Bian et al., 2019), answer questions about a country (Bossavit & Parsons, 2018) or put a series of geometric figures in a certain place (Lu et al., 2018). Thus, there are n = 5 studies that have focused their work on non-social tasks. Only one of the studies has used IVR, the rest have worked with desktop virtual reality. As for the rest of the activities that have been studied, it has been possible to observe that there is a great diversity of context. In this sense, there are a total of 7 studies where activities related to the school context are implemented. For example, in the work of Halabi et al. (2017) using IVR, the user starts by navigating through the school until the arrival in the classroom. This classroom consists of two students and a teacher. The teacher explains the instructions to introduce himself by addressing all participants including the avatar of the autistic child. In this way we try to work on presentation skills. In this line is also the work of Ke et al. (2020) who among the various scenarios have a school café where the user has to sit and negotiate with other peers. Similarly, it is also included within the classroom where he carries out a series of mathematics activities to learn flexibility. All these activities are carried out with desktop virtual reality. Within this group, the activities developed by Ip et al. (2018) also stand out. In the first of the user activities, the child practises the routines for going to school. The scenario starts in the bedroom when the alarm clock has been set. The child is encouraged to go to the alarm clock and stop it by ringing. A checklist will appear to indicate that the task has been completed and to direct the child to the next step, which is to use the toilet. In each of the situations the therapist may introduce an alternative situation. The second scenario designed by Ip et al. (2018) consists of a series of routines that children can practice and experience during school days in the setting such as greeting the teacher, handing in homework, following the teacher's instructions, and joining in learning activities, etc. These activities were developed with the IVR. It is also the case that there were n = 4 studios that have designed their activities for school-related settings but do not take place within the school, such as the cafeteria and getting on transport. The activities carried out in the cafeteria take place with desktop virtual reality, with the work of Ke and Im (2013) standing out, while the transport activities, such as those of Schmidt et al. (2021a, b), are carried out with immersive virtual reality. In both cases the user has to choose a place to sit. Activities have also been developed in non-school settings such as money management, cleaning the house, a restaurant, or a shop. However, in all of them activities were designed in which the user was supported by a therapist through virtual environments. These were all interactive and realistic. To summarize, it can be concluded that the activities have been planned in the form of games while mostly using desktop virtual reality. This is in addition to all the activities needing the user to provide some feedback to make the scenario resemble a real social interaction using immersive virtual reality. Interestingly, the more complex tasks used IVR, while the more basic activities tended to use desktop VR.

3.5 According to the findings

The results obtained in the different studies have been distributed as follows. The results of 18.42% (n = 7) of the studies show an increase in the identification, understanding and interpretation of emotions due to VR. As an example, the research results of Ip et al. (2018) may be analyzed. These authors observed a substantial improvement in emotion expression, emotion regulation and social interaction. Although most of the training took place in virtual environments, generalization of skills was achieved in real environments. Another of the results to highlight is that in 15.78% (n = 6) of the studies it is observed that VR is very well accepted by autistic students. In this sense, the system designed by Jyoti and Lahiri (2020) was accepted in a good way by these students. Similarly, it was a system enabled to estimate the level of group attention skills of autistic child in terms of task performance. In addition, it was able to identify this level individually and adapt to the needs of the students. Following this line, improvements in social skills and attention (10.52%, n = 4) have been experienced due to VR. In this way, Tu et al. (2021) suggest that the designed system has led to an improvement in social skills (affect recognition skills, analytic reasoning skills and social attribution skills).

Regarding attention, Banire et al. (2021) report in their results that there has been an improvement in the time that autistic child are engaged in a social interaction developed with virtual reality. In this sense, 7.8% (n = 3) of the publications show a development of symbolic play. In one example, Halabi et al. (2017) provide a suggestion that VR has led to an improvement in the symbolic play of autistic students after developing the activities in interactive scenarios with VR. Also, some aspects such as communicative behavior (5.2%, n = 2), improved eye contact (2.6%, n = 1) are considered important. In the case of communicative behavior, McGowan et al. (2021) suggest from their results that the tool they used assisted with the development of communicative behaviors such as the initiation of social greetings or interest in starting a conversation. For eye contact, Herrero et al. (2020) state in their research that eye contact had increased in students after working with virtual reality; although it's not clear the benefits this finding provides.

4 Discussions

In this section we will discuss the results of our study focused around the five guiding research questions. The first research question referred to the type of virtual reality. Desktop virtual reality was employed in 52.63% (n = 20) of the studies. These results are slightly less than those of Mosher et al. (2021) who located 72.2% of studies using desktop virtual reality. In addition, Mak et al. (2020) located 75% of studies making use of desktop VR. However, in our study the number of studies employing immersive virtual reality are equal to 42% (n = 16) whereas previous reviews do not find anything more than 20%. The limited application of immersive virtual reality in previous studies is in line with research by Newbutt et al. (2016), who argue that research around the impact and evidence of CAVE or HMD devices on autistic users is scant. It is therefore not entirely clear how widely accepted this tool is for these individuals. Furthermore, Newbutt et al. (2016) claim that despite the accessibility and low cost of these relatively new tools (i.e., HMDs), there is insufficient evidence, or knowledge, on negative effects. Therefore, the case for using desktop virtual reality is higher, as the equipment used is common (i.e., computer monitor connected to a personal computer) (Bellani et al., 2011). As a result of these simple interfaces, desktop VR is accessible for implementation in educational environments.

The second research question focused on the most studied objectives (in terms of targeted outcomes). These were social skills and emotions (31.42%, n = 12). These results are slightly less that found in the study by Mesa-Gresa et al. (2018) who located 65% of studies focused on social skills and emotions. In addition, our findings are similar to those of Thai and Nathan-Roberts (2018) who located 42% of publications focused on emotions. The third most common objective, in 10.52% (n = 4) of the studies is that of design and implementation of VR systems. No other previous research identified this as a key objective of research in this field. The importance of designing immersive systems is due to the fact that there are still no conclusive studies that allow the generalization of activities learned in virtual environments into real environments (Glaser & Schmidt, 2021). For Dalgarno and Lee (2010) it is assumed that the greater veracity of virtual environments the greater the behaviors will be produced in real environments. However, Stokes and Osnes (2016) assert that VR system designs must consider the interaction of tasks, environments, participants, and technology; as well as the way in which performance supports are introduced. This will influence the generalization of learning in different contexts. Another of the most important objectives is that of symbolic play with 7.82% of the studies focusing on this. This is in line with the results of Dechsling et al. (2021) where 2% of the research has targeted this area. According to Wetherby et al. (2004) and Thiemann-Bourque et al. (2012) one reason that some work has focused on symbolic play is because this is considered an early indicator for the diagnosis of autism and its evaluation (APA, 2013).

In relation to the use of instruments for the evaluation of outcomes for autistic students, 42.10% (n = 16) have used a questionnaire. According to Chakraborty et al. (2021), the vast majority of questionnaires are used for diagnosis and not for the evaluation of improvements. The combination of questionnaires with video recording was present in 15.78% (n = 6) of the studies. The inclusion of video as a measurement is a consequence, according to Grossi et al. (2021), of the fact that this instrument can help to describe the intricate pattern of restricted and repetitive behaviors of people with autism. In this way, a better understanding of their behavior is achieved (Melo et al., 2020). This is not possible with the questionnaire, which is restricted mostly to diagnosis. One more of the evaluation systems is automatic systems, which appear in 13.15% (n = 5) of the investigations. There are two reasons for the use of automatic systems. Firstly, Alnajjar et al. (2021) claims that automatic systems collect relevant information on various parameters of social interaction. This will be used for the creation of retrievable databases of user evaluations and history. The second reason according to Rudovic et al. (2018) is that these instruments, unlike traditional ones, enable better monitoring of a larger number of learners with different needs and in varying situations.

The following research question is focused on the characteristics of the activity. Firstly, activities that have been developed to work on emotions, have mostly been carried out with HMD devices and in social situations where the identified emotion can be applied. According to Garon et al. (2018), the reason for designing these activities in this way is due to the fact that children with autism find it easier to interpret synthetic and computer-generated devices than natural stimuli. Similarly, Parsons (2016) justifies those interactions in virtual environments that are more naturalistic, more direct and allow for more interaction will facilitate the generalization of learning. In the same way, Smidth et al. (2021) add another reason justifying that the learning of autistic students will be favored when the user has interaction devices that are as realistic as possible. This contrasts with desktop VR where the user interacts with a joystick or keyboard. Following the analysis, it has been observed that in 5 of the publications, activities have been proposed in which knowledge of VR has been promoted rather than the improvement of the skills of the child with autism. According to Parsons and Cobb (2011), the reason that could justify the work of non-social activities could be that there is still no conclusive research on the characteristics that VR technology should have to support the learning of autistic students. In this way, a better understanding of this technology is achieved to subsequently implement it in social situations. It is important to note that the context in which most of the work has been carried out is the school, with 7 studies. It is important to note that the context in which most of the work has been carried out is the school, with 7 studies. According to Nikula et al. (2021), this may be a consequence of the fact that the school plays a fundamental role for students with special educational needs according to the inclusive policies that are being implemented in many countries. It is therefore necessary to ensure that barriers to access, participation and learning that limit their inclusion in the school along with the rest of their peers are removed. In this way, virtual reality will be the element that will provide the educational response for these students. Finally, according to Dalgarno and Lee (2010), it can be said that the use of IVR in activities that work on complex social situations is due to the fact that VR systems that allow for greater involvement and interaction of the students will be those that facilitate better learning. To this end, these authors suggest that VR systems should provide several features such as immersion, fidelity, and presence. For these authors immersion is based on the technical capabilities of the VR technology to produce sensory stimuli, while presence is context dependent and is based on the individual's subjective psychological response to VR. Whereas fidelity is that which allows the user to feel included in the environment in such a way that he/she considers every action to be as if he/she is performing it for real.

The last of the research questions focuses on what the most frequent results of the studies are analyzed. First, it was found that in 18.42% of the publications (n = 7), there was an improvement in emotion identification and recognition. In the same line, Mesa-Gresa et al. (2018) identified 22% of publications that confirmed improvements in the identification, recognition, and expression of emotions. These results may be a consequence of the fact that VR allows the generation of instructions to guide autistic students on how to respond to an identified emotion (Russo-Ponsaran et al., 2016). Moreover, in autistic learners the ability to recognize and identify emotions from non-human stimuli, such as cartoons, caricatures or schematic faces, or stimuli via VR, remains intact, unlike with the identification of human stimuli (Brosnan et al., 2015).

Second, ASD students' acceptance of VR as a learning tool was found in 15.78% (n = 6) of the studies. Bradley and Newbutt (2018) found that in 50% of the investigations there was no acceptance of VR, with side effects such as dizziness, anxiety, or cybersickness identified. This variability in the acceptance of VR environments may be due to several reasons. On the one hand, ASD is mostly accepted as a complex, pervasive, and heterogeneous condition with a wide range of etiologies, subtypes, participant age, and developmental trajectories (Glaser & Schmidt, 2021; Masi et al., 2017). On the other hand, according to Parsons (2016), the acceptance of VR is conditioned by context, goal, and task type. Moreover, the lack of standardized VR technologies (Parsons, 2016) forces to combine different types of technology, with the problems that this can entail (Skarbez et al. 2017).

Thirdly, it is worth noting that 10.52% of the papers (n = 4) confirmed the improvement of social skills due to VR. Similar are the results of Mesa-Gresa et al. (2018) and Dechsling et al. (2021), who identified 9.6% (n = 3) and 12% (n = 5) of the publications, respectively. In these improvements it is timely to take into consideration that autistic users are more likely to adopt the self-identities of their avatars, which facilitates the perception of simulated social contexts in VR (Wang et al., 2016). Furthermore, Wang et al. (2016) demonstrated that autistic students can be proactive to social situations presented to them through VR. In addition, the acquisition of social skills is faster in social situations that the child experiences on a day-to-day basis and that he/she will be able to work with VR to develop his/her learning (Frolli et al., 2022).

5 Conclusions

This review has highlighted that the application of virtual reality between 1996 and 2021 with and for autistic students has helped to enable and support individuals in the development of autonomy and inclusion in educational contexts. Based on the results, we highlight the following conclusions:

- The most widely used type of virtual reality to date is desktop virtual reality.
- In the research analyzed, the two most frequent research purposes have been: firstly, to develop and teach social skills and secondly, to work on the identification, interpretation, and emotional response of autistic students
- The instrument most widely used in the interventions was a questionnaire, followed by a questionnaire-video combination.
- The most applied activities are of a realistic nature and with elements of interaction that allow autistic users to be included in the environment.
- The most frequent findings have been the improvement in the identification and interpretation of emotions and the students' acceptance of VR as a support tool.

Our study has highlighted that the use of virtual reality for students with autism has been applied schools (in various situations and in non-social contexts.

These are spaces where social situations do not arise due to the absence of another interlocutor. However, the there are some limitations that should be outlined. For example, there are publications that do not include the necessary information for a more complete analysis; they do not include a detailed description of the activity being developed. Also, publications were found that did not define the instrument to evaluate the student's progress or learning. More specifically, some papers mention that they used an instrument developed by them do not indicate its main features. Therefore, to achieve greater transparency in the scientific process and to help the performance of systematic reviews, it would be advisable to agree on minimum indicators that should necessarily be described in all studies.

Regarding the practical implications that can be derived from the study, firstly, the knowledge of the objectives on the use of VR in autistic students provides the educational community information about the applications that VR can have. Teachers, based on this, can consider the use of VR to respond to the behavior of these students. It is recommended to adjust the objectives to the characteristics and needs of the students; placing autistic learners more centrally to the design and development of VR. Likewise, the results allow the educational community to know the most relevant advances that VR has brought about. It is recommended that future research considers work in the areas in which VR has been found to be most effective; ensuring an evidence-based approach. However, it is also advisable to progressively expand the use of VR to other areas, trying to implement methodological and technological improvements based on the limitations identified in the previous studies in the field. The characteristics of the activities applied with VR provide information to the educational community on how to develop the didactic strategies to be applied with autistic students. It is recommended to design activities that solve situations in contexts that and autistic child encounters in everyday life. Moreover, it is suggested that the activities be manipulative in nature and include a virtual instructor who can help the child when he/she does not know how to act in the environment.

Considering the type of virtual reality, our analysis has enabled us to identify what type of hardware has been used the most in studies with autistic students to generate VR. Furthermore, information has been provided on the nature of the virtual reality used. The use of immersive virtual reality and HMD devices is recommended, due to the ease of interaction they offer to autistic students and the realism of the environments that can be created. Likewise, the analysis of the assessment instruments used provides the educational community the possibility of knowing which instruments are suitable for assessing variables in a VR intervention. In this sense, it is recommended to use instruments already validated and successfully used in previous research. However, it is suggested to add an automatic data collection system, which can counteract the possible bias generated by the researchers. For example, a camera system to be able to determine the position and orientation to which the child is looking within the VR environment.

In sum, this study aimed to contribute to educational communities and to better understand how to organize educational responses to students with autism via VR. Thus, if VR is intended to be used for learning emotions, it is recommended to use an avatar to ask the child what his or her mood is. The child could respond with a series of YES or NO cubes if he/she knows the expression that the avatar is expressing. The cubes are used so that this activity can be navigated by autistic students with different levels and input of communication. In addition, VR can be used for learning classroom rules. In this case, a child would have a pictogram agenda to know how to behave in a classroom. Then, the teacher's virtual avatar will tell him/her to arrange a series of pictograms on a sheet classifying the rule as what can and cannot be done in the classroom. Each of the pictograms will have a color associated with it so that the child can relate it to whether the rule is done.

Funding The author(s) declared having received the following financial support for the research, authorship and/or publication of this article: This work was supported by Programa Estatal de I+D+i Orientado a los Retos de la Sociedad del Ministerio de Ciencia e Innovación Español.[grant number PID2020-112611RB-I00] and Proyecto titled " La aplicación de la realidad virtual y la robótica en la comunicación e interacción social de alumnado con Trastorno del Espectro Autista".

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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