International Journal of Social Robotics (2025) 17:845–870
https://doi.org/10.1007/s12369-024-01099-0

Analysis of the Application of the Bee-Bot Robot for the Development of Social Reciprocity Skills in Students with Autism Spectrum Disorder

Elena Pérez-Vázquez[1] · Gonzalo Lorenzo[1] · Alejandro Lorenzo-Lledó[1] · Asunción Lledó[1]

Accepted: 10 January 2024 / Published online: 13 February 2024

Abstract
Increasingly, Information and Communication Technologies (ICT) are being used as a resource in the teaching–learning process of students with special educational needs. Specifically, the needs of children with autism spectrum disorder (ASD) seem to align perfectly with ICT, especially with Pedagogical Robotics, as it enables the creation of predictable and controllable environments. For this reason, the main aim of this research has been to apply the Bee-Bot robot to improve the social-emotional reciprocity responses of students with ASD. Therefore, a quantitative research based on a quasi-experimental methodology and a pre-test-post-test design has been developed. The sample of participants was composed by 22 children with ASD. In this sense, the experimental group was composed by 11 students who developed the activities through the mediation of the Bee-Bot robot. While the control group was composed by 11 other students who developed non-robotics mediated activities. An ad hoc instrument consisting of 44 items divided into three dimensions, related to the communication and social interaction area, was used. Each participant participated in ten individual sessions lasting fifteen minutes. The results indicate improvements in the post-test because of the use of robotics as a mediating learning tool. For example, there are improvements in items 1 and 2 related to attention with p values less than 0.05, as well as improvements in items 13, 15 and 16 related to the identification and discrimination of emotions. Furthermore, the results of the intra-group analysis show, on the one hand, significant differences on the part of the control group in item 13, related to emotion identification and discrimination skills. On the other hand, in the case of the experimental group, the number of items in which there are significant differences is greater. Specifically, participants in the experimental group show significant differences in items related to attention, basic social skills, conversational skills and emotion identification skills. In conclusion, the Bee-Bot robot, accompanied by a pedagogical programme, has potential for learning social-emotional reciprocity skills in these students.

Keywords Robotics · Bee-Bot · Educational intervention · Autism spectrum disorder · Social reciprocity skills

1 Introduction

In the last few decades, the use of Information and Communication Technology (ICT) has expanded across various sectors of society [1]. Specifically, these technologies have been extensively integrated into schools [2], offering new possibilities for educational intervention for students with special needs that should be considered [3]. In this regard, the use of ICT allows for the recreation of everyday life situations where learners with special needs can practice and acquire different skills in a controlled, safe, and autonomous manner within the classroom [4]. These tools also can present information sequentially [5], thereby facilitating easier cognitive access to the curriculum for these students. Additionally, the use of ICT provides visual support for learning, helping process the content being taught more quickly and in a less abstract manner [6]. By incorporating ICT in the classroom, educational inclusion takes a step forward, as its contributions can ensure the presence, learning, and participation of all students in a school context [7].

One of the most widely used ICT tools in the school environment is robotics [1]. When robotics is applied in an educational context, it is referred to as Educational Robotics (ER), as its purpose is to facilitate student learning and improve their educational outcomes [8]. Different types of robots have been employed in the educational setting, such

✉ Gonzalo Lorenzo
glledo@ua.es

[1] Department of Developmental Psychology and Didactics, University of Alicante, Alicante, Spain

as the Lego WeDo Kit [9], Lego Mindstorms NXT [10], Bee-bot [11], Blue-bot [12], and Thymio robot [13]. The first two are utilized in primary education, based on construction and programming using motors, sensors, and LEGO parts [10], while Bee-Bot and Blue-Bot are programmable floor robots that are also used by pre-school pupils [11, 12]. Moreover, Thymio [13] is a programmable and customizable educational robot that has been implemented in swarm educational robotics with pre-school, primary, and compulsory secondary school students.

Among the most used robots for introducing students to robotics concepts and acquiring skills in different areas of knowledge, the Bee-Bot robot stands out [14]. According to Janka [15], this programmable robot was regarded as the most outstanding hardware for children in pre-school and the initial levels of primary education at the British Educational Training and Technology Show 2006 (BETT) fair. The bee-shaped design of the robot allows for the creation of simple and engaging activities that are well-suited for children of these ages due to their ease of use [11]. To utilize this robot in a teaching context, grid-shaped playmats are used along with commands located at the top to program the robot's route [11]. However, it should be noted that the mere presence of these technologies does not guarantee success; the determining factor for their effectiveness is directly related to the pedagogy employed for their implementation in the classroom [16]. Therefore, the pedagogical role of the teacher in making effective use of ICT in the curriculum primarily revolves around two aspects, as outlined by Rogers & Twidle [16]: designing activities for learners and creating a context of activities in which learners can acquire the necessary competences [16]. Thus, a pedagogical model that aligns with the curriculum's fundamental principles is necessary for the integration of ICT into the learning process [17].

This paper is part of a broader research study that examines the inclusion of educational robotics as a mediating learning tool in the teaching process of students with ASD.

1.1 Related Work

In the current framework of inclusive education, there has been an increase in the diversity of the student body in schools. In other words, the number of pupils with special educational needs in mainstream schools has risen [18]. Among these students, individuals with autism spectrum disorder (ASD) can be identified. ASD is a neurodevelopmental disorder that affects individuals' communication abilities, social interactions, and is characterized by restricted patterns of behavior, interests, and activities [19]. According to Schwartz et al. [20], low socio-emotional reciprocity is one of the defining features of autism. Lemoine & Schneider [21] define socio-emotional reciprocity as the ability to engage in back-and-forth conversations, initiate communicative exchanges, and share emotions. Difficulties in socio-emotional reciprocity for individuals with ASD manifest in various behaviors, such as a lack of initiative in social interactions [22], literal interpretation of idioms [23], or challenges in expressing feelings and emotions [24]. Given these characteristics of students with ASD and considering that robotics can act as an integrating element for their inclusion [1], the use of robots in the learning process of children with ASD has gradually improved over the years. Several authors have demonstrated the potential of robotics in enhancing imitation abilities [25], attention skills [26], and speech capacity [27]. These positive outcomes are primarily attributed to the strong affinity students have with robotics [28], the robot's ability to serve as a social mediator [29], the simplicity of instructions provided by robots, and their capacity to provide direct feedback [30].

For these reasons, the use of robotics to target the socio-emotional reciprocity responses of students with ASD is justified. Robins et al. [25] were among the first authors to employ a robot, named Robota, to work on social-emotional reciprocity skills with students with ASD. They aimed to improve imitation and communication initiation skills, and their study demonstrated improvements in these areas. Pioggia et al. [31] designed a robotic face called FACE to enhance emotion recognition skills in students with ASD, and the results showed improved emotional responses in students who interacted with the robotic face. Building on this research, Duquette et al. [32] conducted a study using the robot Tito to compare learning outcomes between a robot-mediated situation and a human-mediated situation. The results, consistent with previous studies, demonstrated more effective learning for participants who used the robot, although the human-mediated situation also improved imitation skills [32]. The robots used thus far have been humanoid, but Stanton et al. [33] examined whether students with ASD could effectively learn with animal-like robots and used the robot dog Aibo. Subsequently, more animal-like robots such as Keepon [34], Pleo [35], Cuddler [36], Probo [37], and Kiliro [38] started to be utilized. Until 2013, research involving robots and students with ASD was primarily pre-experimental. However, Kim et al. [35] expanded the number of participants to 24 and demonstrated higher verbal output when participants interacted with the Pleo robot. To generalize the results, Costescu et al. [34] conducted research involving 81 participants and demonstrated the effectiveness of the Keepon robot as a mediator. The results showed that students with ASD performed better when the robot was involved in the activity. In Wong & Zhong's study [36], a polar bear-like robot called Cuddler was used, showing an increase in eye contact and joint attention in children with ASD during tasks. It was not proven that the robot functioned as a mediator in all cases. Specifically, Simut et al.

[37] found that the Probo robot did not consistently function as a mediator, but it did attract more attention than a human. Bharatharaj et al. [38] demonstrated how the Kiliro parrot robot was an effective tool for reducing stress in individuals with ASD during social interactions. Participants felt relaxed and did not get upset when interacting with the robot. Furthermore, more advanced humanoid robots are being used with children with ASD, such as Troy [39], Kaspar [40], Charlie [27], or NAO [41]. Research involving these human-like robots has shown improvements in social behaviors due to the simple instructions provided by the robot, as seen in the study by Goodrich et al. [39]. These robots are referred to as social assistive robots (SAR) because their main function is to provide assistance to humans through social interaction [42].

The study presented here introduces several novel aspects. Firstly, it utilizes the Bee-Bot robot to teach social-emotional reciprocity skills to students with ASD, which has not been previously explored in interventions with these students. Secondly, unlike previous research [31, 32, 39], the interventions in this study are developed within a curricular pedagogical model, facilitating their integration into the current inclusive educational framework. Thirdly, the inclusion of a control group consisting of students with ASD, rather than typically developing students as in other studies [25], adds to the novelty of this research. Fourthly, the study involves a larger number of participants compared to previous research [25, 31, 32]. Lastly, it includes students from all three levels of ASD, a detail not specified in other studies involving robots like Pleo [35] and Probo [37]. This approach allows for the creation of activities that can be tailored to the heterogeneity of students with ASD.

To establish a systematic teaching–learning process adaptable to the variability of students with ASD and accessible to a broader range of students, researchers such as Pinel et al. [43] have proposed the development of robotic interventions in educational contexts. However, the high cost of social assistive robots (SAR) and the limited availability of such devices have predominantly confined applications to clinical settings [44]. Therefore, it is important to explore low-cost robotic alternatives that do not require advanced programming skills, enabling their wider use in educational environments. The Bee-Bot robot emerges as one such low-cost option that can be utilized with students with ASD. Its ease of use and adaptability to user characteristics, achieved through its shape, lights, and sounds, make it particularly suitable [11]. The Bee-Bot robot's command functions ("move forward," "backward," "turn," "pause," "delete," and "ready") provide students with ASD with spatial and temporal structure, which is crucial for their learning. Without such structure, learners with ASD may experience anxiety and become distracted from the task [45]. Additionally, the command cards serve as visual aids to help students structure the programming of the robot's movements. This visual support is beneficial for individuals with ASD, as they often process information better visually than audibly and rely on visual aids, such as pictures or drawings, to aid their information processing [46]. Lastly, the design of robotic toys like Bee-Bot captures the attention of students with ASD more effectively than non-robotic toys [47]. The mechanics of these robots, including sounds, lights, and simple movements, contribute to their appeal [47].

1.2 Research Process and Purpose of Study

Considering that this research aims to measure the effectiveness of a resource, the research process should be based on the control of variables to see the possible influence of the resource applied with respect to the study variable. In this line, it should aim to measure these variables as a pre-test, before the intervention, and as a post-test, after the intervention with two groups (experimental and control). Based on the above background, the general objective of this study is to apply the Bee-Bot robot to develop the social-emotional reciprocity responses of students with autism spectrum disorder. The following table summarizes the specific research objectives which underlie the general objective. To facilitate a better understanding, Table 1 shows the skills observed, the test considered, and the groups considered in the study.

2 Method

2.1 Methodological Approach

A quantitative approach was chosen for this study. Furthermore, a quasi-experimental method utilizing a pre-test-post-test control group design was employed [16]. According to Dahnial [48], a quasi-experimental design involves a control group and an experimental group that are not randomly assigned. In this study, the control group (CG) will engage in tasks targeting communication and interaction skills using a methodology without the mediation of robotics. On the other hand, the experimental group (EG) will perform the tasks with the assistance of the Bee-Bot robot.

2.2 Research Context and Participants

The sample for this study was selected from public schools in the city of Alicante, Spain. Specifically, the participants were students enrolled in five designated communication and language classrooms. These classrooms are specifically designed for students with Autism Spectrum Disorder (ASD) and are located within regular schools in the Valencian Community. The classrooms are equipped with various personal,

Table 1 Specific research objectives

#	Skills observed	Test(s) considered	Group(s) involved
1	Attentional skills	Pre-test	Experimental group vs control group
2	Attentional skills	Post-tests	Experimental group vs control group
3	Attentional skills	Pre-test, post-test	Control group
4	Attentional skills	Pre-test, post-test	Experimental group
5	Basic social skills	Pre-test	Experimental group vs control group
6	Basic social skills	Post-tests	Experimental group vs control group
7	Basic social skills	Pre-test, post-test	Control group
8	Basic social skills	Pre-test, post-test	Experimental group
9	Conversational skills	Pre-test	Experimental group vs control group
10	Conversational skills	Post-tests	Experimental group vs control group
11	Conversational skills	Pre-test, post-test	Control group
12	Conversational skills	Pre-test, post-test	Experimental group
13	Emotion identification and discrimination skills	Pre-test	Experimental group vs control group
14	Emotion identification and discrimination skills	Post-tests	Experimental group vs control group
15	Emotion identification and discrimination skills	Pre-test, post-test	Control group
16	Emotion identification and discrimination skills	Pre-test, post-test	Experimental group

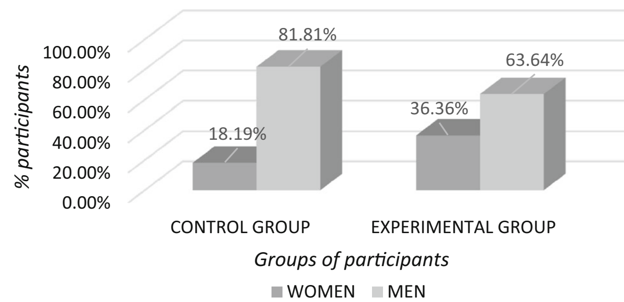

Fig. 1 Sex assigned at birth of the sample

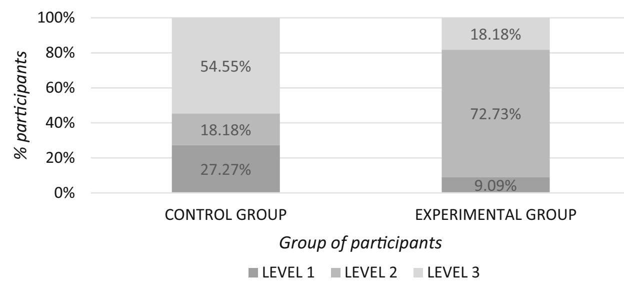

Fig. 2 Level of ASD of the sample

spatial, and material resources that are tailored to the needs of students with ASD. These resources include specialized teachers (Special Education teachers) and educators, well-structured spaces with pictograms, and manipulative materials suitable for the students.

An accidental non-probability sampling method was employed to form both the control group and the experimental group. To be eligible for participation in the study, students had to meet the following criteria: (1) have a clinical diagnosis of ASD based on DSM-5 criteria [45] given by a licensed clinical psychologist, (2) be enrolled in a designated communication and language classroom, (3) not have any other psychiatric diagnoses, and (4) have parental consent along with a completed participant sheet. A total of 22 students with ASD met these criteria and participated in the study, with 11 students assigned to the control group and another 11 students assigned to the experimental group. None of the students had prior experience with educational robots. To assess the equivalence between the groups at the beginning of the intervention, a non-parametric Mann–Whitney U test was conducted, revealing no significant differences (p value < 0.05) between the groups.

Regarding the participants' characteristics, the control group consisted of students aged 4 to 12 years old (M = 10.81 years old), while the experimental group included participants aged 3 to 13 years old (M = 7.00 years old). Furthermore, Fig. 1 provides a breakdown of the participants' distribution based on their assigned sex at birth.

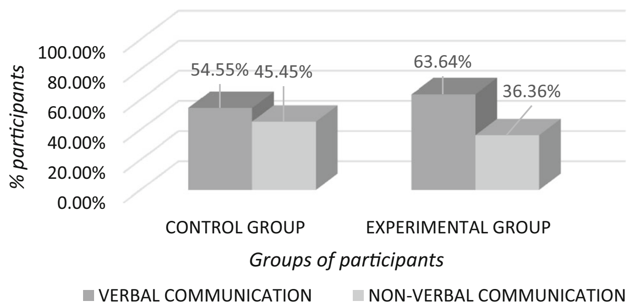

Fig. 3 Type of communication of the sample

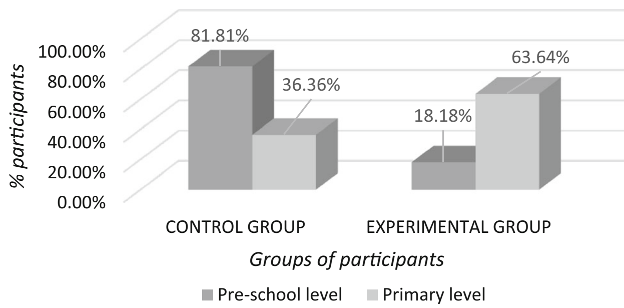

Fig. 4 Level of curricular competence of sample

Further on with the characteristics of the sample, Fig. 2 shows the distribution of the participants, both in the control group and the experimental group, according to the level of ASD based on the diagnostic criteria of the DSM-5 [49]. It is worth mentioning that all participants in the study were assessed by the educational guidance teams of the schools with the Adaptive Behaviour Assessment System-Second Edition test, ABAS II [50].

According to another characteristics, Fig. 3 shows the type of communication of participants from control and experimental group.

To complete the characteristics of the participants in the study, it is necessary to look more closely at their level of curricular competence. In this sense, Fig. 4 shows the classification of participants according to curricular level.

2.3 Instrument

2.3.1 Variable

The definition of variables will be essential for properly evaluating research results in a specific context [51]. To determine the definition of the study variable, a literature review has been conducted [49, 52, 53]. In the present research, the variable of interest is the capacity for socio-emotional reciprocity of students with ASD. This capacity has been defined as the ability of pupils with ASD to engage in social interactions, sustain a conversation, and recognize the emotions expressed by the person they are communicating with. The variable has been structured into four categories:

- Attention skills. It is conceptualised as the set of cognitive skills needed to select and focus on relevant stimuli.
- Basic social skills. A set of behaviours that are essential for initiating and maintaining a conversation: to say thank you, to say hello, to say goodbye…
- Conversation skills. A set of abilities that allow you to ask, refuse, ask, answer or maintain a topic of conversation.
- Emotion identification and discrimination skills. It is conceptualised as the ability to identify one's own and others' emotions in order to manage one's behaviour.

2.3.2 Questionnaire for the Evaluation of the Area of Communication and sociAl Interaction of Students with Autistic Spectrum Disorder

To assess the participants' competence in the area of communication and social interaction of students with ASD, the "Questionnaire for the Evaluation of the Area of Communication and Social Interaction of Students with Autistic Spectrum Disorder" (CACIS-TEA) was utilized.

For the development of the instrument to measure educational actions, various questionnaires were used as references, including the Denver Test [54], the Adaptive Behavior Assessment System-Second Edition (ABAS II) [50], and the severity levels of ASD outlined in the DSM-5 [49]. Based on this review of the scientific literature, the initial version of the CACIS-TEA questionnaire was designed, consisting of two sections. The first section comprises eight questions. The first four questions gather information about the educational center, the initials of the participants' first name and surname, age, and sex. The subsequent four questions inquire about the level of curricular competence, the severity of ASD, the mode of communication (verbal or non-verbal), and the type of schooling (mainstream, specific, or combined). The second section consists of a 59-item scale, aligned with the theoretical definition of the variable and the considered dimensions. The first dimension, titled "Socio-emotional reciprocity responses," consists of sixteen items (items 1 to 16), which are further divided into four subcategories: attention, basic social skills, conversational skills, and emotions. The second dimension, "Verbal and non-verbal communication behaviors," includes fourteen items (items 24 to 38) and encompasses the subcategories of associating verbal and non-verbal communication acts, eye contact, and body language. The third dimension, "Behaviors of maintaining and understanding social relationships," incorporates twenty items (items 39 to 59) divided into three subcategories: behavior adaptation to different contexts, engagement in pretend play, and interest.

In order to determine the content validity, the expert judgment technique was applied to the initial version of the questionnaire. This technique is widely used and considered effective in assessing content validity in educational research due to the detailed insights provided by experts, ease of implementation, and the ability to obtain specific information [55]. Among the different methods of content validity, the Aiken V coefficient [56] was used in this investigation. This choice was based on the fact that the results of validity calculations using Aiken's V are more stable compared to other calculations, such as Gregory's formula [57]. These results contribute to the quality of the measurement instrument by objectively determining the content validity of each item [58]. According to Merino & Livia [59], Aiken's V coefficient is a logical method of validity that assesses the opinions of N expert judges on the validity of an evaluation material, with values ranging from 0.00 to 1.00. A value of 1.00 indicates perfect agreement among the judges. In this case, ten experts in the field participated in the process, including lecturers specializing in special education from different Spanish education faculties, special education teachers, hearing and language teachers, and educational counselors. To enable these experts to examine the content of the questionnaire, several steps were taken. Firstly, a letter of introduction to the research was drafted, specifying the research objectives. Secondly, the structure of the questionnaire was presented, and detailed instructions for conducting the assessment were provided. Thirdly, the evaluation criteria for each element, specifically relevance, were described using a four-point Likert scale (1 = no relevance, 2 = little relevance, 3 = some relevance, and 4 = much relevance). The experts were also given the opportunity to provide comments on the clarity of the item wording. Following these instructions, the questionnaire to be assessed was provided, and additional boxes were included for the judges to make any appropriate comments. According to Penfield & Giacobbi [60], Aiken's V values equal to or greater than 0.80 are considered valid items with a significance level of $p < 0.05$. Based on this criterion, fourteen items were eliminated. Consequently, the final version of the CACIS-TEA questionnaire consisted of a scale of 44 items divided into three dimensions. In addition, a 5-point licker scale was used to measure the frequency of each item. Specifically, the values of scale were: (1) "never", (2) "rarely", (3) "sometimes", (4) "often" and (5) "always". Considering the research objectives and sample characteristics, the questionnaire was administered directly to the teachers.

In the final version, the first dimension, "Socio-emotional reciprocity responses," consists of 17 items (items 1–17) organized into four categories: attention (e.g. item 1, "When we make contact asking for his/her attention, he/she stops what you are doing?"); basic social skills (e.g. item 3, "Say hello when he/she enters the classroom?"); conversational skills (e.g. item 7, "uses language to make requests"), and emotion identification and discrimination skills (e.g. item 13, "Identifies the name of the basic emotions with pictograms"). The second dimension, "Verbal and non-verbal communication behaviors," includes 12 items categorized into integration of verbal and non-verbal communication, eye-gaze skills, and bodily expression of emotions. Lastly, the third dimension, "Behaviors of maintaining and understanding social relationships," comprises 15 items (items 30–44) organized into four categories: behavior adaptation to different social contexts, engagement in pretend play, and interest.

Reliability corresponds to the degree to which an instrument measures without error and accurately the variables of the study [61]. To analyze the reliability of the instrument's internal consistency, the Cronbach's Alpha coefficient was calculated, resulting in a value of 0.986. According to George & Mallery [62], this indicates excellent reliability, demonstrating a high degree of consistency in measuring communication and social interaction skills of students with ASD. Cronbach's Alpha coefficient was also calculated for each dimension separately. For the first dimension (the focus of the present paper), the Cronbach's Alpha coefficient is 0.979. For the second dimension, it is 0.964, and for the third dimension, it is 0.938.

It's important to note that while the questionnaire assesses the communication and social interaction abilities of students with ASD, the present research focuses specifically on the first dimension of the questionnaire: socio-emotional reciprocity.

2.4 Procedure

2.4.1 Pedagogical Model Designed

The pedagogical model that has been applied in this research is based on the one presented by Ovalles et al. [17]. In this regard, the model by Ovalles et al. [17] is based, first of all, on active learning through the creation of real or fictional situations for which students seek solutions. Secondly, this pedagogical approach is based on a structured framework according to the elements of the educational curriculum. And thirdly, the multilevel programming of activities is another aspect that characterizes the model. The proposal encompasses activities ranging from simple tasks to activities with higher levels of abstraction that students will develop according to their progress. Taking into account these three characteristics, a model is presented that is characterized by an active-participatory approach for students with Autism Spectrum Disorder (ASD) through the resolution of small challenges that require their direct involvement to solve them. Furthermore, the educational model presented takes into consideration the basic elements of the curriculum of the Spanish education system, both in preschool and primary education. In this regard, a systematized model is presented through activities based on learning objectives, which help students acquire different core competencies with the assistance of various resources.

The following is a detailed presentation of the pedagogical model that utilizes educational robotics to support the teaching of communication and social interaction skills.

Learning objectives are conceptualized as a description of what students should be able to do at the end of educational activities [63]. Following Sewagegn [64], objectives, as well as educational assessment, should be at the core of the teaching and learning process. They are essential because, as highlighted by Chatterjee & Corral [63], well-established objectives will guide not only the assessment method but also the activities to be carried out. Taking into account all these factors, the learning objectives proposed in this intervention proposal are shown in Table 1.

Competencies are defined as a combination of knowledge, skills, and attitudes adapted to achieve a specific goal [65]. In the field of education, key competencies refer to the competencies that all members of society need to develop holistically and achieve active and inclusive citizenship [66]. Among the key competencies proposed by the European Commission [66], this intervention focused on the development and acquisition of competence in linguistic communication, digital competence, and social and civic competencies. Regarding competence in linguistic communication, the intervention aimed to improve levels of verbal and non-verbal communication through tasks that required students to demonstrate language skills to overcome them. For example, throughout the session, students were asked to read a story aloud or respond to specific situations that evoked the emotion being studied. Additionally, the intervention also emphasized the development of digital competence through learning activities focused on programming a floor robot. Students in the experimental group learned a programming language using different cards that helped them recognize the buttons they needed to press to establish a specific route for the robot. Social and civic competencies were addressed through various activities aimed at developing communication and social interaction skills in students with Autism Spectrum Disorder (ASD), which are fundamental for their inclusion in society. Specifically, basic social skills such as greeting upon entering the classroom, saying goodbye, apologizing, expressing gratitude, or politely asking for things were practiced.

Different learning strategies to engage an effective educative intervention with ASD students should be used in this model. These strategies are based on the Treatment and Education of Autistic and related Communication-handicapped Children (TEACCH) methodology [67]. Following Mesibov and Shea [68], the first strategy implemented was related to time management, structuring the physical environment, and work systems throughout the sessions. Regarding time management, each student had a visual and structured schedule that displayed the activity with the robot. Additionally, the physical environment where the activities took place had a fixed structure, and each location in the room where each activity was performed was marked with a pictogram, aiming to achieve maximum autonomy. The second principle is related to the visual information used throughout the sessions to reduce confusion and increase understanding of the content of the activities. Lastly, meaningful communication was used during the sessions to facilitate the student's understanding of the sequence of activities. For this reason, Alternative and Augmentative Communication Systems were used. Other types of strategies that have been implemented in this model are related to positive reinforcement, which constitutes a strategy to encourage good behavior in students, motivate them to learn, and engage them in classroom activities [69]. Therefore, it is necessary for professionals to recognize and identify appropriate reinforcers that motivate students with Autism Spectrum Disorder [70]. Authors like Jabeen et al. [71] indicate that by using elements of positive reinforcement (verbal, tangible, and non-verbal), the probability of a certain behavior occurring or at least being maintained in the future is increased. Thus, in the course of this research, non-verbal positive reinforcement was implemented through actions such as thumbs up or high-fives, and verbal reinforcement through praise and congratulations like "Well done!" and "Great job!".

Regarding the resources used, they can be divided into different types. Firstly, there is the Bee-Bot robot, and secondly, the play mats. To enable students to program the robot's route using commands, sequence cards were used to assist students with ASD in sequencing the robot's programming step by step. Additionally, five curriculum-based play mats were designed. These play mats contained pictograms taken from the ARASAAC platform, which is a website of pictograms and resources for Augmentative and Alternative Communication (AAC) with a free-to-use license, created by the Aragonese Center for Augmentative and Alternative Communication. In this regard, ARASAAC provides adapted materials to facilitate communication and cognitive accessibility [72]. Furthermore, this platform includes online tools that allow the creation of adapted games, schedules, and calendars. Specifically, two of these play mats were based on different types of pictograms that expressed emotions. Another two play mats were based on photographs of people expressing basic emotions. And a final play mat was based on actions that can elicit the expression of certain basic emotions. Additionally, pictograms were sometimes used with non-verbal students. On the other hand, there were also stories for each of the emotions that were designed by the research team. All of these materials were characterized as simple, visual, and adapted to the needs of the students.

Finally, the evaluation was conducted based on systematic observation during the sessions. This observation technique, as described by Matos and Pasek [73], involves systematically, validly, and reliably recording student behavior. This data collection technique is crucial for formative assessment, which aims to improve the quality of the teaching process [74]. Field notebooks were utilized to record the results of each participant in the ten sessions for this evaluation. Additionally, to assess potential changes before and after the intervention, the Questionnaire for the Assessment of Communication and Social Interaction Area in students with Autism Spectrum Disorder was administered. All dimensions of the questionnaire were covered in the field notebooks. To minimize potential bias effects that could impact the evaluation, several strategies were employed following the guidelines established by Hurtado [62]. Firstly, families and participants were informed about the procedure using adapted language to ensure understanding. Secondly, the "observer as forgotten" technique was implemented, wherein the researcher participated in some sessions of the classroom dynamics with the participating students prior to implementing the intervention. Through this technique, the participants became accustomed to the presence of the researcher. Thirdly, the sessions were integrated into the classroom dynamics with minimal disruption to the students' natural environment. Lastly, the observers were familiarized with the participants' behaviors prior to the evaluation.

Fig. 5 Temporal structuring panel of a session

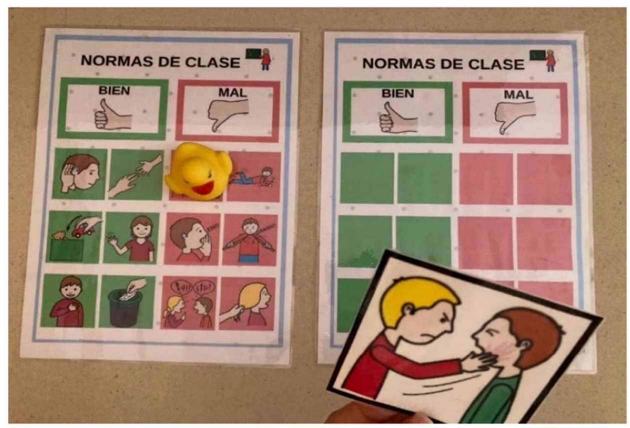

Fig. 6 An example of materials used in the first session with the control group participants

2.4.2 Action Protocol Activities

Due to the characteristics of the students, the principles of the TEACCH method [68] were taken into account to promote the maximum autonomy of students with Autism Spectrum Disorder (ASD). In this regard, the sessions consistently followed the same structure and were accompanied by visual supports. For instance, Fig. 5 illustrates the temporal structuring board of a session with visual supports, which aided the students in anticipating the activities within the session.

Moreover, the same learning objectives related to communication and social interaction skills were addressed in both the control group and the experimental group sessions. Therefore, the sequencing of activities was the same for both groups. However, in the case of the experimental group, the Bee-Bot robot was used as a mediating element, while in the control group, a non-robotic toy in the shape of a duck was used as the mediating element.

In this regard, the first session for both groups aimed to practice basic social skills, understand and interpret simple instructions, maintain eye contact with objects and people, identify and discriminate classroom rules, and recognize appropriate situations and behaviours. In the case of the control group, first, the instructor would show the student the pictograms of the classroom rules. Secondly, the instructor would hand the student the pictograms of the classroom rules, and the student would have to place them on top of the corresponding pictograms on the board. To do this, when the student found the matching pictogram, they would place the duck on top of the corresponding pictogram and leave the card. Additionally, before placing a pictogram on top of its counterpart on the board, it would be read aloud. Thirdly, the instructor would show the learner the pictograms of behaviours that could be performed during the sessions and the pictograms of behaviours that were not allowed. The learner would then have to place these pictograms on top of the matching pictograms on the board. Again, when the student found the matching pictogram, they would place the duck on top of the corresponding pictogram and leave the card. Finally, they would classify the behaviour pictograms on a card consisting of two columns: allowed behaviours and prohibited behaviours. Figure 6 shows an example of the resources required to develop this first session with students in the control group.

In the case of the experimental group, the first session would commence with the instructor presenting the pictograms of the classroom rules to the student, similar to the control group. However, in this case, the instructor would then hand the student the pictograms of the classroom rules one by one, and the student would place them on the play mat by positioning the corresponding card on top of each rule. Next, they would proceed to program the route of the Bee-Bot robot to reach the card representing the specific classroom rule they were working on. This process would be repeated for all the rules. After completing the activity, the student would be provided with an explanation of the allowed and prohibited behaviors during the sessions. Following the same dynamic as in the initial activity, the student would program the robot to move to the square where the pictogram of the behavior they had focused on was located. Finally, similar to the students in the control group, they would classify the behaviors as either allowed or prohibited. Figure 7 shows an example of the materials used for the experimental group in this first session.

From the second to the ninth session, the focus was on the basic emotions: joy, sadness, anger, and fear. Each emotion was addressed in every two sessions.

Sessions 2, 4, 6, and 8 aimed to work on each of the basic emotions, emphasizing spontaneous responses to questions and promoting the use of spontaneous language. This was achieved through the recognition, identification, and discrimination of emotions by reading a story using the Kamishibai technique. In particular, the Kamishibai technique utilizes large illustrations and text that are created in relation to visual effects [76]. The illustrations are placed in a small wooden theater with two doors, and the narrator stands in front of the audience while reading the text [76]. The text can be adapted based on the audience, and interactions with the audience occur at specific points during the story [76]. The Kamishibai technique was applied to both the experimental and control groups as follows. In both groups, the researcher acted as the narrator, responsible for presenting the images in the wooden Kamishibai. During the story reading, questions were posed to the child to ensure their comprehension of the story, such as: “Where is the girl?”, “Where is the dog?”, and “What did the dog lose?” In the case of the experimental group, the student had to program the robot’s route to the square on the play mat that corresponded to the illustrated scene being explained. Conversely, in the control group, the student had a copy of the story illustrations and had to find the one that matched the explained scene and place a rubber duckling on top of it.

For the control group, these sessions began with the reading of a story using the Kamishibai and arranging the story scenes. Next, the student had to recognize and identify the emotion felt by the main character in the story. A response sheet with the final scene of the story and four cards displaying the pictograms of the basic emotions (sadness, anger, joy, and fear) was provided to the student. The student had to select the emotion expressed by the main character by placing the corresponding pictogram card on top of the card. Then, they had to locate the pictograms expressing that emotion on the panels and place the rubber duckling on top. This exercise was repeated with a panel containing images of people expressing emotions on their faces. Figure 8 ilustraste the materials used in these sessions.

In sessions 2, 4, 6, and 8 of the experimental group, the same structure as the control group was followed. However, during the reading of the story using the Kamishibai, the student had the additional task of programming the robot to reach the square on the play mat where the image corresponding to the story being read was located. For the second activity, similar to the control group, the student was provided with a response sheet containing the final scene of the story and four cards displaying the pictograms of the basic emotions (sadness, anger, joy, and fear). From these cards, the student selected the emotion that corresponded to the story. Then, the student was instructed to locate the selected emotion on the play mat and program the robot to reach the squares containing that specific pictogram. Finally, the student was asked to locate on another play mat, all the photographs displaying people expressing the emotion that was being focused on. Figure 9 illustrates an example of the resources used during these sessions.

Sessions 3, 5, 7, and 9 were designed to focus on the identification of emotions through their non-verbal manifestations, learning about the bodily expressions of emotions, and recognizing the causes of emotions. These sessions also built upon the skills developed in previous sessions. Specifically, in the case of the control group, the card sheets from the previous session were utilized in a card format to review the story. After reviewing the story, the students were given sheets with four cards displaying photographs of people expressing the basic emotions. They were then asked to identify the emotion being expressed by the main character in the image. To do this, they had to locate all the photographs on the panel that portrayed that specific emotion and place a rubber duckling on top of each relevant image. The last activity involved presenting an image of a situation to the students and providing them with response options. They were required to select the cause of the main characters’ emotions in the image. Subsequently, they had to place the rubber duckling on the pictogram on the panel that represented the chosen cause. Figure 10 provides examples of the materials used by the control group in these sessions.

For the experimental group, sessions 3, 5, 7, and 9 maintained the same structure as the control group. However, in

Fig. 7 An example of materials used with the participants of experimental group in the first session

Fig. 8 An example of materials used in the session number eight with the control group participants

Fig. 9 An example of materials used in the session two with the experimental group participants

these sessions, the students had the additional task of programming the robot to follow specific routes towards the response boxes for facial expressions and emotional causes. Figure 11 illustrates the materials used during these sessions for the experimental group.

In the tenth session, the aim was to review all the content covered in the previous sessions. The materials used in this session were the same as those used in the preceding sessions.

Table 2 outlines the intervention sessions relating the learning objectives to the role of the researcher and the learner in the session.

It is important to acknowledge that due to the heterogeneity of characteristics among students with ASD, adaptations were made in the activities considering age and different levels of ASD. Various accommodations were implemented to cater to different needs and levels of communication and understanding. Firstly, visual supports were utilized to assist with oral explanations and activity materials. Communication boards were also provided for students who required them during the sessions to express themselves. This allowed for accommodating different levels of ASD, both for students with verbal communication abilities and those without. Additionally, the approach was adapted to cater to different

Fig. 10 An example of materials used in the session number nine with the control group participants

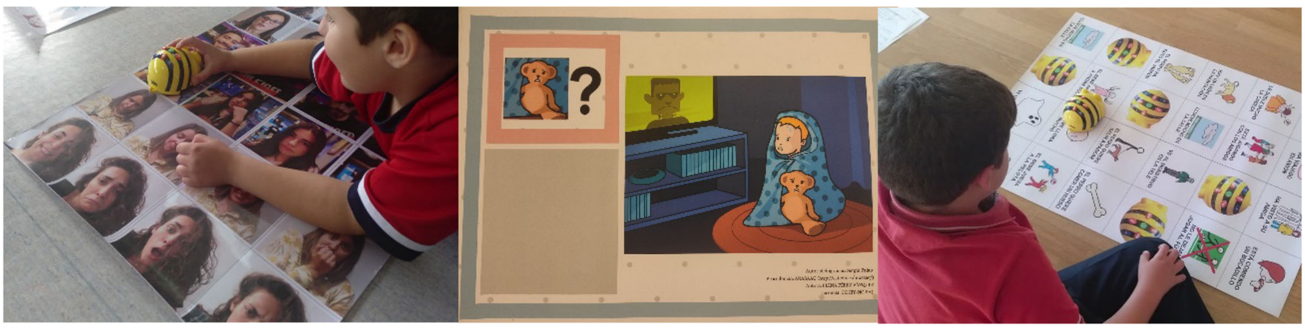

Fig. 11 An example of materials used in the ninth session with the experimental group participants

Table 2 Learning objectives

• To employ basic social skills
• To understand and interpret simple commands
• To practice eye contact with objects and people
• To identify class rules
• To discriminate between appropriate and inappropriate behaviour
• To answer questions spontaneously
• To learn the name of basic emotions: sadness, joy, anger and fear
• To identify emotions through its non-verbal manifestations, learning of bodily expressions of emotions
• To discriminate among basic emotions: sadness, joy, anger and fear
• To imitate expressions of basic emotions: sadness, joy, anger and fear
• To identify the causes of an emotional behaviour

levels of understanding, considering visual thinking as well. Secondly, depending on the child's age and reading level, a combination of pictograms with uppercase written words or solely pictograms was used. The activities themselves were adaptable to the student's level, with variations in the number of instructions provided. For instance, a student with Level 1 ASD and a curricular competency level of 2nd grade might be instructed to find all the photographs expressing the emotion of fear, while a student with Level 3 ASD and a curricular competency level of Early Childhood Education might be asked to find one photograph depicting the emotion of fear. The adaptations made according to the level of ASD can be summarized as follows:

- Level I: Use pictograms with written words; utilize a time structuring panel to specify activity start and end times; ask questions to ensure comprehension of instructions.
- Level II: Incorporate pictograms with written words in uppercase underneath; use gestures to support verbal communication; utilize the time structuring panel to specify activity start and end times; provide short and simple explanations, asking for repetition aloud to ensure comprehension.
- Level III: Use a communication board during the sessions; utilize pictograms without written words underneath; allow more time to complete activities; use gestures to support verbal communication; utilize the time structuring panel to specify activity start and end times; provide short and simple explanations.

2.4.3 How to Program with the Robot

More specifically, in the case of activities in the experimental group where the Bee-Bot robot was used as a mediating element, students with ASD had to interact with the robot using the commands on the top. Each of these commands corresponded to an instruction, as shown in Fig. 12, which allowed students to structure the route to reach the box where the answer to the question posed by the researcher was located.

It should be noted that there are two ways of programming the Bee-Bot robot, so there are two levels of adaptation. The first option consists of programming the sequence of movements one by one. Therefore, if we must programme three forward movements to reach our destination, we press the "forward" arrow (see Fig. 12) once and then press the "GO" command. After moving forward one square, we clear the sequence and repeat this sequence of actions two times. The second option is based on programming the whole sequence in one step. In this sense, it consists of pressing all the commands in the desired order and then pressing "GO". For instance, if we want to move three squares forward, we will press the "forward" arrow three times (see Fig. 12) and then press the "GO" button. In this sense, to work on the same objectives we have two levels of complexity, which can be adapted to the different levels of autonomy of students with ASD. In Fig. 12, a participant from the experimental group can be seen in front of a playmat. This playmat was used in the sessions to teach students to rules of session. The pupil had to program the robot to reach the box representing the behaviour he was asked about. In addition, there are several specifications to take into account when performing activities with the Bee-Bot robot. Thus, it is important to know that the robot's memory is empty at the beginning. In addition, before pressing "GO" it is necessary to enter the commands. The maximum number of instructions is 40. Between one command and another, the robot stops. On the other hand, if the "GO" button is pressed during operation, the robot stops. At the end of the sequence, the robot emits sounds and lights. And, to enter a new sequence, press delete ("X").

2.4.4 Data Collection

The research was conducted following ethical guidelines and with the approval of the Research Ethics Committee of the University of Alicante (UA-2021-09-06-1). The process involved contacting schools to collaborate in implementing the intervention with their students with ASD.

In a first phase, the schools were contacted through the institutional email. Then, a meeting with the principal was held in which the objectives of the study and the programme of lessons were explained. In this meeting, documents of the informed consent and the participant's sheet were provided to the principals who distributed them to the teachers of the students and then, they facilitated them to the families. Once the documents were signed, a new meeting with the teachers was arranged to establish the spatial and temporal organization of the sessions. This phase started in September and ended in October 2019.

After this phase, a second phase began by making a division between the students in the control group and those in the experimental group. The CACIS-TEA questionnaire was filling in. Specifically, the intervention was delivered through two sessions per week, each lasting fifteen minutes. In total, ten sessions were developed with each participant. On the one hand, the control group sessions ran from the beginning of November to the end of December 2019. On the other hand, the sessions with the experimental group took place from January to February 2020. In order to collect information about the intervention in more detail between the pre-test and post-test, two types of field notebooks were used. On the one hand, both notebooks collected demographic, psycho-pedagogical and educational information about the students on the first page. On the other hand, for each of the sessions conducted by the participants, the notebooks include a table. These tables contain questions that are repeated in all the sessions: "does he/she feel attracted by the mediating tool?", "does he/she greet when entering the classroom?", "does he/she say goodbye when leaving the classroom?", "does he/she maintain attention during the activities?", "does he/she use verbal communication to communicate?", and "does he/she use the media to communicate?". In the case of the experimental group, the following two questions are added to this group of common questions: "What is the maximum number of movements that the student programmes with the robot?" and "What type of movements does the student programme with the robot?". Moreover, for each session other questions intrinsically related to the activities performed in them are included. Finally, a section of observations is included in each of the sessions so that the researcher can record the most relevant aspects.

2.5 Data Analysis

Regarding statistical techniques, non-parametric tests were used, as the sample size was less than 30 cases [77] and the distribution of the data was not normal in all cases, according to the results of the Kolmogorov–Smirnov Lilliefors test. In this regard, p values less than 0.05 were observed for 54.55% of the items in the control group and 50.00% of the items in the experimental group [78]. Also, after applying the Shapiro–Wilk test [79], which is used for small samples of less than 50, it was found that the distribution of the data is not normal with W values of less than one [80]. In this sense, after ensuring that the study did not present the necessary conditions to apply parametric tests, firstly, the non-parametric Mann–Whitney U two-group comparison test was applied to

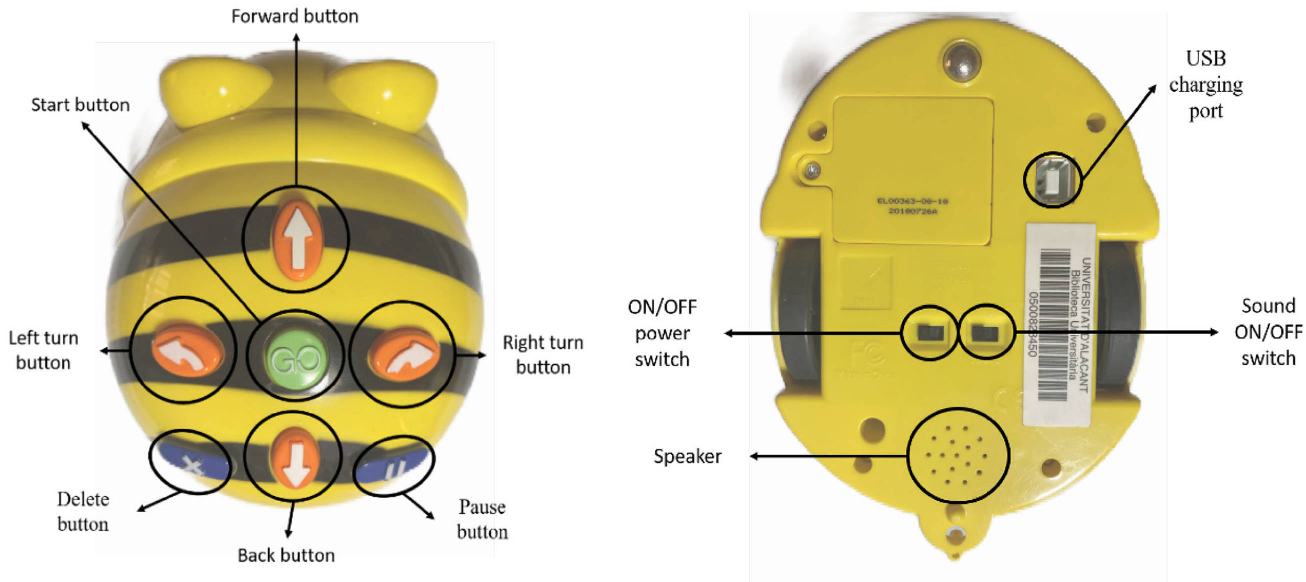

Fig. 12 Commands of Bee-Bot

ensure that there were no significant differences between the groups before the intervention. Secondly, the non-parametric Mann–Whitney U two-group comparison test was re-applied again to estimate possible post-intervention differences due to robotics with p values less than 0.05 between groups [81]. Thirdly, Friedman test [77] was applied to determine whether there were significant differences between the pre-test and post-test scores of the two groups (control and experimental). Then, the Wilcoxon test for two dependent samples was applied to study the items where the differences between pre-test and post-test scores were present [82]. All data were analysed with the Statistical Package for Social Sciences (SPSS) software, version 23.

Table 3 Pre-test comparison between the control and experimental group in attention skills

Item	Group	Mean rank	p	U
1. When we make contact asking for his/her attention, he/she stop what you are doing?	Control	11.23	.82	57.50
	Experimental	11.77		
2. When an explanation is made, he/she follows the interlocutor with his/her gaze	Control	9.55	.11	39.00
	Experimental	13.45		

3 Analysis of Results and Discussion

This section presents the results of the research organized according to the specific objectives.

1. Differences in relation to attentional skills in the pre-test between the experimental group and the control group.

According to the first specific objective, the results regarding potential significant differences in attentional skills before the intervention between the experimental group and the control group are shown in Table 3.

The results presented in Table 4 indicate that there are no significant differences for the two items between both groups in the pre-tests.

2. Differences in relation to attentional skills in the post-tests between the experimental group and the control group.

According to the second specific objective, the results regarding differences in attentional skills between the control group and the experimental group after the intervention are presented in Table 5.

The results (see Table 3) indicate significant differences after the intervention in the two items of the category.

3. Differences in relation to attentional skills between the pre-test and the post-test in the control group.

As per the third specific objective, the results of the Friedman test regarding potential significant intragroup differences in attentional skills within the control group indicate a p value of 0.14. Specifically, the Wilcoxon test results for the two

Table 4 General design of sessions

Session	Learning objectives	Investigator's performance	Student performance
1st	To employ basic social skills To understand and interpret simple commands To practice eye contact with objects and people To identify class rules To discriminate between appropriate and inappropriate behaviour	Firstly, show to the pupil pictures of the classroom rules Secondly, researcher should then show the student pictograms with behaviours that can be done during the sessions and behaviours that should not be done	Firstly, he/she has to match, one by one, the pictogram of classroom rules with the pictures on the playmat or panel Secondly, he/she has to match, one by one, the pictogram of allowed or forbidden behaviours with the pictures on the playmat panel. Then, she/he has to classify it
2nd, 4th, 6th and 8th	To answer questions spontaneously To learn the name of basic emotions: sadness, joy, anger and fear To identify emotions through its non-verbal manifestations To discriminate among basic emotions: sadness, joy, anger and fear	First of all, the stories are read using the *Kamishibai* technique Then, questions are asked to guide the students in the activities. For example, how is the girl?; are you sad?; where is the sad girl?; can you point to the sad girl?…	Identify the emotion felt by the main character in the story, imitating the facial and body expression of the corresponding emotion
3rd, 5th, 7th and 9th	To answer questions spontaneously To learn the name of basic emotions: sadness, joy, anger and fear To identify emotions through its non-verbal manifestations To discriminate among basic emotions: sadness, joy, anger and fear To imitate expressions of basic emotions: sadness, joy, anger and fear To identify the causes of an emotional behaviour	Review the story using the playmat or cards Provide students the playmats or panels for identifying emotions through photographs and the possible causes of the emotion	Find on the playmat or panel all the pictures showing people expressing the emotion and identify the pictograms expressing the possible causes of the emotion Imitate the facial and body expressions of the emotions
10th	To consolidate the learning objectives worked on in previous sessions	Provide students the playmats or panels and the materials for activities	Order the scenes of the stories about emotions Identify the emotions in each of the stories Classify emotional causes

Table 5 Post-tests comparison between the control and experimental group in attention skills

Item	Group	Mean Rank	p	U
1. When we make contact asking for his/her attention, he/she stop what you are doing?	Control	8.77	.036	30.50
	Experimental	14.23		
2. When an explanation is made, he/she follows the interlocutor with his/her gaze	Control	8.32	.01	25.50
	Experimental	14.63		

items in this category (item 1: "When we establish contact asking for your attention, do you stop what you are doing?" and item 2: "When an explanation is given, do you follow the interlocutor with your gaze?") show that the *p* value is greater than 0.05. The Table 6 includes these results.

Therefore, there are no significant differences in the attentional skills of the participants in the control group before and after the intervention.

4. Differences in relation to attentional skills between the pre-test and the post-test in the experimental group.

Table 6 Pre-test and the post-test comparison in control group related to attention skills

Item		N	p
1. When we make contact asking for his/her attention, he/she stop what you are doing?	Negative Ranks	0	.32
	Positive Ranks	1	
	Ties	10	
	Total	11	
2. When an explanation is made, he/she follows the interlocutor with his/her gaze	Negative Ranks	0	.32
	Positive Ranks	1	
	Ties	10	
	Total	11	

Table 7 Pre-test and the post-test comparison in experimental group related to attention skills

Item		N	p
1. When we make contact asking for his/her attention, he/she stop what you are doing?	Negative Ranks	0	.01
	Positive Ranks	8	
	Ties	3	
	Total	11	
2. When an explanation is made, he/she follows the interlocutor with his/her gaze	Negative Ranks	0	.005
	Positive Ranks	9	
	Ties	2	
	Total	11	

Regarding the fourth specific objective, in the case of the experimental group, the results of the Friedman test indicated a p value of 0.00, indicating the presence of significant differences between the pre-test and post-test scores. Specifically, after conducting the Wilcoxon test, p values below 0.05 were obtained for both items related to attentional skills. The results are indicated in Table 7.

5. Differences in relation to basic social skills in the pre-test between the experimental group and the control group.

In accordance with the fifth specific objective, the analysis aimed to identify any significant differences between the pre-tests of the control group and the experimental group in terms of basic social skills. These results are presented in Table 8.

As indicated in Table 8, no significant differences were observed between the groups before the intervention. However, it is worth noting that the p values for items 3 and 4 were lower compared to items 5 and 6. Similarly, the difference in ranks was greater for items 3 and 4 than for the other items in the category. Consequently, the value of U was lower for the third and fourth items, which are related to basic social skills.

Table 8 Pre-test comparison between the control and experimental group in basic social skills

Item	Group	Mean rank	p	U
3. Say hello when he/she enters the classroom?	Control	9.50	.14	38.50
	Experimental	13.50		
4. When he/she leaves the classroom, he/she says goodbye	Control	9.45	.14	38.00
	Experimental	13.55		
5. When someone does something for him/her, he/she says thank you. (For example: hugs, smiles, "says thank you"…)	Control	11.27	.87	58.00
	Experimental	11.73		
6. Shows some sign of regret when he/she behaves inappropriately	Control	11.50	1.00	60.50
	Experimental	11.50		

Table 9 Post-tests comparison between the control and experimental group in basic social skills

Item	Group	Mean Rank	p	U
3. Say hello when he/she enters the classroom?	Control	9.45	.13	38.00
	Experimental	13.55		
4. When he/she leaves the classroom, he/she says goodbye	Control	9.23	.09	35.50
	Experimental	13.77		
5. When someone does something for him/her, he/she says thank you. (For example: hugs, smiles, "says thank you"…)	Control	10.18	.33	46.00
	Experimental	12.82		
6. Shows some sign of regret when he/she behaves inappropriately	Control	10.14	.31	45.50
	Experimental	12.86		

6. Differences in relation to basic social skills in the post-tests between the experimental group and the control group.

In relation to the differences between groups after the intervention in basic social skills (specific objective 6), the results of the Mann–Whitney U test indicate p values greater than 0.05. Specifically, the Table 9 reflects the values obtained.

Table 10 Pre-test and the post-test comparison in control group related to basic social skills

Item	Group	N	p
3. Say hello when he/she enters the classroom?	Negative ranks	0	.16
	Positive ranks	2	
	Ties	9	
	Total	11	
4. When he/she leaves the classroom, he/she says goodbye	Negative ranks	0	.16
	Positive ranks	2	
	Ties	9	
	Total	11	
5. When someone does something for him/her, he/she says thank you. (For example: hugs, smiles, "says thank you"…)	Negative ranks	0	1.00
	Positive ranks	0	
	Ties	11	
	Total	11	
6. Shows some sign of regret when he/she behaves inappropriately	Negative ranks	0	.32
	Positive ranks	1	
	Ties	10	
	Total	11	

The results indicate that there are no significant differences between the groups in any of the items within the basic social skills category.

7. Differences in relation to basic social skills between the pre-test and the post-test in the control group.

Addressing the seventh specific research objective, the results concerning potential significant intra-group differences in the basic social skills of the participants in the control group are as follows. The Friedman test yielded a p value of 0.80, indicating no significant differences. After conducting the Wilcoxon test for each item related to basic social skills, it was observed that the p values were greater than 0.05 for all items. Table 10 shows these data in concrete terms.

The Table 10 shows that there are no significant differences between pre-test and the post-test in the control group regarding basic social skills category.

8. Differences in relation to basic social skills between the pre-test and the post-test in the experimental group.

Table 11 Pre-test and the post-test comparison in experimental group related to basic social skills

Item	Group	N	p
3. Say hello when he/she enters the classroom?	Negative Ranks	0	.02
	Positive Ranks	7	
	Ties	4	
	Total	11	
4. When he/she leaves the classroom, he/she says goodbye	Negative Ranks	0	.02
	Positive Ranks	7	
	Ties	4	
	Total	11	
5. When someone does something for him/her, he/she says thank you. (For example: hugs, smiles, "says thank you"…)	Negative Ranks	0	.32
	Positive Ranks	1	
	Ties	10	
	Total	11	
6. Shows some sign of regret when he/she behaves inappropriately	Negative Ranks	0	.07
	Positive Ranks	4	
	Ties	7	
	Total	11	

The results of the eighth specific research objective revealed significant differences in basic social skills between the pre-test and post-test scores for participants in the experimental group, as determined by the Friedman test ($p = 0.015$). To identify the specific items where differences were observed, the Wilcoxon test was conducted, which indicated significant differences for two items. The results are shown in Table 11.

The results in the Table 11 demonstrate difference between the pre-test and post-test in the item 3 ("Say hello when he/she enters the classroom?") and item 4 ("When he/she leaves the classroom, he/she says goodbye") scores, with p values less than 0.05.

9. Differences in relation to conversational skills in the pre-test between the experimental group and the control group.

To address the ninth specific research objective regarding the differences in conversation skills between the control and experimental groups before the intervention, the results are presented in Table 12.

Based on the results in Table 12, all p values for the items in the "conversational skills" category are greater than 0.05, indicating that there are no significant differences.

10. Differences in relation to conversational skills in the post-tests between the experimental group and the control group.

Regarding the tenth specific research objective, the results of the Mann–Whitney U-test comparing the post-test scores

Table 12 Pre-test comparison between the control and experimental group in conversation skills

Item	Group	Mean rank	p	U
7. Uses language to make requests	Control	9.14	.80	34.50
	Experimental	13.86		
8. Uses the language to ask	Control	10.32	.38	47.50
	Experimental	12.68		
9. Uses language to say no	Control	9.50	.13	38.50
	Experimental	13.50		
10. Uses language to express ideas, experiences, desires…	Control	10.27	.35	47.00
	Experimental	12.73		
11. Responds to questions in a meaningful way	Control	8.86	.56	31.50
	Experimental	14.14		
12. Maintains a topic of conversation in accordance with the question asked	Control	9.18	.75	35.00
	Experimental	13.82		

Table 13 Post-test comparison between the control and experimental group in conversation skills

Item	Group	Mean Rank	*p*	U
7. Uses language to make requests	Control	8.91	.05	32.00
	Experimental	14.09		
8. Uses the language to ask	Control	10.18	.32	46.00
	Experimental	12.82		
9. Uses language to say no	Control	9.36	.11	37.00
	Experimental	13.64		
10. Uses language to express ideas, experiences, desires…	Control	9.91	.23	43.00
	Experimental	13.09		
11. Responds to questions in a meaningful way	Control	8.95	.05	32.50
	Experimental	14.05		
12. Maintains a topic of conversation in accordance with the question asked	Control	9.18	.07	35.00
	Experimental	13.82		

between the control group and the experimental group in conversational skills reveal no significant differences, despite the control group having a lower mean rank compared to the experimental group. In all cases, the *p* value is equal to or greater than 0.05, as can be seen in Table 13.

11. Differences in relation to conversational skills between the pre-test and the post-test in the control group.

Table 14 Pre-test and the post-test comparison in control group related to conversation skills

Item		N	*p*
7. Uses language to make requests	Negative Ranks	0	1.0
	Positive Ranks	0	
	Ties	11	
	Total	11	
8. Uses the language to ask	Negative Ranks	0	1.0
	Positive Ranks	0	
	Ties	11	
	Total	11	
9. Uses language to say no	Negative Ranks	0	.32
	Positive Ranks	1	
	Ties	10	
	Total	11	
10. Uses language to express ideas, experiences, desires…	Negative Ranks	0	1.0
	Positive Ranks	0	
	Ties	11	
	Total	11	
11. Responds to questions in a meaningful way	Negative Ranks	0	.32
	Positive Ranks	1	
	Ties	10	
	Total	11	
12. Maintains a topic of conversation in accordance with the question asked	Negative Ranks	0	.32
	Positive Ranks	1	
	Ties	10	
	Total	11	

There are no significant differences observed after applying the Friedman test ($p = 0.81$). The results obtained by the participants in the control group in relation to conversational skills (the eleventh specific objective of the research) are displayed in Table 14.

As can be seen in Table 14, the values of these items are greater than a.05.

12. Differences in relation to conversational skills between the pre-test and the post-test in the experimental group.

Continuing with the intra-group analysis of the experimental group concerning communication skills (twelfth specific research objective), the Friedman test reveals significant differences with a *p* value of less than 0.05 between the pre-test and post-test scores ($p = 0.000$; $X^2 = 50.23$). Subsequent application of the Wilcoxon test confirms significant differences in items 7, 9, 10, 11, and 12. Specifically, the results are presented in Table 15.

Table 15 Pre-test and the post-test comparison in experimental group related to conversation skills

Item		N	p
7. Uses language to make requests	Negative Ranks	0	.02
	Positive Ranks	6	
	Ties	5	
	Total	11	
8. Uses the language to ask	Negative Ranks	0	.83
	Positive Ranks	3	
	Ties	8	
	Total	11	
9. Uses language to say no	Negative Ranks	0	.04
	Positive Ranks	5	
	Ties	6	
	Total	11	
10. Uses language to express ideas, experiences, desires…	Negative Ranks	0	.03
	Positive Ranks	5	
	Ties	6	
	Total	11	
11. Responds to questions in a meaningful way	Negative Ranks	0	.02
	Positive Ranks	6	
	Ties	5	
	Total	11	
12. Maintains a topic of conversation in accordance with the question asked	Negative Ranks	0	.02
	Positive Ranks	6	
	Ties	5	
	Total	11	

13. Differences in relation to emotion identification and discrimination skills in the pre-test between the experimental group and the control group.

Regarding the results pertaining to the thirteenth specific objective, which examines whether there are differences between the two groups before the intervention in terms of emotion identification and discrimination skills, the findings indicate no significant disparities between the groups ($p > 0.05$). These results are outlined in Table 16 below.

14. Differences in relation to emotion identification and discrimination skills in the post-tests between the experimental group and the control group.

Addressing the fourteenth research objective, the results reveal significant intergroup differences in three items within the emotion identification and discrimination category. These results can be seen in Table 17.

Specifically, differences are observed in items 14 ($p = 0.03$), 15 ($p = 0.02$), and item 16 ($p = 0.02$).

Table 16 Pre-test comparison between the control and experimental group in emotion identification and discrimination skills

Item	Group	Mean rank	p	U
13. Identifies the name of the basic emotions with pictograms	Control	10.27	0.34	47.00
	Experimental	12.73		
14. Identifies the name of basic emotions with pictures	Control	10.23	0.321	46.50
	Experimental	12.77		
15. Identifies the name of the basic emotions through facial expressions of their environment	Control	10.91	0.639	54.00
	Experimental	12.09		
16. Discriminates between different emotions	Control	9.36	0.096	37.00
	Experimental	13.64		
17. Connects various emotional situations	Control	9.36	0.096	36.00

Table 17 Post-test comparison between the control and experimental group in emotion identification and discrimination skills

Item	Group	Mean rank	p	U
13. Identifies the name of the basic emotions with pictograms	Control	10.18	.29	46.00
	Experimental	12.82		
14. Identifies the name of basic emotions with pictures	Control	8.82	.03	31.00
	Experimental	14.18		
15. Identifies the name of the basic emotions through facial expressions of their environment	Control	8.59	.02	28.50
	Experimental	14.41		
16. Discriminates between different emotions	Control	8.45	.02	27.00
	Experimental	14.55		
17. Connects various emotional situations	Control	9.14	.07	34.50
	Experimental	13.86		

15. Differences in relation to emotion identification and discrimination skills between the pre-test and the post-test in the control group.

Table 18 Pre-test and the post-test comparison in control group related to emotion identification and discrimination skills

Item		N	*p*
13. Identifies the name of the basic emotions with pictograms	Negative Ranks	0	.02
	Positive Ranks	6	
	Ties	5	
	Total	11	
14. Identifies the name of basic emotions with pictures	Negative Ranks	0	.32
	Positive Ranks	1	
	Ties	10	
	Total	11	
15. Identifies the name of the basic emotions through facial expressions of their environment	Negative Ranks	0	.16
	Positive Ranks	2	
	Ties	9	
	Total	11	
16. Discriminates between different emotions	Negative Ranks	0	.16
	Positive Ranks	2	
	Ties	9	
	Total	11	
17. Connects various emotional situations	Negative Ranks	0	.16
	Positive Ranks	2	
	Ties	9	
	Total	11	

Table 19 Pre-test and the post-test comparison in experimental group related to emotion identification and discrimination skills

Item		N	*p*
13. Identifies the name of the basic emotions with pictograms	Negative Ranks	0	.04
	Positive Ranks	5	
	Ties	6	
	Total	11	
14. Identifies the name of basic emotions with pictures	Negative Ranks	0	.06
	Positive Ranks	4	
	Ties	7	
	Total	11	
15. Identifies the name of the basic emotions through facial expressions of their environment	Negative Ranks	0	.04
	Positive Ranks	5	
	Ties	6	
	Total	11	
16. Discriminates between different emotions	Negative Ranks	0	.03
	Positive Ranks	6	
	Ties	5	
	Total	11	
17. Connects various emotional situations	Negative Ranks	0	.02
	Positive Ranks	6	
	Ties	5	
	Total	11	

Regarding the results of the non-parametric test conducted to address the fifteenth specific objective, significant differences were observed in the control group between the pre-test and post-test scores. The Friedman test yielded a significant p value of 0.00. Specifically, the Wilcoxon test indicated significant differences in item 13 ("Identifies the names of basic emotions with pictograms") with a p value of 0.02. This result is supported by the fact that six participants (54.55% of the sample) displayed a positive increase from the pre-test. For the remaining items in the category, the p values were greater than 0.05, as can be seen in Table 18.

16. Differences in relation to emotion identification and discrimination skills between the pre-test and the post-test in the experimental group.

Lastly, the findings pertaining to the sixteenth specific objective are presented, which focuses on the comparison of pre-test and post-test scores within the experimental group. The Friedman test yielded significant differences ($p = 0.00$). The Wilcoxon test indicated that the significant differences. These results are presented in Table 19.

3.1 Discussion

The main objective of this research has been to apply the Bee-Bot robot in an educational context to develop socioemotional reciprocity responses in students with Autism Spectrum Disorder (ASD). In this regard, regarding the first objective, it is observed that there were no significant differences in attention skills between the control group and the experimental group before starting the intervention. No significant differences were also found between the pre-tests in the results of objectives 5 (focus on basic social skills), 9 (focus on conversational skills), and 13 (focus on identifying and discriminating emotions). Therefore, as indicated by Hamuddin et al. [83], obtaining a significance value (p) greater than 0.05 indicates that there are no significant differences between the groups and that the distribution is homogeneous. Although the sample of students with ASD showed different individual characteristics, the participants were evenly distributed in the two groups [84]. According to the report by Lorenzo et al. [85], these results are due to the presence of ASD behaviors present at all levels. The findings of this research are consistent with other studies with the same research design and the same type of participants, such as Lorenzo et al. [85] and Lorenzo et al. [86].

Regarding the second specific objective of the research, the results indicate significant differences in attention skills ($p < 0.05$) between the control group and the experimental group that used the robot. These results suggest that robotics led to improvements in attention skills. These differences could be attributed to the external appearance of the robot (colors, lights, rotational mechanics) [87] and its non-anthropomorphic structure [47]. In this sense, these results align with Carlson et al. [88], who demonstrated the usefulness of a non-anthropomorphic animal-shaped robot in capturing the attention of students with ASD.

Furthermore, the findings regarding the third objective indicate that there were no significant differences in attention skills between the beginning and the end of the intervention in the control group. These results, according to Liss et al. [89], could be caused by the restrictive interests specific to students with ASD since if the stimuli are outside the attention focus of the student with ASD, the student will show little reaction to that stimulus. Our results are consistent with those of Hamada & Ahmedb [90], who showed that after their intervention, the control group that used traditional teaching did not experience significant differences in attention-related skills, such as perceptual skills.

Additionally, according to the fourth specific objective, significant improvements in attention skills were found in the experimental group between the pre-test and post-test scores. According to Duquette et al. [32], these results could be attributed to the simplicity and predictability features of robots, which seem to help students with ASD focus their attention on them. These findings are in line with Srinivasan and Bhat [91], who demonstrated that children with ASD, after being exposed to the robot, showed increased attention to the environment after weeks of training.

Regarding the sixth specific objective, the results indicate that there were no significant differences between the experimental group and the control group in the use of basic social skills after the intervention. There are two reasons to explain the results of the proposed research. First, the lack of affective behavior and intelligence of the Bee-Bot, and its inability to react to user behavior [92]. Second, the fact that this floor robot is not equipped with human facial features (mouth, eyes, nose, etc.) [93], which allows students with ASD to develop basic social skills with robots. The results of the present research align with those presented by Tapus et al. [94], who showed that students with ASD did not significantly improve social skills after the application of a robot.

According to the seventh specific objective, the results showed no significant change in basic social skills between the pre-test and post-test scores within the control group. The absence of statistically significant differences, as mentioned by Robins et al. [25], could be attributed to the unpredictable nature of human behavior for students with Autism Spectrum Disorder (ASD). Social interactions in various contexts, such as school, pose challenges for these students. Learning requires social interaction, and if students with ASD do not have control over their environment, their learning process becomes difficult. These findings are consistent with those presented by Lorenzo et al. [86], who demonstrated that the control group, which did not use technology, did not show significant improvement in their social skills. However, throughout the sessions, it was observed that the students paid attention to the toy when they saw it, maintained eye contact with the activities, and desired to repeat the activities as the sessions progressed. This observation could be related to the lack of a positive reinforcer such as the Bee-Bot robot [95].

Regarding the results of the eighth specific objective, the experimental group showed significant improvements ($p < 0.05$) in both the ability to greet upon entering the classroom and the ability to say goodbye between pre-test and post-test scores. These improvements could be related to the intrinsic motivation of using robots in children with Autism Spectrum Disorder (ASD) [96]. In this regard, Pop et al. [97] conducted research that aligns with the current findings, demonstrating that the control group improved their social skills (expressing gratitude or saying goodbye). Additionally, another factor contributing to these results could be associated with the percentage of women comprising our experimental group, which was higher than the percentage in the control group. Some studies [98, 99] suggest that there are differences in the manifestation and degree of these difficulties between genders. The results of Carter et al. [98], indicated that girls with ASD showed a greater inclination to engage in social interactions compared to boys with ASD.

Regarding the tenth specific objective, no significant differences were observed in the post-test between the experimental group and the control group in terms of communication skills. These results support previous research, such as Owens et al. [100], who found no significant differences in communication between the experimental and control groups. The explanation for this lack of significant growth may be attributed to the heterogeneity of communication skills among students with ASD and their initial training, which makes it challenging to individualize the intervention program at such a specific level [101]. Additionally, another reason could be related to the robot's lack of ability to interact with people through sensors or voice recognition, as the use of other robots with this feature in previous research [35, 36] showed improvements in communication skills among students with ASD. Finally, it should be noted that despite an average age difference of approximately three years between the control and experimental groups in the sample, in line with studies by Strofylla et al. [102] and Uljarevic and Hamilton [103], age has also not been a determining factor that has resulted in significant differences.

The findings, in accordance with the eleventh specific objective, indicate that students with ASD in the control group show no significant differences in conversational skills between the pre-test and post-test. These findings may have been influenced by the individual characteristics of the sample [88]. In this regard, modes of communication such as verbal communication or tablet-assisted communication may have influenced these results. Another reason for these results could be related to the fact that teaching in the natural environment is sometimes challenging and presents fewer opportunities for learning [104]. Therefore, as Hayward et al. [104] suggest, in order to achieve greater effectiveness, teaching through discrete trials should be increased. This method can be broken down into smaller components and practiced repeatedly until mastery is achieved.

According to the twelfth specific objective, the experimental group showed significant differences in conversational skills between the pre-test and post-test. These results are in line with those reported by Carlson et al. [88], who suggest that the cause of these results is related to individual variations related to the level of ASD of the participants. The results of this research are consistent with those of Kim et al. [35], as they show that animal-shaped robots act as communication reinforcers for students with ASD. Furthermore, this animal-shaped structure may have acted as a tangible reinforcer [95]. In this way, the Bee-Bot robot could explain the relationship between these findings and the use of the technological tool.

Considering the fourteenth specific research objective, the results show significant improvements in the experimental group in items 14, 15, and 16 related to emotion identification and discrimination. These results indicate that robotics led to improvements in emotion identification skills. These significant improvements could be related, on the one hand, to the design of activities based on the characteristics and needs of students with ASD, using visual support and a helpful robot, allowing the creation of simple and engaging activities [11]. In line with the findings of Lorenzo et al. [86], the visual supports provided through the activities offer a logical pathway to facilitate information processing for students with ASD, as these students tend to think in images. Therefore, these results could be attributed to the use of such supports for programming the robot in steps. On the other hand, the creation of a context of activities in which these students can acquire the necessary skills [105] could have contributed to these results. It is worth noting that these findings align with those obtained by Pop et al. [105], who demonstrated an increase in the ability of students with ASD to identify basic emotions such as sadness and happiness following an intervention with a robot.

Regarding the fifteenth specific objective, the significant differences in the scores of the control group in the item related to the identification of basic emotion names through pictograms, similar to the control group, could be explained by the use of these visual aids throughout the sessions. This positive result could be related to the visual thinking of students with ASD, who process information better when exemplified in images or pictograms [106].

Considering the sixteenth specific objective, the significant differences found between the pre-test and post-test scores of the experimental group may be related to the materials used during the Bee-Bot sessions. As stated by Schina et al. [107], the effective integration of this robot not only depends on the robot itself, but also on the design of activities that engage and have a positive outcome on perseverance and response to classroom activities. These results are in line with Wang et al. [108].

4 Conclusion

This study has shown highlights the fact that the use of Educational Robotics (ER) is as a mediating learning tool to improve capacity for socio-emotional reciprocity of students with ASD. In this sense, the robot Bee-Bot is a useful resource to improve communication and social interaction skills for the inclusion of these students in the classrooms. Based in this study and in line with specific objectives and the findings of the study, the following conclusions are drawn:

1. There are no significant deviations in relation with attentional skills in the pre-test between the experimental group and the control group ($p > 0.05$).
2. Attentional skills of students with ASD have been improved significantly ($p < 0.05$) after the intervention with the Bee-Bot robot, in terms of post-test comparison. These gains have focused on, for instance, the ability to follow the interlocutor with gaze when he/she is making an explanation ($p = 0.01$).
3. The control group has not shown significant differences in attentional skills between pre-test and post-test.
4. The experimental group reported significant differences in attentional skills between the pre-test and the post-test, among which the ability to follow the interlocutor with the gaze when he/she is making an explanation was found to have a lower significance value ($p = 0.005$).
5. There are no significant differences in relation with basic social skills in the pre-test between the experimental group and the control group ($p > 0.05$).
6. Basic social skills of the students with ASD have not significantly improved after the intervention with the Bee-Bot robot with respect to the control group ($p > 0.05$).
7. In terms of basic social skills, the non-robotic intervention has not led to significant improvements between before and after the experience.
8. According to basic social skills, the robotic intervention resulted in a significant improvement in skills such as

saying hello ($p = 0.02$) and saying goodbye ($p = 0.02$), between before and after the experience.

9. There are no significant deviations in relation with conversational skills between the experimental group and the control group ($p > 0.05$) in terms of pre-test comparison.
10. Conversational skills of students with ASD have not been improved significantly ($p > 0.05$) after the intervention with the Bee-Bot robot in terms of post-test comparison.
11. There was no improvement in conversational skills between pretest and posttest in the control group.
12. To identify possible differences in relation with conversational skills between the pre-test and the post-test in the experimental group.
13. No significant differences were shown between the pre-tests of the control group and the experimental group, according to emotion identification and discrimination skills.
14. The robotic intervention has been successful related to emotion identification and discrimination skills of students with ASD in terms of significant differences in the post-test ($p < 0.05$). The skill that showed the lowest p value of significance was the ability to discriminate emotions ($p = 0.02$).
15. The control group shows significant different, with respect to its pre-test scores, in only one item of emotion identification and discrimination skills which refers to the ability to identify the name of emotions through pictograms ($p = 0.02$).
16. Significant differences were observed between the pre-test and post-test score of experimental group in the identification of emotions with pictograms and through facial expressions, as well as in the skills of discrimination and relating to various emotional situations.

Last but not least, the research developed highlights the impact that the robotics application can have on the current inclusive educational model, as a motivating tool for children with ASD (with a familiar and close image for children), very manipulative (easy, small and structured) and easily adaptable to the visual and structured learning activities required for these students. The above conclusions must be assessed in the light of the constraints. In this sense, there were several limitations to this study. Firstly, the size of the sample is limited to 22 participants distributed into experimental and control group. This aspect made the generalization of results more difficult. Secondly and in line with the first limitation, it can be distinguished a lack of equal numbers of participants by age, ASD level and gender. Thirdly, the number of sessions could be improved with the aim to work determine items in a more focused way. And, finally, the lack of a retrospective video analysis and the use of electronic devices to automatically record learners' reactions could be the biases of the research. Nevertheless, new lines of research could complement the findings of this research. On the one hand, an enlargement of the sample and an extension of educational intervention, which would allow for a generalisation of the results to other contexts. Furthermore, after having seen the potential of the Bee-Bot robot and the needs of students with ASD, the pedagogical education line could be used to work on executive functions, another area that influences the pedagogical development of these students and that it could complement these results by adopting a multidisciplinary approach. Moreover, the proposed programme of activities could be adapted to another type of robot. This time a Social Assistive Robot (SAR). These robots bring together a wide range of possibilities, as they are much more human-like and can allow students with ASD to practice real-life social situations in a controlled context.

Several practical implications can be drawn from this research. The protocol of structured tasks designed for the use of the Bee-Bot robot can be transferred to educational classrooms in order to teach social-emotional reciprocity skills to students with ASD. These classrooms can be both regular and special education classrooms. In this sense, when asked how the activity protocol should be integrated into the classroom, the authors recommend having, in the first place, several Bee-Bot robots. These robots should be introduced as classroom mascots. In this way, the robots can be introduced into the classroom routines, allowing students with ASD to become familiar with this type of technological tools. Secondly, in terms of the space required, the classrooms should have a technological corner where the Bee-Bot robots are available to the students and where the activities of the protocol included in this research article can be carried out. Thirdly, the application of robots for teaching these skills should be reflected in the school's organisational documents and, specifically, in the classroom programmes. However, for this educational practice to become a reality, it requires, on the one hand, the provision of resources and, on the other hand, training for the teachers in charge of these activities. In this respect, it is worth mentioning that this is a technological tool with an affordable cost for use in the classrooms of educational centres, which means that the outlay will not be very high. Finally, with regard to the training required, teachers need to know how the robot works and its characteristics (parts of the robot, how to load the robot, how to program the robot…).

Acknowledgements The authors would like to thank the schools involved in the research, as well as the families and the pupils themselves for their trust and good cooperation throughout the process.

Declarations

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

References

1. Lorenzo G, Lledó A, Pérez-Vázquez E, Lorenzo-Lledó A (2021) Action protocol for the use of robotics in students with Autism spectrum disoders: a systematic-review. Educ Inf Techn 26(1):16
2. Gómez MRD, Gómez JIA (2010) La institucionalización de la teleformación en las universidades andaluzas. RUSC 7:1
3. Pennisi P, Tonacci A, Tartarisco G, Billeci L, Ruta L, Gangemi S, Pioggia G (2016) Autism and social robotics: a systematic review. Autism Res 9:165–183. https://doi.org/10.1002/aur.1527
4. Josman N, Ben-Chaim HM, Friedrich S, Weiss PL (2008) Effectiveness of virtual reality for teaching street-crossing skills to children and adolescents with autism. Int J Disabil Hum Dev 7:49–56. https://doi.org/10.1515/IJDHD.2008.7.1.49
5. Grossard C, Palestra G, Xavier J, Chetouani M, Grynszpan O, Cohen D (2018) ICT and autism care: state of the art. Curr Opin Psychiatry 31:474–483. https://doi.org/10.1097/YCO.0000000000000455
6. Comfort T, Tierney D (2007) We have the technology: using ICT to enhance primary languages. CILT
7. Durán S (2021) Tecnologías para la enseñanza y el aprendizaje del alumnado con Trastorno del Espectro Autista: una revisión sistemática. Int J Tech Educ Inn 7:107–121
8. Mubin O, Stevens CJ, Shahid S, Al Mahmud A, Dong JJ (2013) A review of the applicability of robots in education. J Technol Sci Educ 1:13
9. Sánchez Sánchez T, Serrano Sánchez JL, Rojo Acosta F (2020) Influencia de la robótica educativa en la motivación y el trabajo cooperativo en Educación Primaria: un estudio de caso. Int J Tech Educ Inn 6:141–152
10. Blackley S, Howell J (2019) The next chapter in the STEM education narrative: using robotics to support programming and coding. Aust J Teach Educ 44:51–64
11. Bargagna S, Castro E, Cecchi F, Cioni G, Dario P, Dell'Omo M, Di Lieto MC, Inguaggiato E, Martinelli A, Pecini C, Sgandurra G (2019) Educational robotics in down syndrome: a feasibility study. Technol Knowl Learn 24:315–323
12. Pinto MSM, Osório AJ (2019) Aprender a programar en Educación Infantil: análisis con la escala de participación. Pixel-Bit 55:133–156
13. Vitanza A, Rossetti P, Mondada F, Trianni V (2019) Robot swarms as an educational tool: The Thymio's way. Int J Adv Rob Syst 16:1729881418825186
14. Pérez-Vázquez E, Lorenzo G, Lledó A (2021) Aplicación del robot Bee-Bot en las aulas de Educación Infantil y Educación Primaria: Una revisión sistemática desde el año 2016. In Convergencia entre educación y tecnología: hacia un nuevo paradigma (pp. 687–691)
15. Janka P (2008) Using a programmable toy at preschool age: Why and how. In Teaching with robotics: didactic approaches and experiences. In Workshop of International conference on simulation, modeling and programming autonomous robots (pp. 112–121)
16. Rogers J, Revesz A (2020) Experimental and quasi-experimental designs. Routledge
17. Ovalles A, Luna R, Pérez K (2018) Pedagogical model with educational robotics as didactic support in primary mathematics teaching. Educ Sup 25:11–29
18. García SA, Sánchez PA (2020) La escolarización del alumnado con necesidades educativas especiales en España: Un estudio longitudinal. Rev colomb educ 1:78
19. Ziats CA, Patterson WG, Friez M (2021) Syndromic autism revisited: review of the literature and lessons learned. Pediatr Neurol 114:21–25
20. Schwartz L, Beamish W, McKay L (2021) Understanding social-emotional reciprocity in autism: viewpoints shared by teachers. Aust J Teach Educ 46:24–38
21. Lemoine L, Schneider B (2021) Autism spectrum disorder in French children's literature: an analysis of portrayals of children with autism in the light of the DSM-5. Res Autism Spectr Disord 80:101675
22. Crowell C, Mora-Guiard J, Pares N (2019) Structuring collaboration: multi-user full-body interaction environments for children with autism spectrum disorder. Res Autism Spectr Disord 58:96–110
23. Ginestar M, Pastor-Cerezuela G, Tijeras-Iborra A, Fernandez-Andres MI (2019) Effectiveness of social stories in intervention in autistic spectrum disorder: a review. Papeles del Psicol 40:217–225
24. Cerbo SN, Rabi NM (2019) Drama activities as tool for socialization of learners with Autism. Int J Acad Res Bus Soc Sci 9:1250–1261
25. Robins B, Dautenhahn K, Dubowski J (2006) Does appearance matter in the interaction of children with autism with a humanoid robot? Interact Stud 7:479–512. https://doi.org/10.1075/is.7.3.16rob
26. Costescu CA, David DO (2014) Attitudes toward using social robots in psychotherapy. Transylvanian Rev 15:1
27. Boccanfuso L, Scarborough S, Abramson RK, Hall AV, Wright HH, O'Kane JM (2017) A low-cost socially assistive robot and robot-assisted intervention for children with autism spectrum disorder: field trials and lessons learned. Auton Robot 41:637–655
28. Hart M (2005) Autism/excel study. In Proceedings of the 7th International ACM SIGACCESS conference on computers and accessibility (pp. 136–141)
29. Matsuda S, Nunez E, Hirokawa M, Yamamoto J, Suzuki K (2017) Facilitating social play for children with PDDs: effects of paired robotic devices. Front Psychol 8:1029. https://doi.org/10.3389/fpsyg.2017.01029
30. Cabibihan JJ, Javed H, Ang M, Aljunied SM (2013) Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism. Int J Soc Robot 5:593–618. https://doi.org/10.1007/s12369-013-0202-2
31. Pioggia G, Igliozzi R, Ferro M, Ahluwalia A, Muratori F, De Rossi D (2005) An android for enhancing social skills and emotion recognition in people with autism. IEEE Trans Neural Syst Rehabil Eng 13:507–515. https://doi.org/10.1109/TNSRE.2005.856076
32. Duquette A, Michaud F, Mercier H (2008) Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. Auton Robot 24:147–157
33. Stanton CM, Kahn PH, Severson RL, Ruckert JH, Gill BT (2008) Robotic animals might aid in the social development of children with autism. In 2008 3rd ACM/IEEE international conference on human-robot interaction (HRI) (pp. 271–278). https://doi.org/10.1145/1349822.1349858
34. Costescu CA, Vanderborght B, David DO (2015) Reversal learning task in children with autism spectrum disorder: a robot-based approach. J Autism Dev Disord 45:3715–3725
35. Kim ES, Berkovits LD, Bernier EP, Leyzberg D, Shic F, Paul R, Scassellati B (2013) Social robots as embedded reinforces of social behavior in children with autism. J Autism Dev Disord 43:1038–1049. https://doi.org/10.1007/s10803-012-1645-2

36. Wong HYA, Zhong ZW (2016) Assessment of robot training for social cognitive learning. In 2016 16th international conference on control, automation and systems (ICCAS) (pp. 893–898). IEEE. https://doi.org/10.1109/ICCAS.2016.7832420
37. Simut RE, Vanderfaeillie J, Peca A, Van de Perre G, Vanderborght B (2016) Children with autism spectrum disorders make a fruit salad with Probo, the social robot: an interaction study. J Autism Dev Disord 46:113–126
38. Bharatharaj J, Huang L, Mohan RE, Al-Jumaily A, Krägeloh C (2017) Robot-assisted therapy for learning and social interaction of children with autism spectrum disorder. Robot 6:4. https://doi.org/10.3390/robotics6010004
39. Goodrich MA, Colton M, Brinton B, Fujiki M, Alan Atherton J, Robinson L, Acerson A (2012) Incorporating a robot into an autism therapy team. IEEE Intell Syst 27:52. https://doi.org/10.1109/MIS.2012.40
40. Huijnen CA, Lexis MA, Jansens R, de Witte LP (2017) How to implement robots in interventions for children with autism? A co-creation study involving people with autism, parents and professionals. J Autism Dev Disord 47:3079–3096. https://doi.org/10.1007/s10803-017-3235-9
41. Zhang Y, Song W, Tan Z, Zhu H, Wang Y, Lam CM, Weng Y, Hoi SP, Lu H, Chan BSM, Chen J, Yi L (2019) Could social robots facilitate children with autism spectrum disorders in learning distrust and deception? Comput Hum Behav 98:140–149. https://doi.org/10.1016/j.chb.2019.04.008
42. Feil-Seifer D, Mataric MJ (2005) Defining socially assistive robotics. In 9th international conference on rehabilitation robotics, 2005. ICORR 2005 (pp. 465–468). IEEE
43. Pinel V, Rendon LA, Adrover-Roig D (2018) Los robots sociales como promotores de la comunicación en los Trastornos del Espectro Autista (TEA). Let Hoje 53:39–47. https://doi.org/10.15448/1984-7726.2018.1.28920
44. Shamsuddin S, Yussof H, Hanapiah FA, Mohamed S, Jamil NFF, Yunus FW (2015) Robot-assisted learning for communication-care in autism intervention. In 2015 IEEE international conference on rehabilitation robotics (ICORR) (pp. 822–827). IEEE. https://doi.org/10.1109/ICORR.2015.7281304
45. McDougal E, Riby DM, Hanley M (2020) Teacher insights into the barriers and facilitators of learning in autism. Res Autism Spect Disorders 79:101674
46. Koenig KP, Bleiweiss J, Brennan S, Cohen S, Siegel DE (2009) The ASD nest program: a model for inclusive public education for students with autism spectrum disorders. Teach Except Child 42(1):6–13
47. Kozima H, Michalowski MP, Nakagawa C (2009) A playful robot for research therapy and entertainment. Int J Soc Robot 1:3–18. https://doi.org/10.1007/s12369-008-0009-8
48. Dahnial I (2021) The effect of online learning based on socio scientific issues (SSi) on improving learning independence and critical thinking students faculty of education and education science Universitas Muhammadiyah Sumatera Utara in The Pandemic Covid-19. EduTech 7:145–152
49. American Psychiatric Association (2013) Diagnostic and statistical manual of mental disorders, 5th edn. American Psychiatric Association, Washington, DC
50. Oakland T, Harrison P (2013) ABAS-II. Sistema de Evaluación de la Conducta Adaptativa. Madrid: Tea Ediciones. Recuperado de https://goo.gl/RG5SSF
51. Hernández-Sampieri R, Fernández-Collado C, Baptista-Lucio P (2017) Definición conceptual o constitutiva. McGraw-Hill, México
52. Øzerk K, Özerk G, Silveira-Zaldivar T (2021) Developing social skills and social competence in children with Autism. Int Electron J Elem 13:341–363
53. León F (2019) Autism, social connectedness, and minimal social acts. Adapt Behav 27:75–89
54. Dawson G, Rogers S, Munson J, Smith M, Winter J, Greenson J, Donaldson A, Varley J (2010) Randomized, controlled trial of an intervention for toddlers with autism: the early start Denver model. Pediatrics 125:e17–e23
55. Almenara JC, Cejudo MDCL (2013) La aplicación del juicio de experto como técnica de evaluación de las tecnologías de la información y comunicación (TIC). Rev de Eduw 7:11–22
56. Aiken LR (1985) Three coefficients for analyzing the reliability and validity of ratings. Educ Psychol Meas 45:131–142
57. Retnawati H (2016) Proving content validity of self-regulated learning scale (The comparison of Aiken index and expanded Gregory index). REiD 2:155–164
58. Pastor BFR (2018) Índice de validez de contenido: Coeficiente V de Aiken. Pueblo cont 29:193–197
59. Merino C, Livia J (2009) Confidence intervals for the content validity: a visual basic computer program for the Aiken's V. An de Psicol 25:159–161
60. Penfield RD, JrPR G (2004) Applying a score confidence interval to Aiken's item content-relevance index. Meas Phys Educ Exerc Sci 8:213–225
61. Ahmed I, Ishtiaq S (2021) Reliability and validity: importance in medical research. JPMA 71:2401–4016
62. George D, Mallery P (2003) SPSS for Windows Step by Step: A Simple Guide and Reference. 11.0 Update. Boston: Allyn and Bacon
63. Chatterjee D, Corral J (2017) How to write well-defined learning objectives. JEPM 19(4)
64. Sewagegn AA (2020) Learning objective and assessment linkage: its contribution to meaningful student learning. Univ J Educ Res 8:5044–5052
65. Mantecón JMD, Blanco MTF, Laso ZO, Lavicza Z (2021) Proyectos STEAM con formato KIKS para el desarrollo de competencias clave. Comunicar 33–43
66. European Commission (2007) Competencias clave para el aprendizaje permanente. Un marco de referencia europeo. Luxemburgo: Oficina de Publicaciones Oficiales de las Comunidades Europeas. https://www.educacionyfp.gob.es/dctm/ministerio/educacion/mecu/movilidad-europa/competenciasclave.pdf?documentId=0901e72b80685fb1
67. Tiasari LA, Efendi M, Samawi A (2021) Effects of TEACCH model towards the eating skills on student with Autism. J Penel Peng Pend Luar Biasa 7
68. Mesibov GB, Shea V (2010) The TEACCH program in the era of evidence-based practice. Rev J Autism Dev Disord 3:570–579
69. Pratiwi MA, Sudirman S, Adnyani LS (2018) A study of the reinforcement used by english teacher in 6a Class at SD Lab Undiksha Singaraja. Lang Lit (Harlow) 2(3):117–124. https://doi.org/10.23887/ijll.v2i3.16317
70. Virués-Ortega J (2010) Applied behavior analytic intervention for autism in early childhood: meta-analysis, meta-regression and dose-response meta-analysis of multiple outcomes. Clin Psychol Rev 30:387–399. https://doi.org/10.1016/j.cpr.2010.01.008
71. Jabeen S, Kalsoom T, Nader M, Moazzam M (2021) Effect of positive reinforcement on social skills of students with autism spectrum disorder at primary level. LINGUISTICA ANTVERPIENSI*:* 2430–2441
72. Soares L, Ferrari V, Mastrogiuseppe M, Span S, Landoni M (2022) ACCESS+: Designing a museum application for people with intellectual disabilities. In International conference on computers helping people with special needs (pp. 425–431). Springer, Cham
73. Matos Y, Pasek E (2008) La observación, discusión y demostración: técnicas de investigación en el aula. Laurus 14:33–52

74. Fuertes MT (2011) La observación de las prácticas educativas como elemento de evaluación y de mejora de la calidad en la formación inicial y continua del profesorado. REDU 9:237–258
75. Hurtado JCT (1994) La observación en el ámbito educativo: proceso, plan de investigación y control de sesgos. REP 59–73
76. Lespinasse K, Matsui E, Nozaka E (2021) The pedagogical uses of Kamishibai, the Paper Theatre, in Asia. In Storytelling Pedagogy in Australia & Asia (pp. 75–102). Palgrave Macmillan, Singapore
77. Berlanga V, Rubio Hurtado MJ (2012) Clasificación de pruebas no paramétricas. Cómo aplicarlas en SPSS REIRE 2:101–113
78. Berger VW, Zhou Y (2014) Kolmogorov–smirnov test: overview. Wiley statsref: Statistics reference online
79. Shapiro SS, Wilk MB (1965) An analysis of variance test for normality (complete samples). Biometrika 52:591–611
80. Razali NM, Wah YB (2011) Power comparisons of shapiro-wilk, kolmogorov-smirnov, lilliefors and anderson-darling tests. Stat Modelling 2:21–33
81. Lind DA, Marchal WG, Wathen SA, Obón León MDP, León Cárdenas J (2012) Estadística aplicada a los negocios y la economía. México: McGraw-Hill/Interamericana Editores
82. Bird J (2019) Wilcoxon signed-rank test. In Mathematics pocket book for engineers and scientists (pp. 537–540). Routledge
83. Hamuddin B, Julita K, Rahman F, Derin T (2020) Artificial intelligence in EFL context: rising students' speaking performance with Lyra virtual assistance. Int J Adv Sci Technol 29:6735–6741
84. Sidiq Y, Ishartono N, Desstya A, Prayitno HJ, Anif S, Hidayat ML (2021) Improving elementary school students' critical thinking skill in science through hots-based science questions: a quasi-experimental study. J Pendidik IPA Indones 10:378–386
85. Lorenzo G, Lledó A, Gilabert-Cerdá A, Lorenzo-Lledó A (2022) The use of augmented reality to improve the development of activities of daily living in students with ASD. Educ Inf Technol 27:4865–4885
86. Lorenzo G, Gómez-Puerta M, Arráez-Vera G, Lorenzo-Lledó A (2019) Preliminary study of augmented reality as an instrument for improvement of social skills in children with autism spectrum disorder. Educ Inf Technol 24:181–204
87. Cao HL, Simut RE, Desmet N, De Beir A, Van De Perre G, Vanderborght B, Vanderfaeillie J (2020) Robot-assisted joint attention: a comparative study between children with autism spectrum disorder and typically developing children in interaction with NAO. IEEE Access 8:223325–223334
88. Carlson K, Wong AHY, Dung TA, Wong ACY, Tan YK, Wykowska A (2018) Training autistic children on joint attention skills with a robot. In: International conference on social robotics (pp. 86–92). Springer, Cham
89. Liss M, Saulnier C, Fein D, Kinsbourne M (2006) Sensory and attention abnormalities in autistic spectrum disorders. Autism 10:155–172
90. Hamada NJ, Ahmedb YB (2020) The effectiveness of the (TEACCH) program in developing the visual perception skills of autistic child. Inter J Innov Creat Change, 14(10)
91. Srinivasan S, Bhat A (2013) The effect of robot-child interactions on social attention and verbalization patterns of typically developing children and children with autism between 4 and 8 years. Autism 3:1–7
92. Cano S, González CS, Gil-Iranzo RM, Albiol-Pérez S (2021) Affective communication for socially assistive robots (SARs) for children with autism spectrum disorder: a systematic review. J Sens 21:5166
93. Syriopoulou-Delli CK, Gkiolnta E (2020) Review of assistive technology in the training of children with autism spectrum disorders. Int J Dev Disabil 1–13
94. Tapus A, Peca A, Aly A, Pop C, Jisa L, Pintea S, Rusu AS, David DO (2012) Children with autism social engagement in interaction with Nao, an imitative robot: a series of single case experiments. Interact Stud 13:315–347
95. Supariani NKLA, Padmadewi NN, Agustini DAE (2021) THE Identification of reinforcement used by english teacher for students with autism spectrum disorder (ASD). J Lang Lit 5(3):151–157
96. Chung EYH (2019) Robotic intervention program for enhancement of social engagement among children with autism spectrum disorder. J Dev Phys Disabil 31:419–434
97. Pop CA, Simut RE, Pintea S, Saldien J, Rusu AS, Vanderfaeillie J, David DO, Lefeber D, Vanderborght B (2013) Social robots vs. computer display: Does the way social stories are delivered make a difference for their effectiveness on ASD children? J Educ Comput Res 49:381–401
98. Carter AS, Black DO, Tewani S, Connolly CE, Kadlec MB, Tager-Flusberg H (2007) Sex differences in toddlers with autism spectrum disorders. J Autism Dev Disord 37(1):86–97
99. Lai MC, Lombardo MV, Pasco G, Ruigrok AN, Wheelwright SJ, Sadek SA, Chakrabarti B, MRC Aims Consortium, Baron-Cohen S. (2015) A behavioral comparison of male and female adults with high functioning autism spectrum conditions. PLoS ONE 10(9): e0136521
100. Owens G, Granader Y, Humphrey A, Baron-Cohen S (2008) LEGO® therapy and the social use of language programme: An evaluation of two social skills interventions for children with high functioning autism and Asperger syndrome. J Autism Dev Disord 38:1944–1957
101. March-Miguez I, Montagut-Asunción M, Pastor-Cerezuela G, Fernández-Andrés MI (2018) Intervención en habilidades sociales de los niños con trastorno de espectro autista: una revisión bibliográfica. Papeles del Psicol 39:140–149
102. Strofylla G, Charitou S, Asonitou K, Koutsouki D (2021) Profile of social skills in students with autism spectrum disorder. Adv Phys Educ 11(2):195–206
103. Uljarevic M, Hamilton A (2013) Recognition of emotions in autism: a formal meta-analysis. J Autism Dev Disord 43:1517–1526
104. Hayward DW, Gale CM, Eikeseth S (2009) Intensive behavioural intervention for young children with autism: a research-based service model. Res Autism Spect Disord 3(3):571–580
105. Pop CA, Simut R, Pintea S, Saldien J, Rusu A, David D, Vanderfaeillie J, Lefeber D, Vanderborght B (2013) Can the social robot Probo help children with autism to identify situation-based emotions? A series of single case experiments. Int J Humanoid Robot 10:1350025
106. Grandin T (2010) How does visual thinking work in the mind of a person with autism? A personal account. Autism and talent: 141–149
107. Schina D, Esteve-Gonzalez V, Usart M (2020) Teachers' perceptions of bee-bot robotic toy and their ability to integrate it in their teaching. In International conference on robotics in education (RiE) (pp. 121–132). Springer, Cham
108. Wang H, Hsiao PY, Min BC (2016) Examine the potential of robots to teach autistic children emotional concepts: a preliminary study. In International conference on social robotics (pp. 571–580). Springer, Cham

Elena Pérez-Vázquez is assistant professor at the University of Alicante and has completed her doctoral thesis on the application of the Bee bot robot in autistic students.

Gonzalo Lorenzo is a lecturer at the University of Alicante, director of the research group IncluTIC and his line of research is the application of technologies in autistic students.

Alejandro Lorenzo-Lledó line of research is the use of audiovisual media in education.

Asunción Lledó is a lecturer at the University of Alicante and a specialist in inclusive education.