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A Pilot Study of the KIBO Robot in Children with Severe ASD

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Abstract

This pilot study explores the feasibility of using the KIBO Robot as an engaging platform to positively impact social and emotional development in children with ASD. KIBO is a programmable toy robot originally designed to teach coding and sequencing to neuro-typical children between 4 and 7 years of age. To assess its use in children with severe ASD, twelve participants were introduced to KIBO and engaged in a variety of activities with the robot over four consecutive days. Their interactions were observed on site by raters and simultaneously videotaped for later analysis. We performed a detailed quantitative and qualitative analysis in two subjects who completed six or more of the eight planned KIBO play sessions. We observed that most of the participants showed sustained interest in the KIBO robot and increased the frequency of their interactions with adults across play sessions. Although the participants demonstrated only a limited understanding of programming principles during the study, they managed to manipulate the KIBO appropriately, engaged socially with the adults in the room and interacted positively with the robot during individual play. The findings suggest that the KIBO robot warrants further study as an engaging educational platform for children with ASD.

Keywords Education · Robots · Social activities · KIBO · Learning · Social skills · Autism spectrum disorder · Programming

1 Introduction

Autism spectrum disorders (ASD) is a set of neurodevelopmental disorders associated with decreased social interactions, reduced communication and repetitive behaviors or obsessive interests [1]. The low quality of social interactions, social relationships and imaginative thought [2] can increase the affected individual's isolation and create a barrier to learning through collaboration and interactive teamwork [3].

Projects like IROMEC, AURORA, etc. [4] found improvements in the social and communication skills of children with ASD associated with use of robotics technology. Robots like the NAO robot are human-like and can help children learn important social skills [5]. One outcome of such projects has been the addition of full-time psychologists to some schools' staffs to assist teachers and researchers with the implementation of robots to support children with ASD.

Children with ASD seem to take well to the repetitive and predictable nature of robots. Furthermore, robots are versatile and can contribute to collaboration in the classroom by helping to adapt the level of the intervention to students' abilities [6].

It has been suggested that combining social play scenarios and engaging activities can stimulate children to collaborate while working in groups [7]. A social robot can be a useful tool in social play scenarios, serving to stimulate social competence acquisition [8]. Specifically, the use of LEGO Robotics in children with ASD has been shown to significantly increase the frequency of positive social interactions with a correlation between enjoyment and cooperation [3,9–13]. Combining the above-mentioned factors, it is possible to create robot-based activities that enhance education through play, exploration, discovery, social interaction, collaboration, and competition. By observation of these activities, researchers can gain insight into the learning challenges of children with ASD [11].

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Children with ASD may have a range of cognitive and motor disabilities. Robotic platforms like LEGO are recommended for neuro-typical children older than seven and are difficult for young children with ASD to physically manipulate, assemble, and program [14]. Most of these educational robotic platforms require use of a separate computer to program the robot, which in itself poses challenges for some children with ASD.

In previous studies, researchers used LEGO Robotics in play-based sessions with pre-built models. Students programmed these models through a special web-based interface that was customized for them. Teachers were able to use the robots and tablets with the assistance of a technician [15,16]. Even with these pre-built models, customized interfaces, and technical assistance, the LEGO robotic kit was still impractical for use by many children with ASD.

In this study, we explore the feasibility of using of a different robotic platform called KIBO to engage young children with severe ASD. The KIBO robot was created with funding from the National Science Foundation by the DevTech Research Group at Tufts University, led by Dr. Marina Umaschi Bers. The kit was commercialized by KinderLab Robotics [17]. KIBO was designed based on the findings from more than 5 years of research with hundreds of children and early childhood educators [18–23]. This robotics kit is specifically designed for neuro-typical children ages four to seven, allowing them to engage in a developmentally appropriate way with computer science concepts such as sequencing, cause-and-effect, and debugging [21,24–28].

The KIBO robotic kit was chosen for this study for several reasons. First, KIBO is designed specifically for a target population of children ages 4–7 year old. The kit therefore innately reduces both the complexities of manipulation and coding comprehension. In addition, the KIBO kit uses wooden blocks to program the robot that are easily recognized and manipulated. Finally, KIBO is a screen-free robotic platform with an easy visual interface that can potentially promote face-to-face interactions with teachers and peers.

KIBO is different from other available robotic kits in that it does not require screen time on a separate computer. Programming is accomplished by connecting tangible wooden blocks that children assemble in a sequence to provide a set of instructions to the KIBO robot. Each block is color-coded and labeled with an action or instruction that tells the robot what to do. After a sequence is built, starting with a "Begin" block and ending with an "End" block, children can program the robot by scanning the set of blocks in sequence using the KIBO's built-in barcode scanner. Children then simply push a button to see the robot perform the program they created [27]. The robot has slots for up to four sensors that can be assembled and dissembled to add or subtract functionality. The robots can be provided to children with these sensors pre-assembled or the assembly can be done by the children themselves.

Previous studies by the DevTech Research Group shows that when children as young as 4 years old are provided the needed scaffolding, they can successfully program a KIBO robot [23,29]. Additional robotics research by DevTech shows that with proper resources and support, early childhood educators can effectively teach traditional educational subjects as well as collaboration and social skills by integrating the robotics kit and its block programming approach [19,22,24,25,28–31].

In this study, we explore whether the KIBO robot engages, promotes social interaction, and fosters the acquisition of basic programming principles in students with severe ASD. Based on previous studies [14], we hypothesized that KIBO robotics could achieve these outcomes by creating a context in which social and coding skills are practiced and used by children with ASD.

The main question this study was designed to address is:

1. Are children with ASD engaged with the KIBO robot (asking questions, sharing their work, or appearing interested)?

In addition, we obtained information relevant to the following related questions:

2. Do children with ASD comprehend the purpose of KIBO? Do they understand that programming blocks are not simply wooden building blocks?
3. Can the children with ASD learn to code with KIBO?
4. Does KIBO help children in the study to understand the cause-effect order?
5. Does KIBO help to stimulate children to use their social skills with peers and adults?
6. How does the KIBO robot affect social and emotional behavior among children with ASD?

2 Methods

2.1 Overview

This pilot study was conducted over 1 week at the CASPAN center in Panama between 4/4/16 and 4/7/16 in a regular classroom setting. Approval was obtained from Tufts University IRB office with the project number: 1412018. The protocol called for a total of eight sessions per participant in which the children were shown how to program the KIBO as an agent that danced, cleaned itself, travelled from one point to another, etc. To participate in this study, children were required to be between 6 and 14 years of age and diagnosed with severe ASD and cognitive impairments (Fig. 1).

Fig. 1 KIBO Robot and the programing blocks

This was an exploratory study that used an unmodified KIBO robot and the same basic procedures that have been applied with neuro-typical children. We performed a qualitative assessment of engagement and disengagement in all participants. In addition, we conducted a more detailed qualitative and quantitative analysis in two participants who completed six or more of the planned play sessions with the KIBO robot, as per protocol.

2.2 Setting

Centro Alan Sullivan de Panama (CASPAN) is a non-profit public governmental center that provides resources, services, and support in the public interest. CASPAN was founded with the mission to facilitate education and provide needed attention to the population with autism and other cognitive disabilities, as well as their families and communities. Through this task, CASPAN hopes developmentally impaired Panamanians acquire autonomy, better quality of life, and become productive people fully integrated into their society. Tufts University from the US, and La Salle—Ramon Llull University from Spain, are promoting the use of new technologies to enhance and support the inclusion of children with ASD into society. The groups' goals include fostering autonomy and improved quality of life through the cultivation of social skills and problem-solving capabilities.

2.3 Participants

A total of 12 students classified as having Severe ASD with cognitive impairments were recruited from one grade level at CASPAN. All the students had previous contact with LEGO Robots in the classroom, but no previous contact with KIBO. The robotic sessions took place in addition to their every-day classroom activities. The study ran for a total of 4 days, with two robotics sessions each day (Table 1). Between sessions students had a break where they had a snack and clean up activity (to learn about caring for themselves by washing their hands and cleaning the table). We coded each participant with a letter and a number to protect their confidentiality (Figs. 2, 3).

2.4 The KIBO Robotic Activities

Based on what we learned in previous studies [16], we prepared the study environment as follows: we placed three working stations in the classroom, each consisting of a white table with the KIBO robot and additional materials needed for the session. Two students sat next to one another at each station. A video camera at each working station faced the students and was used to record each session.

From a curricular perspective, the sessions were divided in two parts. The first part included teacher-guided activities that introduced novel elements and tasks for children to com-

Table 1 Study curriculum covered during the study

Activity	KIBO actions	"Social Actor" scenario
Study curriculum part one		
"Car" robot horn	Begin, beep, forward, end	The robotic car does not want to run over the pedestrian
Puddle	Begin, forward, shake, end	The robotic pet jumps into a puddle and cleans itself
Dancing robot (triggered by clap)	Begin, wait for clap, shake, end	The robotic dancer starts to dance when it hears that people areclapping
"Car" stop station 1, 2, 3	Begin, forward, forward, end	The robotic car is transporting people to different stations

Activity	Description
Study curriculum part two	
Free play with a pre-built robot	Children get KIBO built with sensors/actuators to program
Free play with unassembled robot	Children get unassembled KIBO with sensors available

Fig. 2 Two children working with KIBO during one of the sessions

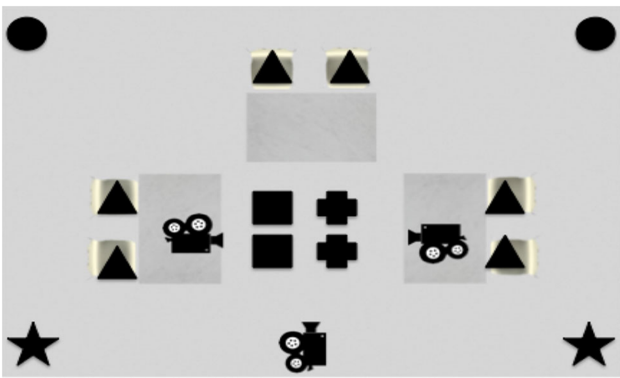

Fig. 3 Simulation of the room with KIBO experts (plus signs), teachers (squares), observers taking notes, and filling out modified PTD checklist around the room (circles, and stars) and students (triangles). Three cameras were placed around the room

plete. In each of these activities the robot served as a "social actor" that carried out defined task (see Table 1 below).

The tasks were sorted from simpler to more complex, adding new elements in each successive session. In the second part, we used pre-built robots with specific sensors added to engage children in coding and robotics free play activities. We then observed if children were applying their learning to new situations of their own choice.

One curricular goal of these activities was to reinforce the concepts of cause and effect. In most children's play, intention happens simultaneous to action. However, programming by virtue of introducing a time delay as well as an ability to control the outcome, helps foster real life cause and effect learning. Another curricular goal was for the KIBO robot to play a role as a social agent through interactive play-based sessions related to real life situations. The curriculum that we chose is designed to encourage children to work together to program KIBO to act in realistic situations.

At the end of the activity session, we conducted an adapted Solve-It Assessment. Solve-it Assessments are tasks or activities that involve problem solving and serve to assess the mastery of coding and sequencing skills [23].

2.5 Data Collection and Analysis

A KIBO expert on the research team led each session, explaining each activity and the schedule of events. The expert collaborated with the regular teachers and other researchers to conduct the sessions each day. Two observers were taking notes about what was happening during the sessions, and two others filled in modified PTD (Positive Technology Development) Observational checklists. At the end of each session the research team had a debriefing meeting to review what had happened.

We collected information using the following methods: (1) video recordings of all the sessions; (2) PTD observational checklists [32], and (3) notes that were taken by the observers during the sessions. For the qualitative analysis, two researchers took notes about each child participant during every session. The events in these notes were classified by a single independent rater as engagement or disengagement occurrences using established protocols [33]. For the detailed analysis, video data was coded and analyzed using the BORIS PC application with ratings by an independent observer [34]. In order to obtain a sufficient within-subject data, we restricted the detailed analysis to subjects who met the criterion of having participated in 80% or more (> 5) KIBO play sessions throughout the week.

2.6 Video Coding

The interactions of the participants with their teachers, peers and the KIBO robot were recorded on videos made of each session over four consecutive days. An independent rater, aware of the study design and familiar with both ASD and the KIBO robot scored the videos. We analyzed the frequencies and durations of the 23 predetermined micro-behaviors (see "Appendix 1"). These micro-behaviors were selected based on typical behavior of children with severe ASD, and are further connected to the typical interaction of children with the KIBO robot, with peers and with adults.

The video data obtained from two children who completed at least six sessions, hereafter referred to as subjects B1 and E1, were further analyzed using the video analysis software BORIS. The purpose of the detailed analysis was to explore the frequencies of micro-behaviors and their correlation with the robotic technology and specific situations that arose during the activity [33].

2.7 Positive Technological Development Checklist

In Dr. Bers' book, *Designing Digital Experiences for Positive Youth Development: From Playpen to Playground* (2012), a theoretical framework called Positive Technological Development (PTD) is presented for incorporating the use of technology in educational settings to foster a myriad of posi-

Table 2 Participant attendance at each session

Day	Session	Attending participants	Missing participants	Total participants
Day 1	1	A1, A2, B1, B2, C1, C2, D1, D2, E1, E2, F1	F2	11 participants
	2	B1, C1, D1, D2, E1, E2	A1, A2, B2, C2, F1, F2	6 participants
Day 2	3	A1, A2, B1, B2, C1, C2, D1, D2, E1, F1, F2	E2	11 participants
	4	A1, A2, B1, B2, C1, D1, D2, E1, F1, F2	C2, E2	10 participants
Day 3	5	A2, B2,C2, D1, D2, E1, E2, F1, F2	A1, B1, C1	9 participants
	6	A1,A2, B1, B2, C1, C2, D1, D2, E1, E2, F1, F2	–	12 participants
Day 4	7	A1, A2, B1, B2, C1	C2,D1, D2, E1, E2	5 participants
	8	A1, A2, B1, C1, D2, E1, E2, F2	B2, C2, D1, F1	8 participants

tive developments and behaviors. The PTD framework serves to guide the implementation of new technologies, such as the KIBO robotics kit, in educational settings. The PTD framework identifies six positive behaviors that engagement with technologies in the classroom can promote: communication, collaboration, community building, content creation, creativity, and choices of conduct.

To make these behaviors measurable, the DevTech Research Group developed a tool for evaluation called the PTD Engagement Checklist that allows the observation and coding of behaviors of children who are engaging with a technology in an educational setting [31]. The PTD checklist is divided into six sections, each one representing one of the different behaviors identified by the PTD framework. Each section includes various descriptions of behaviors that may be observed when a child or group of children is using a given technology. For example, to measure a child's level of collaboration fostered by the technology, an observable behavior on the checklist is "Students are helping each other to understand materials." The tool is meant to measure how often students demonstrate the given behaviors using a 5-point Likert scale. This scale ranges from 0 "Never" up to 5 "Always". It can be used as often (i.e. after every lesson that includes technology) or as infrequently (i.e. once per unit) as the evaluator deems necessary.

The goal of the PTD Engagement checklist is to help quantify the observable behavior. In using the checklist to evaluate the same children over time, adults can create a quantifiable view of behavioral trajectories as they pertain to engagement with a particular technology. Previous pilot research in preschool classrooms in Singapore used this evaluation tool to measure the six behaviors of communication, collaboration, community building, content creation, creativity, and choices of conduct throughout a 7-week curriculum called Dances from Around the World [31]. The educators filled out checklists at the end of each session, and the average scores were calculated at the end of the 7-week robotics program. Based on the score calculations, the PTD checklist demonstrated that the curriculum was most successful at fostering content creation, communication, and collaboration [31].

For this study at the CASPAN School in Panama, we modified the PTD Engagement Checklist to better reflect the potential behaviors of the ASD study population ("Appendix 2"). For example, since several of the students with ASD in this study were non-verbal, the behaviors used to measure communication were condensed in terms that could apply to both verbal and nonverbal students, such as "Student takes direction from teacher (e.g. sits when told)." Furthermore, the Likert Scale to score the students' behaviors was condensed from 0 "Never" through 5 "Always", to 0 "Task not completed/Particular behavior not observed" through 3 "Needed almost no or no support," since many of the behaviors were either present or absent. The checklists were filled out by researchers observing the children's sessions with KIBO at the end of the second day, and at the end of the fourth day (see "Appendix 2").

3 Results

3.1 Cohort and Protocol Compliance

The students participating in the study ranging from 6 to 14 years old (mean = 9.83) including 11 boys and 1 girl. All students showed enthusiasm about participating in the robotic sessions. However, most students missed one or more days of school attendance during the week of the study (see Table 2). Children diagnosed with severe ASD commonly exhibit mood fluctuations and behavioral disturbances [35]. This study was conducted everyday for the time span of 4 days. Due to the day-to-day fluctuations in our participants' mindset and behavior, not every child was capable of participating in all sessions. Therefore, perhaps four consecutive days of research is a more suitable research design for typically developing children and future should allot more flexible time arrangements for children with severe ASD.

Table 3 Number of occurrences of engagement and disengagement

	ENGAGEMENT OCC								DISENGAGEMENT OCC								ENG-DISENG										
	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8	E>D	AVG	Normal
A1	2	X	1	0	X	2	1	4	1	X	2	1	X	1	2	0	1	X	-1	-1	X	1	-1	4		0.50	0.03
A2	0	X	1	2	0	0	0	0	1	X	2	0	3	4	5	3	-1	X	-1	2	-3	-4	-5	-3		-2.14	0.07
B1	4	11	4	0	X	4	2	12	1	0	0	0	X	0	0	0	3	11	4	0	X	4	2	12		5.14	0.18
B2	2	X	0	0	0	0	0	X	2	X	1	1	5	2	8	X	0	X	-1	-1	-5	-2	-8	X		-2.83	0.19
C1	1	2	0	2	X	2	0	3	0	2	1	0	X	1	1	2	1	0	-1	2	X	1	-1	1		0.43	0.19
C2	0	X	1	X	4	0	X	X	0	X	0	X	0	3	X	X	0	X	1	X	4	-3	X	X		0.50	0.19
D1	5	4	0	0	0	0	X	X	1	1	0	0	0	0	X	X	4	3	0	0	0	0	X	X		1.17	0.19
D2	3	3	1	1	0	0	X	3	1	1	2	0	3	0	X	0	2	2	-1	1	-3	0	X	3		0.57	0.19
E1	7	6	3	2	4	3	X	5	0	0	3	0	0	1	X	0	7	6	0	2	4	2	X	5		3.71	0.19
E2	2	5	X	X	1	0	X	2	1	3	X	X	2	1	X	0	1	2	X	X	-1	-1	X	2		0.60	0.17
F1	5	X	3	1	0	2	X	X	2	X	1	1	0	1	X	X	3	X	2	0	0	1	X	X		1.20	0.12
F2	X	X	2	2	1	4	X	1	X	X	0	1	0	1	X	0	X	X	2	1	1	3	X	1		1.60	0.03

Only two subjects (B1, E1) completed 80% or more of the sessions, meeting criteria for detailed video analysis.

The characteristics of these two participants were as follows:

Participant B1 is a boy with severe ASD with some verbal communication ability. He can engage in some activities, and tends to be somewhat preoccupied with sharing his work with classmates.

Participant E1 is a boy with severe ASD who is non-verbal and can communicate with others only through gestures and sounds. E1 generally dislikes sharing and cooperating with his peers.

1. Are children with ASD engaged with the KIBO robot?

We found that most of the participants showed interest in the KIBO robot. Children with severe ASD typically experience strong difficulties engaging, communicating, focusing on tasks and sharing with peers. However, there is evidence in this study that they engaged positively with the KIBO robot. The following lists include examples of engagement occurrences and disengagement occurrences. These observations are taken verbatim from researchers' observational notes during the study:

- Engagement occurrences:
  - Holds KIBO from the beginning. Teacher helps him scan, the KIBO goes, He grins, high-fives teacher.
  - Touching robot a lot, eyes looking at it.
  - Smiles at the box containing the robot parts and blocks.
  - Seems interested, wants to play with the pieces
  - Puts blocks away back in box when time to clean up!
  - Asks questions actually pertaining to the activity
- Disengagement occurrences:
  - Looking all over throughout, and at the observer.
  - Getting up and walking around.
  - Participant is putting blocks into the mouth, running around and grinning.
  - Disinterested even when teacher tries to engage him.
  - Not playing at all, sitting with head against the art platform in his hands.
  - Soon throwing things again.
  - All over the place. Hugging the observer, not responding to teachers.

Table 3 lists the frequency of engagement/disengagement events across all subjects and sessions. The table is divided into four sections. The first section represents the number engagement occurrences per session, the second section shows the disengagement occurrences, the third one, the calculated difference between engagements and disengagements and the fourth section lists the average number of occurrences per session and the normal distribution per child.

With the information from the table we have plotted the distribution of engagement/disengagement events for the study population in Fig. 4 Modeled as a normal distribution, the maximum value is 5, the minimum is -3, the average 0.92, and the standard deviation 2.065.

On the basis of these results, we can observe that KIBO sessions tend to engage children with severe ASD and cognitive impairment slightly more than disengage them because the peak of the normal distribution is located at 1. Although this result is not dramatic, it excludes strong disengagement which might be the expected outcome in light of the baseline proclivity towards disengagement that children in this population tend to demonstrate [1,2]. The latter was the case for only two subjects, A2 and B2, who did not engage in any ses-

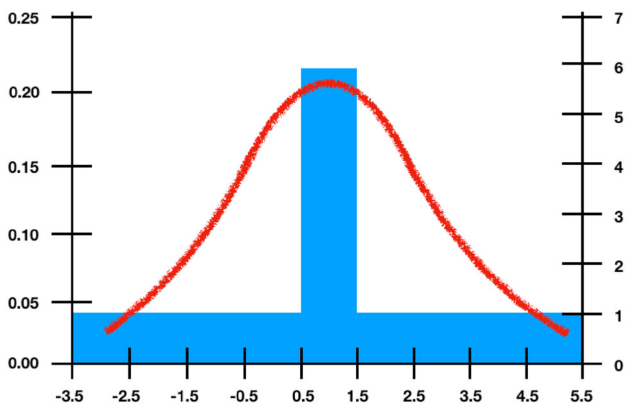

Fig. 4 Normal Distribution of Engagement vs Disengagement with KIBO Robot

sion. In addition, we can see that the two children analyzed in detail, B1 and E1, show a predominance of engagement events across most sessions.

2. Do children with severe ASD comprehend the purpose of KIBO? Do children with ASD understand that programming blocks are not simply wooden building blocks?

Observations made on individual participants suggest that most participants recognized that the KIBO is an interactive toy and showed some appreciation of the role of the programming blocks. However, the level of understanding and retention of information was variable across subjects and sessions. For example:

- Subject B1 appeared to understand how to put on and remove parts of the KIBO in sessions one and two. When successful, B1 became excited and "high fives" others often. He appeared to enjoy experimenting and exploring with different parts and seeing where they fit. He manipulated the robot often. On the following sessions, B1 was able to assemble a program with the blocks, but needs help scanning.

  However, by the last sessions it is unclear whether B1 actually understands what KIBO does—he likes playing with the blocks and stacking them on KIBO, manipulating the parts, but does not know when a program requires him to clap, and still needs help scanning (doesn't wait for beep—keeps running the scanner left to right but KIBO isn't capturing the code).

3. Can children with severe ASD learn to code with KIBO?

Some but not all of the participants demonstrated coding abilities in the course of the week-long study, including more advanced capacities such as debugging. For example:

- E1 is excited by KIBO and non-verbally expresses his excitement when the KIBO moves. E1 tried scanning from different heights on Day 2. By Day 3, E1 appears to truly understand the programming steps for KIBO. He puts together correct sequences of blocks (although he tends to order them upside down/backwards—but still syntactically correct). He scans, rearranges blocks, and attempts to debug if something goes wrong. By Session 2 on Day 3, E1 put together the KIBO body and its parts before anyone else. He is further engaging in imaginative play with KIBO, pretending it is on water, pretending it was flying, sleeping when it shuts off, or that it is carrying bananas.

4. Does KIBO help children in the study to understand the cause-effect order?

KIBO can be manipulated by children who have motor impairments. However to create a sequence to program KIBO, children have to interlock the wooden programming blocks by inserting a peg from one block into the hole of the next block in the sequence (for reference see Image 1). There was one child that understood that blocks should connect one next to the other one, but was unable to figure out that he should connect the blocks by placing the peg inside the next block's hole.

All children understood that pressing the green blinking button starts the KIBO, leading us to conclude that KIBO is very useful in helping them understand concepts like cause and effect.

5. Does KIBO help to stimulate children to use their social skills with peers and adults?

Past research suggests children with ASD are more inclined to communicate with adults rather than peers [36]. The behavior of participants in this study were generally consistent with that observation.

For example, PTD data indicates that E1 was always eager to share his work with the teacher or other adults in the room, but not as much with his peers. This could in part be due to his peers not being as engaged with KIBO as he was or because the communication with his peers was more difficult than with adults.

From the PTD checklist data, B1 received "0"'s for each session in every "cooperative behavior" category, indicating that he did not collaborate with classmates or share work with peers at all during the sessions.

E1 was able to remain focused on the task at hand with KIBO throughout the week. However, E1 exhibited no improvement in social behavior when it came to collaborating with peers, helping to clean up, being respectful to

Table 4 Lists the behavior correlations

	Gaze KIBO	Gaze Human	Affect Sharing	KIBO manipulation
Gaze Human	0.894**	1	0.541	−0.045
Pointing Person	0.931*	0.952*	0.920*	−0.075
Initiates conversation	0.690	0.894*	0.553	0.740
Affect Sharing	0.569	0.541	1	0.188
Proximity	0.884**	0.763*	0.304	0.224
Collaboration	0.669*	0.552	0.611	−0.007
Disengagement	0.705**	0.759	0.393	0.590

**Correlation is significant at the 0.01 level (2-tailed), *correlation is significant at the 0.05 level (2-tailed)

others, and using materials responsibly. E1 might have benefited from the introduction of more collaborative activities when being taught to program KIBO (i.e. one puts the blocks together, the other scans).

Based on observational notes by researchers, E1 was possessive of the KIBO and often did not want to share with his table-mate. He preferred to put pieces together on his own. Lack of sharing could have been due to the fact that each child was given their own KIBO kit rather than sharing kits, which perhaps would have made collaborating more of a requirement.

In summary, the current study provided evidence of increased interaction with adults in attendance while playing with the KIBO, but did not provide evidence of increased peer interactions.

6. How does the KIBO robot affect social and emotional behavior among children with ASD?

To help address this question, we performed quantitative analysis of the micro-behaviors of subjects B1 and E1 with the intention of explaining and validating the observed outcomes and also helping to direct further studies with this population. Since we are looking for linear relationships we chose to use Pearson r correlation.

Correlation analysis suggests there was engagement on an individual level with the KIBO robot in these participants and that this had a relationship with social behaviors and social skills involved in related to adults more than peers.

For example, Gaze KIBO was correlated with Gaze Human (0.894**), Pointing Person (0.931*), Affect Sharing (0.569), Collaboration (0.669*) and Disengagement (0.705**). While not all of these correlations were significant at the 0.05 level, they all trended toward this "*p*" value. The Gaze KIBO variable was not correlated with the majority of the other variables examined. Specifically, Gaze KIBO was not correlated with mutual attention, group attention, pointing KIBO, meaningful conversation, tangential, echolalia/scripting, initiates conversation, interrupts, turn taking, collaborative point, distractive behavior, ask for help, or independence.

Gaze Human was positively correlated with Pointing Person (0.952*), Initiates Conversation (0.894*), and Proximity (0.763*). This indicates some baseline propensity towards interaction with others but is not necessarily reflective of an effect of the KIBO robot (see Table 4).

4 Discussion

This study was inspired by previous work [3,7,8] suggesting that educational robotic platforms could create a context to stimulate children to use their social skills. Based on the qualitative and quantitative analyses we performed, it appears that children with severe ASD do engage with the KIBO in individual play. Participants did not appear to engage in collaboration with their peers around KIBO. This could be due to various factors such as the physical set up of our play stations (i.e. children facing each other rather than straight ahead) [14]. Also, the activities were not designed to create a context of sharing the material, as we wanted to validate the usefulness of KIBO by itself. Designing activities for the specific sharing purpose should increase sharing the materials [3].

From observations it is clear that that verbal participants performed better compared to non-verbal participants, perhaps because they were able to ask questions. This hypothesis is validated in studies such as [37], in which authors observed that functional play was correlated significantly with expressive language.

After each session we talked to the teachers, and 100% of them agreed that children performed better during the robotics sessions than in their regular classroom sessions. In fact, the robotics sessions were so highly regarded, that the teachers used robotics as a reward for motivating the children to perform better in the regular activities. This motivational effect can be considered a positive incidental finding of this study.

KIBO is a platform conceived for introducing coding to children between 4 and 7 years old inspired by the theories of constructionism and exploration. For these children with ASD, behavioral-based activities would be more correlated to what they are accustomed to doing in the classroom because of the model that the CASPAN school follows, and in the regular every-day sessions in which the children are heavily instructed by teachers and follow a strict routine.

We observed that ten of the 12 children (83.3%) engaged with KIBO in a variety of different set of activities (free play, specific topic, guided), which is a good indicator of the potential utility of this robotic platform. This is also supported by the quantitative analyses done with video-coding, which show that the children pointed at KIBO, gazed at KIBO, and manipulated KIBO relatively frequently.

We observed saw a range of KIBO programming abilities in the participants. For example, participant B1 was able to learn programming concepts: putting sequences together with the wooden KIBO programming blocks and scanning them, while E1 was able to manipulate KIBO but did not demonstrate clear understanding of what he was doing and why.

In general, the children appeared to thoroughly enjoy manipulating the KIBO parts and stacking the different blocks. This manipulation of parts is a very useful activity to engage the children and may help increase their fine-motor skills. Children with ASD may benefit from a different type of connecting system, perhaps a system that can complete the connection for them, such as magnets.

When successful at programming correct sequences, children demonstrated happiness and excitement through gestures (i.e. high fives) and exclamations (i.e. "Mira! Mira!"). Furthermore, the children appeared satisfied in instances when pressing KIBO "start" button led to the robot acting out a program they had scanned.

From the qualitative and quantitative data, we can conclude that participants tended to get excited about showing work and sharing accomplishments with adult teachers and researchers more than their peers. According to [36], which focused on the interaction of children with ASD with adults and peers, children with ASD are more likely to initiate conversations with adults rather than peers, and that is supported by what we have observed. Also, the cognitive and social skills of the peers affect the interaction, so placing a verbal child with a non-verbal child at the same table or workspace may decrease sharing and collaboration with the KIBO kit.

Children with a very low cognitive level may not be able to engage in robotics activity. Also the lack of consistency between some correlations from session to session is an indicator of how influential a mood or mental state can be during a particular session.

5 Limitations and Lessons Learned

Based on data from this pilot case study we can conclude that KIBO can be a suitable tool for children with ASD because it engages the children and can exert a motivating influence. We can further conclude that KIBO creates a context that triggers curiosity. Notably, we did not observe these behaviors with children with severe ASD activities using the LEGO Mindstorms robotics kit. Unlike other programming tools, KIBO is a robot specifically designed for young children and does not require a computer. Therefore, this study deserves more in-depth research with ASD population.

There are several limitations to the current study. The number of participants in this pilot study is small and it is not a representative sample of children with ASD. In particular, the study did not include children with milder forms of ASD or sample the full range of abilities associated with ASD. Some children with ASD have special talents in mathematics, art and other areas that make them truly unique. In a rare form of ASD, the so-called "savant syndrome" people surpass normal expectations in their abilities and may be geniuses in specific areas [38]. Instead, this study focused on the more commonly observed range of aptitudes seen in community centers and schools such as the one in Panama where the data was collected.

The quality of the video data obtained was sufficient for the purpose of this study. However, only one camera angle was collected for each pair of students and the children that were the subject of each session were not always in the camera's focus. This video documentation is adequate but not ideal for video analysis. In addition, there were limitations in video data collected due to participant absences that resulted in our being able to quantitatively analyze only two of our participants.

This study does not have a control group. Perhaps future studies will compare the KIBO interaction sessions with these neuro-diverse children to video available from neurotypical children interacting with the KIBO robot. However, there is currently no available video where participants are under exactly the same conditions as the present study.

We ran two robotics sessions per day for four consecutive days. However, children with ASD are very influenced by other variables in their lives (i.e. how they slept, what happened in the school just before the activity, etc.). These variables can have a profound effect on their performance in school and social activities. Therefore, when children were absent for one full day, we did not have their data for 25% of the duration of the study. In the future, it may be beneficial to have a longer duration as seen in [14]. Regarding the analysis of the socials skills of each child, and taking into account [36], we should consider multiple sessions matching every child with children with different socials and cognitive levels.

In the future, it may be worth giving children clearly defined roles when trying to get them to collaborate and work together (i.e. participant A will put together the blocks in a sequence, and participant B will scan and press the button).

Although further adaptations and study will be needed before the KIBO robot can be recommended for use in this population, these results are promising and encourage further investigation. A future study may include a longer-term period of observation, comparing different types of activities, and introducing small add-ons or changes to the platform to facilitate more successful manipulation and understanding.

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Compliance with ethical standards

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

Appendix 1

See Table 5.

Table 5 Micro-behaviors for video coding

Micro-behavior	Description	Category
Gaze KIBO	Participant maintains gaze on KIBO > 1 s	Non-verbal communication
Gaze human	Participant maintains gaze on face/eye > 1 s, not reciprocated	
Mutual attention	Mutual eye contact between participant and another person	
Group attention	Groupmates jointly look at same object	
Pointing KIBO	Hand/finger/arms directed to KIBO	
Pointing Person	Hand/finger/arms directed to person	
Meaningful conversation	Meaningful, in relation to activity	Verbal communication
Tangential conversation	Non-meaningful relative to activity	
Echolalia/ scripting	Repetitive phrases	
Initiates conversation	Participant begins talking to another person	
Responds	Participant responds to conversation started by others	
Interrupts	Participant verbally/non-verbally interrupts another person	
Turn taking	Participants takes turns in activity with one or more other persons	Construction/Dynamics
Collaboration	Participant takes part in negotiation, sharing, asking for opinion of others	
Affect Sharing	Participant shares positive affect with at least one other person	
Proximity	Participant is within 100 cm of another person	
Distractive behavior	Participant disrupts activities of group mates (not conversation)	
Ask help/permission from Adult	Participants seeks out adult input	
Collaboration	Participant puts KIBO together with another student	
Independence	Participant puts KIBO together alone	
Disengagement	Participant is not focused on KIBO	
KIBO manipulation	Participant is actively attempting to manipulate KIBO	
KIBO access	Participant has access to KIBO	

Appendix 2

See Table 6.

Table 6 Modified PTD engagement checklist for ASD

Scoring criteria
0: Particular behavior not observed. Task not complete
1: Needed almost complete or complete support
2: Needed moderate support, but partially independent
3: Needed almost no or no support

Tasks/behaviors	Score	Category
Students take directions from teacher (e.g. sits when told)	0 1 2 3	Communication

Table 6 continued

Tasks/behaviors	Score	Category
Students responds back to the teacher (answering questions…)	0 1 2 3	
Student initiates relevant communication with teacher	0 1 2 3	
Student shares their work with teachers	0 1 2 3	Cooperative behavior
Student shares their work with classmates	0 1 2 3	
Student helps to clean up at the end of the session	0 1 2 3	
Student can create a functional program for their robot	0 1 2 3	Content creation
Student is enthusiastic/interested about their project/creation	0 1 2 3	
Student persists in spite of obstacles or setbacks	0 1 2 3	
Student can put KIBO blocks together	0 1 2 3	
Student can scan the code	0 1 2 3	
Student is playing/exploring different KIBO parts, blocks	0 1 2 3	Creativity
Student is exploring in unexpected ways	0 1 2 3	
Student is having fun as they work on their projects	0 1 2 3	
Student is focused on the activity chooses to engage with it	0 1 2 3	Choice of conduct
Student is able to focus on the task	0 1 2 3	
Student is respectful to peers and teachers	0 1 2 3	
Student are using materials and resources responsibly	0 1 2 3	

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